Criteria and Indicators of Sustainable Rangeland Management

A publication of the Sustainable Rangelands Roundtable and the Society for Range Management

John E. Mitchell, Editor

University of Wyoming Extension

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CHAPTER 1
Introduction

John E. Mitchell,[1] Kristie A. Maczko,[2] Lori A. Hidinger,[3] and E.T. Bartlett[4]

Keywords: Sustainable Rangelands Roundtable, sustainability, sustainable development, sustainable management, monitoring and assessment

Abstract: The concept of sustainable management encompasses ecological, economic, and social criteria and indicators (C&I) for monitoring and assessing the association between maintaining a healthy rangeland base and sustaining the well-being of communities and economies. During a series of meetings from 2001 to 2003, the Sustainable Rangelands Roundtable (SRR) developed five criteria and 64 indicators of sustainable rangeland management. The SRR is a collaborative, inclusive organization, comprised of participants representing universities, federal research agencies, federal, state and local land management agencies, tribal governments, scientific societies, and both environmental and commodity-oriented non-governmental organizations. To achieve its goal, the SRR dealt with multiple issues, including those of scale and definitions. The Delphi technique was employed to maintain participant involvement between meetings and to help reach consensus about topics pertaining to the SRR's mission and the various indicators being considered. We used a six-point framework to develop indicators and standardize reporting upon them. One of the factors affecting indicator consideration was potential for obtaining data. To record attributes of various data sets in a way that allows summarizations and comparisons, SRR participants devised a data matrix that considered the kind of data, its grain and extent, applicable spatial and temporal scales, and various aspects of data quality. The SRR coordinated with other C&I programs in developing its suite of indicators. Applications and challenges to employing C&I for monitoring sustainable rangeland management are discussed.

Authors are [1]Rangeland Scientist Emeritus, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 80526,USA; [2]Research Scientist, Dept of Renewable Resources, University of Wyoming, Laramie, WY, 82071, USA; [3]Program Manager, Consortium for Science, Policy, and Outcomes, Arizona State University, Tempe, AZ, 85287,USA; and [4]Professor Emeritus, Dept of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO, 80523, USA.

***Correspondence:** John E. Mitchell, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO, 80526-8121, USA; phone 970-295-5957; email: john.mitchell@colostate.edu.*

Historical Background

Human values concerning rangelands and the environment have slowly shifted during the past half century. Until the mid-20th century, people thought of rangelands primarily in terms of domestic livestock production. Citizens allowed management and policy decisions to be made by professional range conservationists and land management agencies (Stoddart and Smith 1955). The 1970s marked the beginning of the environmental movement when Congress passed a number of laws (Table 1.1) that began transferring management oversight to the public and established the importance of non-commodity uses and environmental goals.

The concept of sustainability arose with the environmental movement. The 1972 United Nations (UN) Conference on the Human Environment, held in Stockholm, Sweden, acknowledged widespread evidence of pollution, disturbances of ecological processes in forests and other biomes, and natural resource depletion (Hopgood 1998). In 1987, the World Commission on Environment and Development report entitled *Our Common Future* called for progress in achieving sustainable development. Referred to as the Brundtland Report after its chair, Gro Harlem Brundtland, this document defined sustainable development as "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The Brundtland Report suggested that economic growth, social equity, and environmental quality are closely related.

Building upon the Brundtland Report, the UN Conference on Environment and Development, or Earth Summit, met in Rio de Janeiro, Brazil, in June 1992 to help governments reassess economic development and losses of natural capital. Five different agreements resulted from the Earth Summit, including Agenda 21, a blueprint for achieving sustainable development in the 21st century (Panjabi 1997).

Table 1.1. Some environmental laws passed by the U.S. Congress during the 1970s.

National Environmental Policy Act of 1969	Requires consideration of environmental impacts of federal actions.
Wild Free-Roaming Horses and Burros Act of 1971	Protects wild horses and burros.
Endangered Species Act of 1973	Provides a means for protecting and restoring threatened and endangered species.
Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)	Requires renewable resources assessments and programs to manage them.
Federal Land Policy and Management Act of 1976	Retains remaining public domain lands in public ownership. Acts as Organic Act for the Bureau of Land Management.
National Forest Management Act of 1976	Requires management plans for national forests that address environmental protection and provide for public participation.
Soil and Water Resources Conservation Act of 1977	Requires a recurring appraisal of all non-federal lands and authorizes a national soil and water conservation program.
Forest and Rangeland Renewable Resources Research Act of 1978	Expands research activities to encompass natural resource issues on a global scale.
Public Rangelands Improvement Act of 1978	Avows policy of monitoring and improving rangeland conditions. Sets grazing fee protocol.
Archaeological Resources Protection Act of 1979	Protects archaeological resources and sites on public and tribal lands.

After the Earth Summit, Canada convened an international seminar in Montreal on sustainable development of boreal and temperate forests. The seminar proposed developing criteria and indicators (C&I) that could help define and measure forest contributions to sustainable development. Subsequently, in 1994, an initiative began among representatives of non-European countries with temperate or boreal forests to develop C&I for sustainable forest management at a national scale. The protocol for accomplishing this effort became known as the Montreal Process (Coulombe 1995). The 12 countries participating in the Montreal Process agreed upon seven criteria and 67 indicators at their sixth meeting in Santiago, Chile. The U.S. Department of Agriculture (USDA) Forest Service represents the United States in the Montreal Process. It recently released the first national report on sustainable forests based upon the Montreal Process C&I (USDA Forest Service 2004).

Following a series of meetings in 1998, the Roundtable on Sustainable Forests (RSF) was self-chartered to promote cooperation and multi-stakeholder participation in the implementation and use of the Montreal Process C&I. Originally, the RSF was called the Roundtable on Sustainable Forests and Rangelands because some of the conveners wanted to include rangelands in the process. At its third meeting, however, the RSF decided to concentrate only upon forests because of technical and political considerations (unpublished minutes, RSF, 16 November 1998).

Unrelated to discussions taking place within the RSF, a group of scientists at the USDA Forest Service Rocky Mountain Research Station, analyzed the applicability of Montreal Process C&I to rangelands. The group's work, published in two issues of *The International Journal of Sustainable Development and World Ecology* (Table 1.2), showed that linking rangeland sustainability to that of forests is a logical extension of the Montreal Process protocols (Mitchell and Joyce 2000, Mitchell and Hill 2002). Nearly three-fourths of the world's rangelands are found within the borders of the 12 Montreal Process signatory nations (Graetz 1994).

Table 1.2. Papers showing relevance to including rangelands as part of the Montreal Process in the United States.

Flather, Curtis H. and Carolyn Hull Sieg. 2000. Applicability of Montreal Process Criterion 1 – conservation of biological diversity – to rangelands. Int. J. Sustain. Dev. World Ecol. 7:81-96.

McArthur, E.D., S.G. Kitchen, D.W. Uresk, and J.E. Mitchell. 2000. Applicability of Montreal Process Criterion 2 – productive capacity – to rangeland sustainability. Int. J. Sustain. Dev. World Ecol. 7:97-106.

Joyce, L.A., J.E. Mitchell, and S.R. Loftin. 2000. Applicability of Montreal Process Criterion 3 – maintenance of ecosystem health – to rangelands. Int. J. Sustain. Dev. World Ecol. 7:107-127.

Neary, D.G., W.P. Clary, and T.W. Brown, Jr. 2000. Applicability of Montreal Process Criterion 4 – soil and water conservation – to rangeland sustainability. Int. J. Sustain. Dev. World Ecol. 7:128-137.

Joyce, L.A. 2000. Applicability of Montreal Process Criterion 5 – maintenance of rangeland contribution to global carbon cycles. Int. J. Sustain. Dev. World Ecol. 7:138-149.

Shields, Deborah J. and E.T. Bartlett. 2002. Applicability of Montreal Process Criterion 6 – long-term socio-economic benefits – to rangeland sustainability. Int. J. Sustain. Dev. World Ecol. 9:95-120.

Mitchell, J.E. and R.G. Woodmansee. 2002. Applicability of Montreal Process Criterion 7 – legal, institutional, and economic framework – to rangeland sustainability. Int. J. Sustain. Dev. World Ecol. 9:121-134.

Sustainable Rangelands Roundtable

Following the decision by RSF to exclude rangelands from the Montreal Process within the United States, the USDA Forest Service Washington Office Range Staff convened a workshop in Denver, CO, to evaluate the potential for establishing a parallel strategy to assess rangeland sustainability at a national scale. Organizers sought to ascertain whether adequate support existed among rangeland stakeholders, including both commodity users and the environmental community, to initiate a process to develop C&I for sustainable rangeland management. After two days of discussion, the group decided to move forward with this strategy, culminating with formation of the Sustainable Rangelands Roundtable (SRR) in April 2001 (Rowe et al. 2002).

The SRR is a collaborative, self-chartered process, involving about 100 participants and more than 50 organizations since its inception (Appendix 1-A). Participants include federal land management and research agencies; tribal, state, and local governments; conservation and commodity-oriented non-governmental organizations (NGOs); scientific societies; academics; and other researchers. The SRR operates as an inclusive, open partnership with all interested representatives having an equal voice.

The original purpose of SRR has been to develop and report upon a set of C&I for sustainable rangeland management at a national scale. Criteria are explicit conditions or processes by which sustainable rangeland management may be assessed, but they are too general in scope to monitor directly. Thus, each criterion is characterized by indicators that can be periodically measured or described to demonstrate trends (Board on Sustainable Development 1999).

Sustainability Definitions

Two important definitions were problematic for the SRR: what rangelands are and sustainability. A discussion on the issue of defining rangelands is presented in a later section. Three separate definitions of sustainability have evolved in the literature: *sustainable development*, *sustainable management*, and *sustainability*.

Sustainable development was defined above. It refers to the ability of a nation or state "to meet the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987). It infers that countries cannot promote environmental quality when their citizens are suffering from economic or social difficulties. Nor can a country achieve long-term economic and social gains when its environment is continually degraded.

Sustainable management is a term commonly used in the sustainable development literature (Brang et al. 2002), including these papers. Although no agreed-upon definition of sustainable management exists, sustainable rangeland management involves the kinds of management that consider all aspects of rangelands, including their environmental, economic, and social values and the attempts to integrate them to achieve a sustainable future.

Sustainability is the least precise of these three definitions. Originally, "sustainability" was defined as maintaining natural systems over the indefinite future, such as living, working, and managing in ways which are environmentally "sustainable," promoting biodiversity, and so on. In recent years, the expression has applied to more numerous disciplines, including economic development, food production, energy, and lifestyles. Essentially, "sustainability" refers to accomplishing goals with the long-term in mind.

Spatial and Temporal Scale

Both ecological and socio-economic activities have causes and consequences that reveal different characteristics at multiple temporal and spatial scales. While ecologists have understood the importance of scale for some time (Levin 1992), social scientists have only recently realized the importance of scale when studying relationships between people and the environment (Gibson et al. 2000). Scale definition is required to comprehend the concept of sustainable systems. It is also a necessary prerequisite for understanding the relationships between indicators and selecting appropriate monitoring methods at any given level in a hierarchy.

The choice of scale interacts with the grain and extent of data and must be commensurate with the system being monitored, particularly regarding monitoring properties of system behavior. Patterns evident at one level of resolution can be lost at lower or higher levels. Properties are not only manifested in space, but in time, through rates of generation, turnover, and change. Explanatory landscape variables can change substantially across scale, i.e., patterns found at different scales are rarely explained by a single mechanism. For example, species richness at a local level is monitored within plant communities and habitat patches, and it is measured by monitoring fine-scale biotic and abiotic interactions involving processes occurring on time scales of months to a few years. At broad scales, species richness may be best monitored by looking at species groups in relation to slower changing variables such as land use and climate change. These processes manifest across time scales of several years to decades or longer (Willis and Whittaker 2002).

Erosion illustrates the importance of understanding scale. Accelerated soil erosion is an indicator associated with the SRR criterion called Conservation and Maintenance of Soil and Water Resources. Soil degradation is a function of soil resilience and quality, management, and weather/climate. At a local level, soil and topographic factors to be monitored for this indicator deal with detailed spatial variables like slope length, rill density, etc. Models are sensitive to specific storm events. At a national level, however, sediment yield and sediment property data from larger watersheds are used to monitor trends. These data synthesize soil qualities, broad management strategies (as embodied in farm bills, etc.), and multi-year climatic patterns involving droughts and wet periods.

Indicators developed by the SRR had to be relevant at the regional and national levels. When possible, the criteria groups tried to identify and give priority to those indicators that are important at multiple scales. Additional research clearly is needed to show how indicators change across scales and how similar indicators at different scales are related (Allen and Hoekstra 1992).

Sustainable Rangelands Roundtable Process

Developing, describing, and validating the C&I for assessing sustainable rangeland management in the United States required 14 meetings of the SRR (Appendix 1-B). Between meetings, dialogue and development continued using the Delphi Process. A first approximation report was prepared and posted on the Internet after the 11th meeting in Albuquerque, NM. After undergoing both internal and external reviews, the report was presented to agency, NGO, and professional society stakeholder groups at briefings made in Washington, DC, during May 2003. Later, SRR participants revised the five criteria reports by refining indicators, identifying additional data sources, and more rigorously linking relationships concerning indicators to literature references.

Collaborative Delphi

A modified Delphi Process provided a mechanism to augment progress made at meetings and allowed SRR members unable to attend meetings to remain involved with salient issues and decisions. The Delphi process is a method for systematically gathering and integrating expert opinion to reach collaboratively agreed upon conclusions (Linestone and Turoff 1975). Historically, it has been employed to establish research results where data-driven methods are infeasible, to aid in policy decision-making, to resolve environmental disputes, and to facilitate economic planning (Miller and Cuff 1986)

The iterative Delphi Process requires experts to anonymously respond to questions, and individual answers then are tabulated and returned to the participants, along with summary analyses and comments. Participants have repeated opportunities to revise their original answers in response to group feedback until a pre-determined level of consensus is achieved. The SRR called its Delphi approach a "collaborative Delphi" because experts were not selected solely for the Delphi method but for participation in the entire SRR process (Rowe 2002).

Criteria Development

The SRR utilized an issue-based framework for identifying criteria, and it then organized indicators within them. Such a framework is commonly adopted because it deals with highly visible conditions and situations pertaining to the system being appraised (Wright et al. 2002). Participants began by identifying specific issues to frame indicators for sustainable rangeland management. These issues transcended agencies, land ownership, and other artificial boundaries, in recognition of sustainable management's transboundary characteristics (Knight and Landres 1998). SRR members subjectively grouped these distinct issues into topical clusters to represent broader rangeland management issues.

SRR participants then converged upon six clustered issue groupings that formed the basis for criteria identification. These categories were 1) soils, 2) rangeland health, 3) invasives, 4) change of the range, 5) capacity, and 6) social goods and commodities. At this point, participants opted to explore integration of these "issues" and the seven Montreal Process criteria.

After intensive discussions, SRR settled upon five criteria: 1) conservation and maintenance of soil and water resources on rangelands, 2) conservation and maintenance of plant and animal resources on rangelands, 3) maintenance of productive capacity on rangeland ecosystems, 4) maintenance and enhancement of multiple economic and social benefits to current and future generations, and 5) legal, institutional, and economic framework for rangeland conservation and sustainable management (Bartlett et al. 2003). The second criterion was originally called "maintenance of ecological health and diversity on rangelands" but was changed to make it consistent with the first criterion, as well as to be more reflective of the indicators included under it.

Indicator Identification

Participants employed a multifaceted approach to developing indicators supporting the five criteria of sustainable rangeland management. Initially, they divided themselves into criterion groups, one for each of the five criteria. Selection of indicators was a slow, arduous task, an expected consequence of the broad range of stakeholders and differences in technical training and experience within the criterion groups. The five groups held extended discussions at meetings and exchanged ideas and perspectives using the Delphi technique to maintain progress between meetings.

Individual SRR criterion groups began by evaluating relevance of the Montreal Process indicators of sustainable forest management. It quickly became apparent that participants did not want to be restricted to an existing indicator set, so the Montreal Process indicators became an information source against which indicators developed by the SRR could be evaluated for completeness and consistency.

To guide indicator development and standardize the manner in which indicators were described, the SRR devised a six-point indicator evaluation framework:

1. What the indicator is; what it measures.
2. Importance of the indicator as a measure of the criterion. This included the indicators' scientific importance, based upon literature, and its robustness to changes in technology, as described by the Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments (2000).
3. Geographic applicability of the indicator throughout the United States.
4. Spatial and temporal scales of the indicator. An indicator valid at multiple scales can be more useful.
5. Data availability according to the following categories:
    a. Methods and data exist to monitor the indicator on all rangelands.
    b. Methods exist to monitor the indicator, but useable data are not available.
    c. Data sets only partially exist and/or methods are not standardized for the indicator.
    d. Although the indicator is conceptually feasible, no methods or data exist to monitor it.
6. The degree of understanding that stakeholders and the general public have for the indicator.

In general, the process of indicator selection for all five criteria groups was one of reducing a large indicator set proposed by individual participants during the first few meetings. Occasionally, an indicator would be added in response to information appearing in the literature and findings coming from other C&I programs. An example is indicator 9, changes in the frequency and duration of surface no-flow periods in rangeland streams, adopted from The State of the Nation's Ecosystems (Heinz 2002).

After two years and 11 meetings, SRR participants converged upon 64 indicators, categorized under the five aforementioned criteria, for monitoring sustainable rangeland management at regional and national scales (Appendix 1-C). It may not be coincidental that nearly 60 percent of the indicators are associated with the two criteria dealing with social/economic benefits and the legal/economic/institutional framework for rangeland conservation and sustainable management.

Data Set Evaluation

Data availability is a critical attribute of SRR indicators. When indicators have not been monitored at the proper spatial and temporal scales with adequate sample sizes, their value in assessing sustainable rangeland management declines commensurately. Consequently, the SRR criteria groups expended considerable effort to identify data sets pertaining to indicators and to describe them in terms of type of data, extent (spatial and temporal), grain, scale, and quality attributes (statistical power, etc.).

To record attributes of various data sets in a way that allows for summarizations and comparisons, SRR participants devised a data matrix. The data matrix contained the data sets as columns and the evaluation measures as rows (Appendix 1-D). Embedded in the data matrix was a four-category estimate of data sufficiency (Appendix 1-E).

An indistinct association exists between data availability and data quality and the recognized importance of indicators. Generally, if useful data already exist, relationships between variable(s) and system response have been more thoroughly studied and reported upon in the literature. Lack of comprehensive data can result from low scientific interest, high costs, inadequate technology, or disagreement over measurement methods. Many data sets are not national in extent.

Coordination With Other Rangeland C&I Efforts

A number of programs related to measuring or monitoring sustainable rangeland management are ongoing in the United States. At the USDA Agricultural Research Service Jornada Experimental Range, scientists are developing a monitoring manual for grassland, shrubland, and savanna ecosystems to be published by the University of Arizona Press. One of their indicators, soil aggregate stability (Herrick et al. 2001), is also used by SRR as an indicator of soil resource conservation and maintenance. The National Resources Inventory (NRI), conducted by USDA Natural Resources Conservation Service (NRCS), recently modified the monitoring data it collects from non-federal rangelands to include more rigorous indicators (Spaeth et al. 2003). Data from the NRI promise to be increasingly important for monitoring a number of biotic and abiotic indicators proposed by SRR. However, the NRI, along with the USDA Forest Service Forest Inventory and Analysis (FIA) monitoring system, do not include federal non-forested rangelands as part of their sampling populations. The NRI and FIA are therefore not collectively exhaustive in sampling the U.S. rangeland base.

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires USDA Forest Service to report to Congress every 10 years upon the status and trends of U.S. forests and rangelands. The 2000 RPA Assessment based its report upon the Montreal Process C&I (Mitchell 2000).

At a local level, various agencies within the USDA and the U.S. Department of the Interior (USDI) have collaborated to develop a series of qualitative indicators of rangeland health (Pyke et al. 2002). Qualitative measures are generally considered to be point-in-time appraisals for making a preliminary decision about the status of rangeland ecosystems and not indicators for monitoring trends over time. Regardless, advances in qualitative measures can lead to better quantitative measures as more is learned about states and processes of ecological systems. It is also important to note that USDA scientists and staff members working with these qualitative indicators have made significant contributions to SRR C&I identification.

The U.S. Environmental Protection Agency (EPA) is evaluating the nation's ecosystems, including rangeland, under its Environmental Monitoring and Assessment Program (EMAP). The EMAP program focuses primarily on indicators that assess watershed and water quality (De Soyza et al. 2000). EPA senior scientists have collaborated with SRR by continuously participating in the development of SRR C&I.

Within the USDI, the National Park Service (NPS) implemented the Vital Signs Program to identify indicators for long-term evaluation of national park system resources. There are 32 monitoring networks within the NPS. The Vital Sign Program has five goals: 1) determine the status and trends in selected environmental indicators, 2) provide early warning of abnormal conditions, 3) provide data to better understand park ecosystems as environmental reference points, 4) provide data to meet legal requirements, and 5) provide a means of measuring progress toward performance goals. The Vital Signs framework is similar to the C&I structure. Level 1 contains six environmental criteria (air and climate, geology and soils, water, biological integrity, human use, and ecosystem pattern and processes). Level 2 are general indicators, and the Vital Signs are specific indicators that can be monitored by the NPS. Scientists with the NPS also contributed to the SRR C&I development.

In addition to federal agencies, several other organizations are involved in monitoring rangelands using specific indicators. The H. John Heinz III Center for Science, Economics, and the Environment (The Heinz Center) report divides the United States into six ecosystems: coasts/oceans, farmlands, forests, fresh waters, grasslands/shrublands, and urban/suburban areas (Heinz 2002). Within each ecosystem, indicators are placed within four categories: system dimensions, chemical and physical conditions, biological components, and human uses. The Heinz Center's grassland/shrubland, or rangeland, ecosystem contains 14 indicators. None deal with social conditions, and only two are tied to economic measures.

The Nature Conservancy (TNC) has recognized the need to plan and work at broad geographic scales to conserve biodiversity. Its approach, called ecoregion-based conservation, identifies natural communities and target species, develops strategies for promoting the survival of the target species, and implements actions for achieving these strategies. To achieve its goals, TNC identifies various ecological indicators to be monitored within the 63 ecoregions comprising the United States, including patch size and extent of plant communities (TNC 1996).

Indicator Benefits and Potential Applications

The incorporation of SRR C&I into national monitoring programs helps describe trends in resource condition and management and can identify economic benefits and social values derived from rangelands. For public and private rangeland managers and stakeholders, potential benefits include:

1. The implementation of standardized periodic inventory, monitoring, and reporting on private and public rangelands.
2. Improved coordination among local, regional, and national assessments.
3. Enhanced interagency cooperation and collaboration.
4. Identification of indicator gaps where more research is needed.
5. A starting point for stakeholder dialogue and better informed national policy deliberations.
6. Justification of resource allocations for rangeland management and science.
7. Expansion of public awareness and understanding of rangeland sustainability.

Using Indicators to Inform Public Land Management

Indicator-based monitoring is part of a comprehensive process that includes classification, inventory, monitoring, reporting, assessment, and adaptive management. Society's values and objectives are reflected in strategic planning goals of agencies and organizations, which, in turn, drive classification and monitoring protocols that assess progress toward these goals (Shields et al. 2002).

Rangeland monitoring is an important way to measure the performance of governmental land management organizations. Indicators of sustainable rangelands provide accountability and encourage effective public land management practices to achieve organizational goals and objectives (Board on Sustainable Development 1999). Use of indicators within public land management organizations may be described as part of an adaptive cycle (Fig. 1.1). Information gathered through a selected suite of indicators provides feedback and data for review by on-the-ground land managers and policy-level decision makers. At each stage, performance indicators can be used to determine successes and failures through observed consequences of specific land management practices.

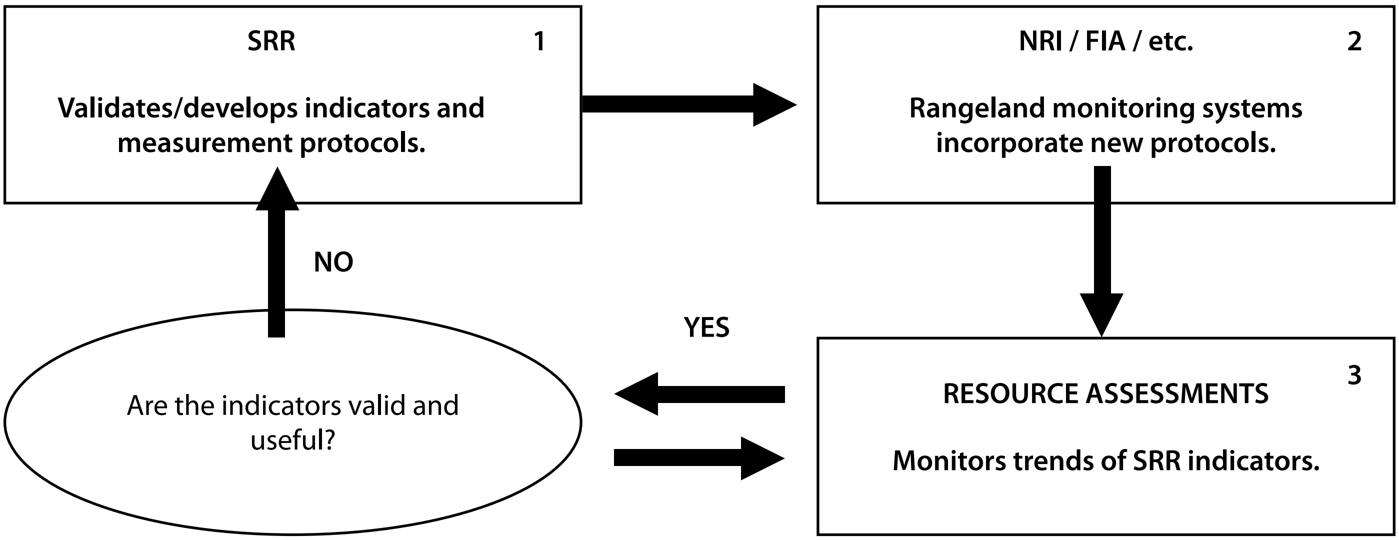

Figure 1.1. Indicator interactions with existing monitoring and reporting programs.

Indicators are also useful when incorporated into national land management monitoring systems, such as FIA and NRI. Regional and national resource assessments provide opportunities to evaluate indicator validity and can suggest areas where further indicator research and development are needed. Understanding the relationships between various indicators and sustainable management, as well as developing better ways to measure or estimate these indicators, requires both basic and applied research in multiple disciplines. More work is particularly needed at the interfaces of economics, social sciences, and ecology.

Drought and Fire

Drought and fire are important factors in rangeland management. One or two indicators are rarely adequate to characterize these complex and poorly understood topics. Rather, a suite of SRR indicators are used to address and monitor these subjects.

Fire. Fire is both a natural disturbance factor and a valuable management tool on rangelands. It is a key ecological driver in many ecosystems, facilitating nutrient cycling and promoting the growth of grasses and forbs over woody species. Thus, periodic fire maintains a number of major grassland, shrub steppe, and savanna ecosystems. In recent years, however, the interaction of fire with invasive species outbreaks has modified how fire affects ecosystem structure and function (D'Antonio 2000). Scientists recognize that human activities have shifted the season, intensity, and frequency of fire from historic patterns in a number of rangeland ecosystems.

One SRR indicator, "Integrity of Natural Fire Regimes," relates directly to fire. Additional indicators, associated with human activities and climate change, also may be useful in explaining long-term changes in the integrity of fire regimes. These include "Annual Productivity," "Ecosystem and Landscape Fragmentation," "Area and Level of Infestation by Invasive Weeds," "Presence and Extent of Representative Species," "Area of Rangeland with Accelerated Erosion," and "Change in the Extent of Bare Ground."

Drought. Drought impacts rangeland conditions, both ecologically and socio-economically, in many ways. In the short term, it decreases forage availability for wildlife and livestock. Over extended periods, droughts can cause native plants to die out, soil to erode, and water supplies to dry up. Drought indices, alone, do not provide managers with adequate information needed to make decisions. Some of the SRR indicators that may be sensitive to drought include "Change in the Area of Bare Ground," "Changes in Groundwater Systems, "Change in Stream No-flow Periods," "Condition of Riparian Systems and Wetlands," "Value of Forage Harvested," Employment Diversity," "Sources and Amounts of Community Income," and "Return on Rangeland Investments."

Challenges to Successful Indicator Application

A number of challenges to C&I applications exist. Priority issues include 1) database management, consistency, and integration, 2) definitions of forest and rangeland, and 3) human community and economic indicators (Bartlett et al. 2003). Discussions concerning data and data management are presented above.

Operational definitions of forest and rangelands are numerous and inconsistent. The general definition of rangeland – a kind of land on which the indigenous vegetation is predominantly graminoids, forbs, and shrubs (Glossary Update Task Group 1998) – is inadequate for technically dividing rangeland from forests, pastures, and deserts on the ground. In an unpublished 2004 report to the Meridian Institute, "Process to Develop a Definition of Forest and Rangeland," H.G. Lund (2007) identified literally scores of definitions adopted by federal agencies, professional societies, the UN, and others.

Perhaps the greatest definitional inconsistency is manifested in how different federal agencies define pinion-juniper (P-J) and other woodlands. The USDA Forest Service currently defines "woodland" as forest land (O'Brien 1999), while the U.S. Department of the Interior (USDI) Bureau of Land Management and the NRCS define "woodland" as rangeland (Grazing Lands Technology Institute 1997). The P-J land base amounts to approximately 23 million ha (Powell et al. 1993), and the Oregon Demonstration Project (Goebel et al. 1998) found up to a 15 percent difference in areas of forests and rangelands, depending on definitions. Many of the indicators presented in the following papers are based upon the rangeland base, so this issue is not trivial.

The SRR relies on the Federal Geographic Data Committee (FGDC) to resolve the dilemma of technically defining rangeland. The FGDC is a 19-member interagency federal committee composed of representatives from the Executive Office of the President and Cabinet-level and independent agencies. Its mission is to develop a national spatial data infrastructure and to develop policies, standards, and procedures for organizations to cooperatively produce and share geographic data. The FGDC has employed a 12-step process for developing, approving, and endorsing standards, and it is presently using the process to work through a proposal for an operational definition of forest and rangeland (personal communication, Paul Geissler, USGS, Fort Collins CO).

Possibly the most obvious example of challenges facing our understanding of human community and economic indicators is the title of the sub-criterion given to eight indicators in Criterion 4, "Maintenance and Enhancement of Multiple Economic and Social Benefits to Current and Future Generations." This sub-criterion, entitled "Community-level explanatory indicators that might be relevant to sustainability," intrinsically recognizes that some socio-economic indicators might seem to be important variables that should be monitored and reported. However, little scientific evidence is available to correlate such indicators with sustainability.

Adequate funding has always been an obstacle to establishing regional and national monitoring systems, particularly on rangelands. Many of the indicators identified by SRR are not measured because the costs for doing so are prohibitive.

Future Plans and Priorities

Long-term goals envisioned by SRR are tightly linked to the participants' vision of a future in which rangelands provide a desired mix of social, economic, and ecological benefits to current and future generations. The SRR wants to provide widely accepted and used C&I for monitoring and assessing rangelands sustainability. Short-term SRR objectives include C&I implementation and refinement, data set identification and analysis, communication planning and education and outreach efforts, interagency and organizational coordination, and categorization of research needs, including recommended protocols and prioritization (Maczko et al. 2004).

Indicator refinement includes identifying and reaching consensus upon a suite of key indicators that have been shown to be sensitive to their respective criteria and can be monitored using today's technology at reasonable costs.

In the United States, as in other countries, programs strongly supported by landowners and rangeland stakeholders will garner similar support from politicians and appointees representing these groups. Thus, outreach efforts designed to increase awareness of and support for SRR are critical for continued progress.

Coordination with other sustainability organizations remains a primary focus. These organizations include the Roundtable on Sustainable Forestry, the Sustainable Minerals Roundtable, the Sustainable Water Roundtable, and The Heinz Center report on the nation's ecosystems (Heinz 2002).

Additionally, SRR promotes research to better monitor and analyze indicators of sustainable rangeland management, as well as research on how well various indicators serve as metrics of the criteria. On a broader level, research is needed to address interrelationships among ecological, economic, and social indicators. Obtaining the maximum monitoring benefits from available funding is an important research component of indicator refinement.

The SRR and related sustainability efforts invite innovation and experimentation, opportunities to develop cooperative research protocols, and collaborative partnerships. SRR participants will continue to promote social, ecological, and economic sustainability of rangelands through indicator-based rangeland assessments and will provide a forum for rangeland sustainability discussions (Hidinger 2002). SRR conveners and participants look forward to engaging all interested stakeholders in the SRR process. Collaborative efforts involving affected stakeholders' typically foster sound decision-making in the areas of community capacity building and improved resource management (Fernandez-Gimenez et al. 2004). C&I emanating from monitoring frameworks developed collaboratively from multiple stakeholders can often help illuminate and better define important issues associated with rangelands (Wright et al. 2002). This effort will require proactive involvement of private and public land managers and policymakers responsible for rangeland resources.

Ultimately, comprehensive, comparable information will inform debate about economic, social, and ecological rangeland sustainability, as well as improving public awareness and understanding of rangeland management issues.

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Appendix 1-A. List of participating organizations in the Sustainable Rangelands Roundtable. Adapted from Hidinger 2002 (see Chapter 1 references).

Government Agencies and Tribes

Boulder County Open Space
Chippewa Cree Tribe
Confederated Tribes of Warm Springs
General Accounting Office
Hopi Tribe
DOE, Oak Ridge National Laboratory
DOE, Pacific Northwest National Laboratory
San Antonio Water System
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Geological Survey
USDA Agricultural Research Service
USDA Cooperative State Research, Education, and Extension Service
USDA Economic Research Service
USDA Forest Service
USDA Natural Resources Conservation Service
USDI Bureau of Indian Affairs
USDI Bureau of Land Management
USDI National Park Service
White House Council on Environmental Quality

Universities

Arizona State University
Bradley University
Colorado State University
Montana State University
New Mexico State University
Northern Arizona University
Oklahoma State University
Oregon State University
South Dakota State University
Texas A&M University
University of Arizona
University of California, Berkeley
University of Colorado
University of Idaho
University of Nevada
Utah State University
Washington State University
University of Wyoming

Private Organizations

Ridley Block Operations
S.M. Stoller Corporation

NGOs and Professional Societies

American Farm Bureau
Ecological Society of America
Grazing Lands Conservation Initiative
Gray Ranch and Malpai Borderlands Group
The H. John Heinz Center for Science, Economics, and the Environment
Idaho Conservation League
Invasive Species Advisory Committee
Lady Bird Johnson Wildflower Center
National Association of Counties
National Association of State Foresters
National Audubon Society
National Cattlemen's Beef Association
National Wildlife Federation
Public Lands Foundation
Quivira Coalition
Society for Conservation Biology
Society for Range Management
The Nature Conservancy
Welder Wildlife Foundation
Western States Land Commissioners Association
World Wildlife Fund
Wyoming State Grazing Board

Appendix 1-B. Meetings of the SRR that led to the development of the criteria and indicators.

2001		2002		2003	
Location	**Date**	**Location**	**Date**	**Location**	**Date**
Denver, CO	10-11 April	Tucson, AZ	9-10 January	Fort Myers, FL	15-16 January
Salt Lake City, UT	4-5 June	Denver, CO	26-27 March	Albuquerque, NM	18-19 March
Reno, NV	24-25 July	Washington, DC	29-30 May	Jackson, WY	4-5 June
San Antonio, TX	7-8 November	Billings, MT	30-31 July	Portland, OR	20-21 August
		San Diego, CA	30-31 October	Boise, ID	21-22 October

Appendix 1-C. Criteria and indicators developed by the Sustainable Rangelands Roundtable

Conservation and maintenance of soil and water resources on rangelands

1) Area and percent of rangeland soils with significantly diminished organic matter and/or high carbon:nitrogen ratio.
2) Extent of rangelands with changes in soil aggregate stability.
3) Assessment of microbial activity in rangeland soils.
4) Area and percent of rangeland with significant change in extent of bare ground.
5) Area and percent of rangeland with accelerated soil erosion by water or wind.
6) Percent of water bodies in rangeland areas with significant changes in natural biotic assemblage composition.
7) Percent of surface water on rangeland areas with significant deterioration of the chemical, physical, and biological properties from acceptable levels.
8) Changes in groundwater systems.
9) Changes in the frequency and duration of surface no-flow periods in rangeland streams.
10) Percent of stream length in rangeland catchments in which stream channel geometry significantly deviates from the natural channel geometry.

Conservation and maintenance of plant and animal resources on rangelands

11) Extent of land area in rangeland.
12) Rangeland area by plant community.
13) Number and extent of wetlands.
14) Fragmentation of rangeland and rangeland plant communities.
15) Density of roads and human structures.
16) Integrity in natural fire regimes on rangeland.
17) Extent and condition of riparian systems.
18) Area of infestation and presence/absence of invasive and other non-native plant species of concern.
19) Number and distribution of species and communities of concern.
20) Population status and geographic range of rangeland-dependent species.

Maintenance of productive capacity on rangelands

21) Rangeland aboveground biomass.
22) Rangeland annual productivity.
23) Percent of available rangeland grazed by livestock.
24) Number of domestic livestock on rangeland.
25) Presence and density of wildlife functional groups on rangeland.
26) Annual removal of native hay and non-forage plant materials, landscaping materials, edible and medicinal plants, and wood products.

Maintenance and enhancement of multiple economic and social benefits to current and future generations

27) Value of forage harvested from rangeland by livestock.
28) Value of production of non-livestock products produced from rangeland.
29) Number of visitor days by activity and recreational land class.
30) Reported threats to quality of recreation experiences.
31) Value of investments in rangeland, rangeland improvements, and recreation/tourism infrastructure.
32) Rate of return on investment for rangeland livestock enterprises.
33) Number of conservation easements purchased.
34) Expenditures (monetary and in-kind) to restoration activities.
35) Threat or pressure on the integrity of cultural and spiritual resource values.
36) Poverty rate (general).
37) Poverty rate (children).
38) Income inequality.
39) Index of social structure quality.
40) Community satisfaction.
41) Federal transfers by categories (individual, infrastructure, agriculture, etc.)
42) Presence and tenure of natural resource non-governmental organizations at the local level.

Appendix 1-C. Criteria and indicators developed by the Sustainable Rangelands Roundtable (continued).

43) Sources of income and level of dependence on livestock production for household income.

44) Employment diversity.

45) Agriculture (ranch/farm) structure.

46) Years of education.

47) Value produced by agriculture and recreation as percent of total.

48) Employment, unemployment, underemployment, and discouraged workers by industrial sector.

49) Land tenure, land use, and ownership patterns by size classes.

50) Population distribution and population change.

51) Income differentials from migration.

52) Length of residence (native, immigrant > 5 years, immigrant < 5 years).

53) Income by work location vs. residence.

54) Public beliefs and attitudes about natural resources.

Legal, institutional, and economic frameworks for rangeland conservation and sustainable management

55) Extent to which laws and regulations clarify property rights and land tenure arrangements, recognize customary and traditional rights of indigenous people, and provide means of resolving property disputes by due process.

56) Nature and extent of institutions and organizations that affect rangeland sustainability.

57) Nature and extent of economic policies and practices that affect rangeland sustainability.

58) Nature and extent of laws and programs that ensure access to public information and provide opportunities for public participation in land management.

59) Nature and extent of natural resource and land management education and assistance programs.

60) Nature and extent of land management programs implemented by owners of rangelands.

61) Nature and extent of large scale land planning and assessment projects and related policy review.

62) Nature and extent of rangelands set aside to protect special values.

63) Nature and extent of the various monitoring programs used to evaluate rangeland sustainability.

64) Nature and extent of research and development of new technologies as they affect rangeland sustainability.

Appendix 1-D. Data matrix used for evaluating data sets supporting SRR indicators.

	Data set 1	Data set 2	Data set 3	Data set 4
Brief Title for Data Set:				
Contact Person/Agency/Group (email, phone, address):				
Citation (if published):				
Website (if available):				
Additional information on data set:				
Response from #5 of 6-point evaluation framework (A-D)				
For what years are data available and how often are data collected?				
In what format is the data set available? (map only, data point, …)				
Are data nominal, ordinal, continuous, or interval?				
What will be the approximate cost of collecting data?				
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidentiality barriers, etc.?) Or are data easily accessible?				
What is the spatial grain of the data?				
What is the spatial extent of the data?				
At what spatial scales can these data be aggregated and reported?				
What is the temporal grain of the data?				
What is the temporal extent of the data?				
At what temporal scales can these data be aggregated ?				
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology.)				
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)				
Quality: how biased are the sampling methods?				
Quality: how precise are existing data?				
Quality: how valid are existing data?				
Quality: how responsive are existing data?				
Quality: how much statistical power to detect change does this data set have?				
Quality: how well does this data set meet the data needs for this indicator?				
Other comments: (Include any other relevant aspects of the data set that should be included.)				

Grain: Size of the observational units. Grain sets the fineness of the distinctions that can be made from the observations.
Extent: Size of the sampling universe. Inferences cannot be beyond the range of the observations.
Repeatable: Independent observers would obtain similar results.
Bias: The sampling population differs from the true population.
Valid: The indicator measures what is intended.
Precise: Replicate observations have similar values (low variance).
Responsive: Relates to the ability of the measurements to detect changes in the phenomena. Measurements are not responsive if they show little change when the phenomena changes or if changes in the measurement lag changes in the phenomena. For example, the number of endangered species is not responsive because the species are already in serious trouble before the problem is reflected in the data. Population levels or recruitment would be more responsive. We will probably want to include some data that are not responsive such as the number of endangered species, but we should be aware of their limitations and also include more responsive measures.

Appendix 1-E. Data sufficiency categories for indicators.

Category designation	Description
A	Methods and procedures exist for data collecting and reporting. Data sets of useable quality exist at the regional or national level.
B	Standardized methods and procedures for data collecting and reporting exist at the regional or national level, but useable data set(s) do not exist at the regional or national level.
C	Some data set(s) exist at the regional or national level, but methods and procedures for data collection are not standardized.
D	Conceptually feasible or initially promising, but no regional or national methods, procedures, or data sets currently exist.

Part I

Bio-physical Criteria and Indicators

CHAPTER 2
Criterion I: Soil and Water Conservation on Rangelands

Michael G. "Sherm" Karl,[1] Paul T. Tueller,[2] Gerald E. Schuman,[3] Mark R. Vinson,[4] James L. Fogg,[5] Ronald W. Shafer,[6] David A. Pyke,[7] D. Terrance Booth,[8] Steven J. Borchard,[9] William G. Ypsilantis,[10] and Richard H. Barrett, Jr.[11]

Keywords: rangeland sustainability, soil indicators, water indicators, Sustainable Rangelands Roundtable

Abstract: The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion of rangeland sustainability. Within the soil/water criterion, 10 indicators – five soil-based and five water-based – were developed through the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. These indicators are not inclusive but provide a suite of variables that, when complemented with indicators from the four other criteria, produce a viable system to monitor and assess rangeland sustainability.

Authors are [1]Inventory and Monitoring Specialist, Division of Resource Services, National Operations Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA; [2]Professor Emeritus of Range Ecology, University of Nevada, Reno, NV, 89512, USA; [3]Soil Scientist (retired), High Plains Grasslands Research Station, USDA Agricultural Research Service, Cheyenne, WY, 82001, USA; [4]Supervisory Research Fishery Biologist, Lake Superior Biological Station, Great Lakes Science Center, U.S. Geological Survey, Ashland, WI, 54806, USA; [5]Hydrologist (retired), National Training Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA; [6]Operations Research Analyst, U.S. Environmental Protection Agency, Washington, DC, 20640, USA; [7]Research Rangeland Ecologist, Forest and Rangeland Ecosystem Science Center, U.S. Geological Survey, Corvallis, OR, 97331,USA; [8]Rangeland Scientist, High Plains Grasslands Research Station, USDA Agricultural Research Service, Cheyenne, WY, 82001, USA; [9]District Manager, California Desert District, USDI Bureau of Land Management, Moreno Valley, CA, 92553, USA; [10]Deputy Division Chief, Division of Environmental Quality and Protection, USDI Bureau of Land Management, Washington, DC, 20036, USA; and [11]Rangeland Management Specialist (retired), Oregon State Office, USDI Bureau of Land Management, Portland, OR, 97204, USA.

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Correspondence: Michael G. "Sherm" Karl, Division of Resource Services, National Operations Center, USDI Bureau of Land Management, Lakewood, CO, 80225, USA, email: sherm_karl@blm.gov

Introduction

Soil and water are essential for ecosystem processes. Primary production of ecosystems requires soils in terrestrial systems and water bodies in aquatic systems to support energy capture through photosynthesis and energy flow through consumption, growth, and respiration. Terrestrial nutrient cycling generally requires soil before nutrient uptake can occur in plants, whereas aquatic nutrient cycling requires physical or temperature-induced mixing of nutrients within the water. In terrestrial systems, soil influences hydrologic processes by the capture, storage, and release of water (Whisenant 1999), but water and wind can erode soil. Soil erosion is regarded as a major contributor to declines in human civilizations over the past 7,000 years (Lowdermilk 1953). Rangelands and their associated communities rely on conservation and maintenance of soil and water resources to maintain them over time.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion to assess rangeland sustainability. As a criterion, conservation and maintenance of soil and water resources is too general to monitor directly, but it can be characterized by a set of indicators monitored over time to detect change.

The indicators for the conservation of soil and water resources are divided between soil-related and water-related components of this criterion (Table 2.1). Soil indicators will directly reflect the conservation of soils on rangelands, whereas water indicators will reflect the conservation of water as it flows through rangelands. This is an important distinction because changes in indicators of soil resources will be measured or monitored directly on rangelands and will reflect direct effects on rangelands, whereas changes in indicators of water resources would be measured on rangelands but might reflect changes occurring on non-rangelands (e.g., forest, agricultural, or urban lands). These changes can influence the availability or quality of water resources for sustaining rangeland resources even though they are occurring elsewhere.

Table 2.1. Indicators for soil and water conservation on rangelands, in no particular order of importance, Criterion I.

Indicator	What the Indicator Describes
Soil-based	
Area and percent of rangeland with significantly diminished soil organic matter and/or high carbon:nitrogen (C:N) ratio[1]	Soil productivity, infiltration, nutrient content, nutrient availability, nutrient cycling, carbon sequestration, resistance to erosion
Extent of rangelands with changes in soil aggregate stability[2]	Resistance to erosion by water and wind, soil water availability, root growth
Assessment of microbial activity in rangeland soils[2]	Soil productivity, decomposition, nutrient content, nutrient availability
Area and percent of rangeland with a significant change in extent of bare ground[2]	Erosion potential, aboveground vascular plant productivity
Area and percent of rangeland with accelerated soil erosion by water and wind[1]	Soil loss by water or wind, soil productivity
Water-based	
Percent of water bodies in rangeland areas with significant changes in aquatic biota assemblage composition[1]	Water quality and aquatic habitat conditions
Percent of surface water on rangeland areas with unacceptable levels of chemical, physical, and biological properties[1]	Water quality
Changes in groundwater systems[2]	Water quantity, watershed functioning, change in geographic extent of riparian and wetland ecosystems
Changes in the frequency and duration of surface no-flow periods in rangeland streams[3]	Aquatic and terrestrial biodiversity, watershed functioning
Percent of stream miles in rangeland catchments in which stream channel geometry significantly deviates from the natural channel geometry[2]	Watershed functioning, including sediment transport, sediment filtering and retention, substrate composition, flood amelioration, fish and wildlife habitat, aquifer recharge, water temperature, and season and duration of surface flow

[1] Originated with Roundtable on Sustainable Forests and was retained in SRR.
[2] A new indicator identified by SRR.
[3] Originated with Heinz (2002) and was retained in SRR.

The indicators are the outcome of an evaluation of the soil and water resource indicators identified in the Roundtable on Sustainable Forests (RSF), the soil and water resource indicators from The H. John Heinz III Center for Science, Economics, and the Environment report entitled: *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States* (Heinz 2002), plus our identification of new indicators that relate specifically to rangeland sustainability. Neary et al. (2000), in an effort not associated with the SRR, evaluated the applicability to rangeland sustainability of the eight RSF soil and water indicators. We evaluated Neary et al. (2000), and, based on this evaluation, we retained four of the RSF soil and water indicators (Table 2.1).

We applied a standard set of questions to each indicator: 1) what the indicator is, 2) what the indicator measures and why it is important to rangeland sustainability, 3) geographic applicability of the indicator, 4) the meaning of the indicator at various spatial and temporal scales, 5) the availability and quality of data sets, and 6) the degree of understanding that stakeholders have for the indicator. By indicator, answers to these questions are presented below.

Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter and/or High Carbon:Nitrogen (C:N) Ratio

Description and Importance of the Indicator

This indicator measures the soil organic carbon (soil organic matter) content of the soil and the carbon:nitrogen (C:N) ratio of the soil organic matter. The C:N ratio is a relative measure of soil organic matter's potential for biological decomposition. Soil organic matter provides many benefits to the soil and is associated with the productive potential of soils and soil sustainability. Soil organic matter 1) binds soil particles together into stable aggregates, thus improving porosity, infiltration, water storage, root penetration, and reduction of runoff and erosion, 2) supplies the primary source of nitrogen in a soil system, enhancing soil fertility and plant productivity, 3) supplies the primary energy source for microbial soil organisms that are responsible for biological nutrient cycling, 4) reduces physical soil crust formation, thus reducing runoff potential, and 5) improves water quality by reducing the negative environmental effects of pesticides, heavy metals, and other pollutants by actively trapping or transforming them (USDA NRCS 2001a). Grazing management that ensures a healthy plant community can result in increased soil organic matter through increased carbon sequestration (Schuman et al. 2002).

The C:N ratio of soil organic matter provides an indication of the potential availability of the organic matter to microbial decomposition and, therefore, nutrient release for plant growth. Litter or organic amendments with a high C:N ratio will likely result in nitrogen immobilization in the system. If the C:N ratio of organic inputs is high, then the decomposition of those inputs will be slow. Soils with a high C:N ratio would indicate that the organic matter is more resistant to biological decomposition whereas soils with a C:N ratio of < 10:1 would indicate a good healthy soil and one that would have good biological decomposition of organic matter occurring. Elevated atmospheric CO_2 levels have been shown to reduce the nitrogen content of the plant community, which may influence soil C:N ratio over time (Morgan et al. 2001).

Geographic Applicability and Scale in Time and Space

Soil organic matter levels vary by soil type, plant community, and climate. Fine-textured soils with greater clay content generally exhibit greater soil organic matter levels because the productivity potential is greater. This can be attributed to the greater water holding capacity and reduced decomposition and oxidation rates in fine-textured soils (Reeder et al. 1998). Changes in vegetation and litter inputs, for example as a result of a significant shift from C3 grass-dominated plant communities to C4 grass-dominated plant communities, result in greater root:shoot ratios and greater C:N ratios (Schuman et al. 1999). Shifts from a C3-dominated to a C4-dominated plant community generally reflect an increase in soil carbon because C4 species tend to transfer more energy to belowground plant parts (Coupland and Van Dyne 1979; Frank et al. 1995). Climate and its effects on soil moisture and temperature affect rangeland productivity, which directly influences soil organic matter levels. For example, tallgrass prairie has greater soil organic matter levels than shortgrass prairie. This is because its higher productivity leads to greater contributions of litter and root biomass to the soil. Climate also affects decomposition rates, which influence soil organic matter levels. Long-term severe drought conditions have resulted in decreased soil organic matter in heavily grazed rangelands because of the shallower deposition of soil organic matter by a C4-dominated grassland community compared with a more natural complex plant community (Ingram et al. 2008). The drought conditions also result in a shift in the microbial community structure. A synthesis of soil organic matter (carbon sequestration) data across rangeland ecosystems of the Great Plains indicated that ecosystems receiving greater than 440 mm of precipitation were likely to have lower rates of carbon sequestration in the 0-10 cm soil depth than those ecosystems receiving less than 440 mm of precipitation (Derner and Schuman 2007). For the 0-30 cm soil depth, the precipitation threshold appears to be 600 mm of precipitation.

Soil organic matter and its C:N ratio also can reflect temporal changes attributable to changes in management. Although temporal changes in soil organic matter and C:N ratios lag somewhat to temporal changes in vegetation and litter, the changes can be detected in enough time to initiate management changes to prevent serious degradation of soil. Spatially, soil organic matter varies considerably, reflecting the heterogeneity of soils across short distances. The degree of heterogeneity across short distances infers difficulty in sampling rangelands adequately for a national-level assessment of soil organic matter; however, baseline-sampling sites can be established to compare and detect change over time and space.

Data Collection and Availability

Methods of assessing soil organic matter and C:N ratios are available and are adaptable to the regional and national level. Soil organic matter is generally reported as soil organic carbon, rather than vice-versa (Appendix 2-A). The laboratory methodologies available for measuring soil organic carbon are economical, repeatable, and accurate. To date, no in situ field methodology exists for assessing soil organic carbon. Some methods being developed show promise but presently do not possess the required accuracy and sensitivity necessary to assess soil organic carbon. Soil organic matter can be indirectly estimated by multiplying the soil organic carbon by 1.74, the ratio of organic matter to organic carbon commonly found in the soil. However, many studies (see Nelson and Sommers 1982) have found that 1.74 is too low for many soils, and its use underestimates soil organic matter. Conversion factors need to be developed for individual soils because of the wide range of climates and soils being assessed for soil organic carbon response to management. It is recommended that soil organic carbon be assessed to detect spatial and temporal changes in soil organic matter.

Methods of assessing soil organic carbon generally involve collection of soil samples for laboratory evaluation. Soil samples are typically collected from various sample depths and depth increments, causing problems when comparing soil carbon stocks (Schuman et al. 1999). For example, soil samples collected from the 0-30 cm depth will not adequately reflect the soil organic carbon in surface soils at 0-5 cm depth. This is because changes in soil organic carbon occur more rapidly in the 0-5 cm depth from management and management changes, and mixing the 0-5 cm depth increment with the remaining 5-30 cm depth dilutes the effect.

Soil organic carbon should be expressed on a volume basis rather than a mass or concentration basis, and to do so requires measurement of soil bulk density. In many instances, however, soil bulk density data sets do not exist for soil organic carbon data sets. If care is taken in obtaining soil samples for soil carbon assessment, soil core increment weights can estimate soil bulk density because soil core volume is known. The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) recently initiated a national research program called Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet) (Jawson and Shafer 2002) to assess the effects of management on soil organic carbon stocks in croplands, rangelands, and forest lands. Sampling protocols are being developed for soil sampling, soil carbon assessment, trace gas emissions, and data presentation through GRACEnet. While a great deal of soil organic carbon data exist that can be used to make initial assessments, C:N ratio data are not as prevalent because simultaneous nitrogen data were not always collected in earlier studies. Recently, researchers have begun to collect soil organic carbon and nitrogen because of the heightened recognition of the interrelationships of carbon and nitrogen from a microbial and nutrient cycling standpoint. Also many laboratories are now using combustion methods to determine soil organic carbon, which routinely includes nitrogen analyses. In general, soil organic carbon and nitrogen data are limited for rangelands compared with croplands.

Clarity to Stakeholders

Stakeholders generally understand the importance of organic matter as it relates to soil. However, soil organic carbon and the C:N ratio are less well understood, particularly in how they relate to litter decomposition and nutrient cycling.

Extent of Rangelands With Changes in Soil Aggregate Stability

Description and Importance of the Indicator

Soil aggregates are groups of soil particles bound to each other more strongly than to adjacent soil particles. Aggregate stability refers to the ability of aggregates to resist degradation (USDA NRCS 2001b) and erosive forces (Chaudhary et al. 2009). Soils with stable aggregates at the surface are more resistant to water erosion than other soils because soil particles are less likely to be detached and the rate of water infiltration tends to be greater on well-aggregated soils. Soils with stable aggregates are also more resistant to wind erosion because large stable aggregates are heavier and can resist degradation and removal by wind compared with smaller weak aggregates. Aggregated soils hold more water than other soils and provide pores for root growth (USDA NRCS 2001b).

This indicator may provide an early-warning indicator of erosion (Herrick et al. 2002). We anticipate that changes in soil aggregate stability would occur before significant changes in erosion would be detected over large areas. However, dramatic reductions in ground cover increase soil erosion risk regardless of soil aggregate stability. Soil erosion as a direct measure of soil conservation is a difficult measure to obtain and may need to be modeled using other data (see indicator on accelerated soil erosion below).

Detectible changes in soil aggregate stability have been noted with changes in land management practices and changes in biotic factors such as plant community composition, biological soil crust cover, and arbuscular mycorrhizal fungi (although not always, see Rillig et al. 2003). Therefore, soil aggregate stability can be sensitive to these factors (Herrick et al. 2001b; Seybold et al. 2002, 2003; Rillig et al. 2003; Beever et al. 2006; Chaudhary et al. 2009). Where soil aggregate stability has not been particularly sensitive to biotic factors, abiotic factors such as soil mineral content have been speculated to be of more influence on soil aggregate stability (Rillig et al. 2003).

Geographic Applicability

Soil aggregate stability measurements appear to be applicable across regions. Herrick et al. (2001b) and Seybold et al. (2002, 2003) have evaluated the field soil aggregate stability kit over a wide range of agricultural and natural ecosystems throughout North America and found the method to be sensitive to differences in management, land use (for example, forest versus cropland), and plant community composition. These evaluations were performed on a wide range of soil textures, from clay loams to sands. The only soils in which the method has not been useful are wetland soils and extremely sandy soils in which there is little formation of aggregates larger than 1.5 mm in diameter even under good conditions.

Evaluations by Herrick et al. (2001b) and Seybold et al. (2002, 2003) provide evidence that soil aggregate stability methodology is applicable in different regions. An inference that can be drawn from this is that a change (increase, decrease, or neutral) detected for soil aggregate stability for a given region can be interpreted the same way as a change detected in any other region in regard to a change in resistance to erosion by water or wind.

Scale in Time and Space

Soil aggregate stability has been measured most frequently at the patch scale within a site (ecological site or range site, USDA NRCS 2003). At the patch scale, differences in soil aggregate stability and other soil properties have been detected for areas: beneath shrubs, compared with areas beneath grasses, compared with areas of bare ground in shrub and grass interspaces; for areas beneath vegetation compared with bare ground; with varying levels of livestock grazing intensity; and with time since removal of grazing (Herrick and Whitford 1995; Bird et al. 2002, 2007; Bestelmeyer et al. 2006; Beever et al. 2006). Patch scale differences in soil aggregate stability between areas of bare ground and types of vegetation are indicative of fragmentation of plant-soil pattern within plant communities and are predictive of desertification processes and degradation of rangelands in the Chihuahuan desert (Herrick and Whitford 1995; Bestelmeyer et al. 2006; Bird et al. 2007).

Soil aggregate stability varies widely across a variety of scales (Pierson et al. 1994; Bird et al. 2007) and soil textures (Herrick et al. 2001b). Much variability in soil aggregate stability is typical for rangeland and can be attributed to spatial variability in organic matter inputs and aggregation and degradation processes (Herrick et al. 2001b). This sensitivity to changes in soil texture, organic matter content, and spatial scale can be viewed as limiting in regard to regional- to national-level reporting because the large variability poses sampling problems. Herrick and Whitford (1995) and Herrick et al. (2005) recommend a spatially stratified sampling approach to minimize the spatial variability associated with measuring soil properties, including soil aggregate stability (Appendix 2-B).

Aggregate formation varies temporally, largely attributable to the timing and amount of precipitation and the resultant soil moisture levels. Soil moisture levels affect biological activity and physical processes such as frost heaving, which in turn affect aggregate formation (Herrick and Whitford 1995). Given the temporal responsiveness of aggregate formation to temperature, precipitation, and soil moisture conditions, repeated sampling of soil aggregate stability needs to be stratified, preferably during times of similar temperature, precipitation, and soil moisture conditions.

Data Collection and Availability

A field soil aggregate stability kit (Herrick et al. 2001b) is a standardized method for data collection of soil aggregate stability and allows measurements without having to transport soil samples to the laboratory. Standardized methods and procedures for data collecting and reporting exist at the regional to national level, but useable data set(s) do not exist at the regional to national level (Appendix 2-B). Although useable data set(s) do not yet exist at the regional to national level, soil aggregate stability has been incorporated into the USDA Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI), which focuses on non-federal rangelands—this will likely result in a national-level data set of soil aggregate stability on non-federal rangelands.

Clarity to Stakeholders

Soil aggregate stability is not well understood by stakeholders at the present time. We believe that the best way to make soil aggregate stability understandable to stakeholders is to relate soil aggregate stability to the soil's level of resistance to soil erosion and to help them understand that this may provide an early warning signal before significant erosion occurs. Stakeholders understand the value of reducing soil erosion.

Assessment of Microbial Activity in Rangeland Soils

Description and Importance of the Indicator

Soil microbial organisms are important contributors to decomposition and nutrient cycling. They are crucial in the incorporation of organic material into soil, which aids soil infiltration and improves productivity. Productive soils provide nutrients and water to maintain primary production and biodiversity of plants and animals. This indicator will assess microbial activity in rangeland soils through the measurement of microbial respiration. Microbial respiration is correlated with nitrogen mineralization potential, soil organic carbon, and microbial biomass. These microbial parameters are useful in assessing soil sustainability on rangelands. Ingram et al. (2005) found that a modified short-term method of evaluating microbial respiration was a good indicator of organic matter and nutrient cycling in rangeland soils and reclaimed rangeland soils.

This indicator is closely associated with the soil organic matter indicator. They differ because the soil organic matter indicator provides the soil organic matter (soil organic carbon) content of the soil without disclosing the microbial activity of that soil. Microbial activity infers that there is a biological community in place that can respond to the moisture and carbon already in the soil, or to moisture and carbon inputs.

Geographic Applicability

The absolute values derived from this indicator would vary considerably among locations because of climate and climate's effects on soil development and microbial activity. This indicator will require some level of standardization for various climatic zones and soils but will be a useful tool to assess general soil microbial activity. A general decline in microbial activity over time could indicate that the system is being degraded through reduced carbon inputs or severe climatic factors. Because this indicator is assessed under optimal moisture and temperature conditions (0.5 bar moisture tension near field capacity and 25°C), we must keep in mind that it is telling us the soil's microbial potential.

Scale in Time and Space

This indicator will exhibit large spatial variation across soils because of soil texture variation and organic matter content variation. Large temporal variation is inherent in microbial activity but can be minimized somewhat by using the "3-day flush method" mentioned below. Therefore, changes in this indicator over time will best describe the potential for nutrient cycling and whether a healthy microbial population exists. This indicator will likely be evaluated against some minimal value to indicate either adequate or inadequate soil microbial activity.

Data Collection and Availability

It is conceptually feasible to assess the microbial status of rangeland soils, but no regional to national methods or data sets currently exist. Despite the lack of regional- to national-level methods, localized methods do exist for measuring soil microbial respiration as a proxy for soil biological activity. Recent research resulted in the evaluation of the "3-day flush method" compared with standard 21- to 25-day incubation methods (Franzluebbers et al. 1996; Franzluebbers 1999; Franzluebbers et al. 2000). The "3-day flush method" was highly correlated with soil biological evaluations such as nitrogen mineralization potential and microbial biomass, as well as soil organic carbon. This "flush method" has recently been evaluated in rangeland soils and reclaimed mined lands and was an excellent indicator of general microbial activity (Ingram et al. 2002, 2003, 2005).

Limited, incomplete data sets are available on rangeland soils at selected regional sites. The flush method is simple and requires no special handling of soil samples in the field. Samples should be air-dried to ensure a common baseline and enable samples to be collected and stored for short periods during transport to the laboratory. Air-drying of samples also reduces variability attributable to antecedent climatic conditions and soil moisture. The flush method assesses the potential soil microbial activity under good moisture conditions and temperature, which is more appropriately indicative of soil quality/condition. Data that are available likely represent small plot research and were collected using standardized methods.

Clarity to Stakeholders

Stakeholders will not likely understand this indicator because microbial activity of rangeland soils is not a common parameter associated with rangeland sustainability. This indicator would be new for most stakeholders, yet with some education it would be easy to understand because we can relate it to emission of CO_2 by the microbial population during organic matter decomposition.

Area and Percent of Rangeland With a Significant Change in Extent of Bare Ground

Description and Importance of the Indicator

Bare ground is exposed mineral or organic soil that is susceptible to raindrop splash erosion (Morgan 1986). Increases in bare ground and greater homogeneity of existing bare ground relate—directly—to a site's susceptibility to accelerated wind or water erosion (Smith and Wischmeier 1962; Morgan 1986; Benkobi et al. 1993; Blackburn and Pierson 1994; Pierson et al. 1994; Gutierrez and Hernandez 1996; Cerda 1999). The distribution of bare ground is important. Bare ground as numerous small patches (high fragmentation) is less susceptible to soil movement than a few large patches (low fragmentation) where the velocity of soil-moving wind or water accelerates. The importance of bare ground as an indicator is a function of 1) its direct relationship to erosion risk, 2) its known value as an indicator of changes in land management and watershed function (Branson et al. 1972), and 3) the ease and economy with which this indicator can be monitored over extensive areas, particularly when using remote sensing methods (Tueller and Booth 1975a; Abel and Stocking 1987; Booth and Tueller 2003). It also lends itself, more than most other natural resource indicators, to automated measurement by computer image-analysis techniques (Bennett et al. 2000; Booth et al. 2003, 2008; Booth and Cox 2008a).

Geographic Applicability

The amount and distribution of bare ground varies. On many rangelands little bare ground exists because litter, rock, gravel, and sometimes functional biological soil crusts cover the non-vegetated areas. Bare ground also varies among 1) soils of differing parent materials, texture, and age, 2) plant communities, 3) lands with differing precipitation patterns, and 4) grazing intensities—to name some of the more prominent variables. Badland soils like those in South Dakota inherently have high amounts of bare ground compared with grasslands. Areas where a high percentage of bare ground cause ecological concerns on U.S. rangelands usually occur where non-grazing uses (i.e., farming, construction, off-road vehicle disturbance, roads, mineral exploration and extraction) have disturbed soil-protecting characteristics or where animals concentrate (i.e., drainage ways and riparian areas, fence corners, trail ways, sheep bed grounds). Bare ground is common on extensive areas of over-grazed lands and often leads to desertification (UNEP 1990).

Bare ground is a meaningful indicator in all different regions when compared by site over time so that the natural range of variation is established. Soil series or ecological site descriptions (USDA NRCS 2003) might become useful for predicting bare ground; however, that use must be preceded by years of trend-analysis data collection and correlation of bare ground with relevant variables such as climate, aspect, vegetation (existing and historical), geology, and slope.

Scale in Time and Space

Until the stability and range of variation of a given ecosystem or management unit is established, it seems advisable to measure bare ground frequently (1- to 5-year intervals). Where the natural range of variation is established and data indicate bare ground is relatively stable over time, a 5- to 10-year sampling interval seems appropriate unless there is a significant disturbance or change in management. Methods of measuring bare ground include point, plot (area), and linear (line intercept) methods. Point methods include the point frame (Levey 1927) and the point-step (Evans and Love 1957). A common procedure is to measure 100 points per m2 (that is, points are spaced on a 10-cm grid) using the point frame or 100 to 200 points in a paced transect using the point-step method. Plot methods include the now archaic charting (usually of a 1-m^2 plot) by means of a pantograph (Stoddart and Smith 1955) and 2-cm diameter Parker loop (Parker 1951).

Bare ground measurement by image analysis has developed considerably since Cooper (1924) described his methods for obtaining vertical photographs of vegetation from 1.8 m above ground level. Daubenmire (1968) observed that cover could be measured from an image (chart, map, or photograph) by using a planimeter, by cutting out and weighing parts of the image, or by using a dot grid. Computers greatly facilitate cover measurements from images. Where image pixel resolution is similar to the 2 mm per pixel used by Bennett et al. (2000), image analysis can be considered a direct point-sampling of ground-cover that gives greater precision than is obtained by on-the-ground methods like the point frame (Walker 1970; Wells 1971; Bennett et al. 2000). Images with less resolution give an area measurement. Point sampling (dot grid or pixel count) used with lower-resolution images measures image cover (as opposed to ground cover), and image cover converts to a ground-area measurement. The greater the ground area per pixel, the greater the inaccuracies attributable to pixels containing mixtures of bare ground and other attributes (for example, vegetation, rock, gravel, litter, and biological soil crusts). These are inaccuracies of absolute bare ground per unit area. The inaccuracies are less problematic if we consider only temporal changes by delineating the exact area and using the same method to measure change over time. Regardless of methods, season and annual variation in vegetation cover may impact the measure of bare ground and must be considered when interpreting changes (Anderson 1974; Gutierrez and Hernandez 1996).

As with all indicators, data collected at a local level are not easily extrapolated to, and reported over, larger geographic areas without a sampling design consistent with the inherent variability of the larger geographic area being monitored. It is usually impractical for extensive land areas such as public grazing allotments or watersheds to be monitored using sample numbers and a distribution adequate to something like a 95-percent confidence interval if sampling is limited to ground-based methods. Aerial sampling as used by Booth (1974), Abel and Stocking (1987), Booth et al. (2003, 2006, 2008), and Booth and Cox (2008a, 2008b) greatly enhance the practicality for adequate sampling over extensive areas.

Data Collection and Availability

Some data sets exist at the regional to national level, but methods and procedures are not standardized at the regional to national level. For most available data, bare ground was not measured using the strict definition we used above, although the NRI began using our strict definition in 2003 for rangeland surveys (Pyke et al. 2002; Spaeth et al. 2003). The data sets exist as two types: ground data collected with various methods and remotely sensed data. We list two potential data sets that currently exist: the NRI and various remote sensing formats (Appendix 2-C).

Ground data: Bare ground is included in vegetation analyses for many agencies and non-governmental organizations, including most military reservations in the United States (for example, the military's Land Condition and Trend Analysis). The data within and among these agencies and organizations have been collected using various methods and for numerous sites yet lack adequate sampling designs for regional to national aggregation. However, where sequential, comparable data exist they may provide a useful measure of the natural range of variation for the site. Another potential source for obtaining the natural range of variation for bare ground is the NRCS individual soil pedon data for recent surveys. The aggregated data for soil map units and taxonomic units are stored in NASIS (National Soil Information System) and available through the SSURGO (Soil Survey Geographic) Database for digitized surveys. A limitation here is that ground cover is probably ancillary data in most soil surveys, without stringent standards for providing estimates (Schoeneberger et al. 1998).

Remote sensing data: Data sets (United States or otherwise) with an image resolution that potentially allows an accurate measure of bare ground (Morgan 1986) are rare and largely limited to research efforts (Wells 1971; Bennett et al. 2000; Table 1 in Booth and Tueller 2003; Booth et al. 2003). No remote sensing study has measured bare ground classification accuracy using the strict definition adopted from Morgan (1986). Theoretically, bare ground can be measured using existing remote sensing databases; however, measurement inaccuracies are likely, attributable to pixels containing mixtures of factors and to variable amounts of soil moisture and organic matter that confound image analysis. Research is addressing these limitations. For example, there has been some limited success reported for remotely sensed discrimination of biological soil crust from other soil surface components (Karnieli et al. 2001). Reflectance characteristics vary considerably as soil moisture content changes. Soil textural differences can provide different spectral curves. For example, a sandy-textured soil has a relatively flat spectral curve hovering around 30-percent reflectance, while a silty-textured soil's spectral curve climbs more steeply and has a much greater reflectance particularly at mid-infrared wavelengths above 1.7 µm. A clayey-textured soil is intermediate between these two extremes. The amount of organic matter affects the spectral curve, with lesser reflectance values for soils with greater amounts of organic matter.

The brightness, or intensity, of radiation reflected from bare ground is high because there is nothing to absorb it. Conversely, a dense vegetation cover absorbs most of the incoming red radiation, so its brightness is low. The light that vegetation does not absorb well is the infrared wavelengths. Heavily vegetated areas therefore reflect a high proportion of infrared light. The combination of low red and high infrared reflectance is often referred to as "greenness." Most remote sensing studies categorize areas as bare ground in an indirect manner, by assuming that areas not reflecting infrared must be non-vegetated. This is somewhat simplistic, however, because of the confounding classification factors mentioned previously and the fact that many arid land plants exhibit little spectral greenness. However, the results of such studies do describe increases in bare ground associated with land degradation.

A number of remote sensing studies have shown a high accuracy for a bare ground category when classifying images at various scales (Tueller et al. 1988; Tueller and Oleson 1989). However, these studies do not adhere to our strict definition for bare ground nor do they partition out the confounding factors mentioned previously. For arid rangelands, areas of bare ground can be identified with high accuracy using representative fraction scales varying from 0.2 m pixel Kodak Color infrared digital air photo data, to 0.6 m Quick Bird (commercial satellite system) data, to 1 m IKONOS data (commercial satellite system provided by Space Imaging, Inc., Thornton, CO), to 5 m pixel IRS satellite data. Changes can be quantified easily where areas are classified and the bare ground category is reasonably accurate based on image processing techniques. Resolution of these confounding classification factors at various scales enhance the usefulness of remote sensing for quantifying bare ground and monitoring bare ground changes on rangelands.

Recently, remote sensing experts have been experimenting with hyperspectral data. Hyperspectral systems provide complete spectroradiometric curves of various sized polygons, representing individual plants or plant communities (vegetation types) depending on the scale. Spectroradiometric curves show discrete absorption features that can represent bare ground, individual soils, or the mineral characteristics of specific kinds of soils. The shape of spectroradiometric curves can be indicative of the amount of bare ground in a pixel. Research in this field is promising and should be encouraged. In addition, new Interferometric Syntheic Aperature Radar (IFSAR) systems may provide new data that will be useful to evaluate bare ground.

Ground vs. remote sensing: West (1999) stated the feelings of many when he wrote, "I see no hope that traditional methods of monitoring, *via point sampling on the ground* [italics added], will be able to accomplish those [monitoring] needs . . . especially when landscape and regional perspectives are required. There are simply not enough adequately trained people and that approach would not be affordable, even if the necessary professionals existed." This was demonstrated by the NRI Colorado Test (a prototype procedure) where random sampling and ground data (objective and subjective) collection was used (Pellant et al. 1999). Pellant et al. (1999) reported an average 2.5 hours travel time for 3-person teams to reach sample sites. This included the use of helicopters for sites not accessible to wheeled vehicles. Field data collection cost (with no data analysis included) was $893 per sampled site. The field crews sampled 448 locations at a total cost of $400,000 (Pellant et al. 1999).

The dilemma has been in choosing where to err. The smaller the scale (larger-sized pixels) used in remote sensing the greater the extensive information about large-sized geographic areas, but the lower the accuracy of our inference about specific details (that is, the area of land susceptible to raindrop splash). Conversely, accurate measurement of bare ground at specific sites limits the geographic area of inference and has high cost and increasingly difficult access for ground work. Hopefully the newly evolving technologies will solve the dilemma.

Clarity to Stakeholders

The public generally understands that bare ground is less desirable than soils covered by vegetation. Changes in the extent of bare ground over time, rather than how much bare ground there is at any moment in time, are more compelling in regard to rangeland sustainability. The concept of some bare ground being normal for many rangelands, rather than all bare ground being viewed as negative, is a concept that stakeholders still need to understand.

Area and Percent of Rangeland With Accelerated Soil Erosion by Water and Wind

Description and Importance of the Indicator

Soil erosion by wind or water begins with the loss of all or part of the surface horizon. Surface horizons of soils are important to maintain because they contain the majority of the organic material and are the exchange medium for transferring nutrients from the soil to plants. Losses of soil through erosion may lead to reductions in the productivity of the site (Dormaar and Willms 1998; Davenport et al. 1998). Because upper soil horizons typically contain the highest organic matter and nutrient content, this component of the soil generally controls the rate of water infiltration and plant establishment and growth (Wood et al. 1982). Excessive erosion can contribute soil sediments to waterways thereby reducing water quality.

Since 1945, the United Nations Environment Programme (UNEP 1990) estimates that 11 percent of Earth's vegetated soils (1.2 billion ha) have become degraded to the point that their original biotic functions were damaged and that reclamation would be impossible or too costly. Wind and water erosion is the process that caused most of this degradation. Accelerated erosion is arguably the number one contributor to declines in human civilizations over the last 7,000 years (Lowdermilk 1953). This points to the importance of monitoring soil erosion rates as an indicator of rangeland sustainability and the sustainability of human civilizations associated with rangelands.

This indicator will identify areas where erosion is greater than expected for the soils on a specified site. It does not identify areas with high natural erosion rates (for example, areas with an inherently low vegetative cover and with steep and dissected topography, such as the South Dakota badlands). This indicator measures soil loss by the action of water or wind.

Geographic Applicability

Soil erosion on rangelands was recognized as a serious problem at both local and national levels in the United States in the 1920s (Weltz et al. 1998). Soil erosion varies from soil to soil and from plant community to plant community but is important in any region. Local, regional, and national data on soil erosion can only be accumulated if similar soils and vegetation are affected and the data summarized for the total of the affected areas.

Scale in Time and Space

This indicator is applicable at various spatial and temporal scales. Its applicability depends on the kind of soil involved as well as the ability to measure rills and gullies, provide evidence of inter-rill erosion, and measure soil movement through the air. Rill erosion is caused by concentrated runoff water flowing over the soil, whereas inter-rill (sheet) erosion results from raindrop impact and splash. Soil aggregate size and stability, biological soil crusts, physical crusting, random and oriented roughness, and extent of vegetative cover are related to wind and water erosion. The distribution of these erosion characteristics and their changes across spatial scales from an individual plot to large geographic areas will influence changes in erosion. The temporal scale would be in terms of years but often related to individual storm events in relationship to overgrazing and other sources of rangeland degradation.

Data Collection and Availability

Accelerated erosion by water can be observed using several parameters including movement of litter downslope, evidence of sheet erosion, or an increase in the number and size of rills and gullies (Pellant et al. 2005). Soil erosion rate can be viewed as a function of site erosion potential (SEP) determined by climate, slope conditions, soil erodibility, and ground cover. In pinyon-juniper dominated areas with high SEP, the erosion rate is highly sensitive to ground cover and can cross a threshold so that erosion increases dramatically in response to a small decrease in cover (Davenport et al. 1998). After disturbance, both runoff and erosion amounts tend to increase and remain at elevated levels for a decade or more although the rate is not increased with time (Wilcox et al. 2003). As rangeland vegetation mosaics change as the result of disturbance, ecologically important changes in runoff and erosion can result (Reid et al. 1999).

Wind erosion and transport of surface materials depend on the strength of the wind, the soil surface texture, and the surface protection materials including rocks, biological soil crusts, and vegetation. Surface soil texture is an important key to wind erosion hazard potential. Loamy sand and sand, characterized by particles ranging between 50 and 2,000 μm in size, are the most vulnerable soil textures to wind erosion. Clayey soil, because of the ultrafine particle size with highly reactive surfaces, has better structure and is thus more resistant to wind erosion. Coarse sand and gravelly or rocky soils also are more resistant to wind erosion because the particles are too heavy to be removed. Wind erosion can lessen soil productivity because it physically removes soil particles and organic matter near and at the soil surface and because soil fertility (for example, nitrogen and phosphorus) decreases with diminished organic matter content (Foth 1984). Soil particles transported by wind erosion can enter suspension and become part of the atmospheric dust load. Dust obscures visibility, pollutes air, and fills road ditches, potentially resulting in decreased water quality, automobile accidents, fouling of machinery, and imperilment of animal and human health (Skidmore and Layton 1988). Accelerated erosion constitutes a very strong indicator of rangeland degradation.

Standardized methods and procedures for data collection and reporting have been studied for use at the regional to national level, but useable data set(s) do not exist at the regional to national level (Appendix 2-D). However, the Universal Soil Loss Equation (USLE), Revised USLE (RUSLE), RUSLE2 and Water Erosion Prediction Project (WEPP) have been or are being evaluated for rangeland use. Early models (USLE and RUSLE) were developed for cropland and failed as useful predictors of erosion on rangelands. NRCS soil survey data can potentially provide a national-level soil erodibility and soil erosion data set on rangelands, but erosion was a visual estimate of an observer at an NRI point while erodibility was calculated using the inaccurate USLE or RUSLE models.

Remote-sensing techniques provide a promising technology to obtain information on soil erosion, but limited testing has been done. We encourage additional research to refine and test various methods for obtaining accurate data over larger areas. Recent publications using large scale imagery may be useful for measuring erosion features (Booth et al. 2006; Booth and Cox 2008a).

Clarity to Stakeholders

Erosion is understood by stakeholders. When interested individuals see active or past erosion, the reaction is often a concern for the health of the land. More subtle signs of erosion and the concept of wind-caused dust and the relationship of these to good land stewardship is obscure, requiring further stakeholder education over time.

Percent of Water Bodies in Rangeland Areas With Significant Changes in Aquatic Biota Assemblage Composition

Description and Importance of the Indicator

Measurements of biological assemblages have a long history of use as indicators of change in resource condition. On rangelands, these indicators have traditionally been based on vegetation assemblages. To estimate rangeland condition and trend in condition, plant composition existing at a given moment in time is compared with the plant composition that the given area is capable of supporting at its potential (Stoddart et al. 1975). Downward trends in rangeland condition can also be associated with declines in water quality, aquatic and riparian habitats, and the ability of aquatic habitats to support native biota. These changes can cause aquatic native biota assemblages to shift away from that which would be expected to occur under natural, unimpaired hydrologic conditions (Karr 1991; Hawkins et al. 2000).

The importance of this indicator lies in its relation to watershed conditions and natural biological diversity. Expanding human populations and technology have resulted in a myriad of impacts to our nation's watersheds and water resources (Karr 1991) and a subsequent decline in the biodiversity of aquatic systems (Allan and Flecker 1993), changes in taxonomic composition (Hawkins et al. 2000), and an increase in invasive nuisance exotic species to the detriment of native species. These impacts can be observed in rangeland aquatic systems throughout the western United States. The recognition that multiple stresses are occurring within watersheds has led to the development of ecosystem assessment techniques that evaluate ecosystem attributes that integrate and reflect these multiple impacts. In aquatic habitats, biological assemblages are thought to integrate multiple stressors. Algal, macroinvertebrate, and fish assemblages have all been used as indicators of ecosystem health, with aquatic macroinvertebrates being most often used because of the ease in collection and identification and the relatively high degree of ecological understanding that exists for this group of organisms (Rosenberg and Resh 1993). Monitoring programs based on changes in aquatic macroinvertebrate assemblages are relatively easy to implement, and the data appear to be ecologically meaningful and relevant to the public and decision makers (Karr 1991; Karr and Chu 1999; Norris and Hawkins 2001).

Geographic Applicability

Aquatic systems are dynamic in the number and kinds of species they support within a local habitat and at broader spatial scales (Vinson and Hawkins 1998, 2003). An intuitive and easily understood measure of determining if human activity has affected the biological health or integrity of a place is to compare the fauna observed (O) at that place to that predicted or expected (E) to exist at that place in the absence of human-caused stresses. This comparison between observed and expected (O/E) ecological conditions has proven to be a powerful tool for assessing biological integrity (e.g., Wright et al. 1994; Wright 1995; Hawkins et al. 2000; Hawkins and Carlisle 2001). The units of this comparison can be taxonomic composition, species richness, or functional ecosystem properties such as production or mineral cycling. But in practice, a measure of community composition has proven to be most effective and widely applied (Wright et al. 1994; Wright 1995; Hawkins et al. 2000; Hawkins and Carlisle 2001).

The basis for this comparison is being able to accurately and precisely predict taxa occurrences in the absence of human disturbances. We thus need to identify and then determine the biotic composition at a wide range of undisturbed sites that exist throughout a region. These reference sites need not be pristine, yet they need to be representative of the environmental and biological potential of unaltered or minimally altered places in the region of interest. An additional assumption is that spatial variation in the overall biotic composition among similar sites is similar to the range of variation that an individual site might exhibit over time scales relevant for monitoring objectives.

Scale in Time and Space

Comparisons of observed to predicted species occurrences can provide a meaningful measurement of the degree of impairment at local and regional scales (Wright et al. 1994). Regional scale inferences can be made by aggregating local data across broader geographic areas to evaluate the degree of change occurring within a basin or ecoregion, for example. A hypothetical example would be that at 50 percent of the local sites, 80 percent or more of the species predicted to occur at these sites were observed (O/E = 0.8), whereas at the basin scale, only 60 percent of the species predicted to occur were observed. This would suggest that cumulative impacts are likely occurring within the basin. The cause of the measured effect (the lack of species occurrence) can also be evaluated by correlating trends in assemblage changes with local and regional human-altered environmental factors or known contaminants—for example, by evaluating the strength of the relationship between O/E and nitrate values.

At the temporal scale, variability in aquatic macroinvertebrate assemblage data is typically greater across sites than that observed at the same site over time in the absence of human impairment (Wright et al. 1994). This suggests that natural changes in assemblage composition over time will be less than that observed after human-caused impairment. Thus, data from reference sites do not need to be collected at the same time as data from managed sites, and these data can be used for extended periods of time.

Data Collection and Availability

Standardized methods and procedures for data collecting and reporting for aquatic macroinvertebrate assemblages exist at the regional to national level, and useable data set(s) exist at the local and regional levels (Appendix 2-E).

Clarity to Stakeholders

Comparing the number of aquatic macroinvertebrate taxa that are found at a site to what was expected should be an easily understood concept for stakeholders. A ratio of 0.5 indicates that 50 percent of the species predicted to occur at a site were not found. Thus, the site may have lost its ability to support 50 percent of the species that should occur there. Similarly, these results could be communicated to stakeholders as a 50-percent loss in the natural biodiversity at the site.

Percent of Surface Water on Rangeland Areas with Unacceptable Levels of Chemical, Physical, and Biological Properties

Description and Importance of the Indicator

This indicator measures the percent of surface water with impaired water quality. Surface water includes the length of small, medium, and large streams and rivers, and the area of lakes and reservoirs. Under the Clean Water Act, states and authorized tribes develop water quality standards for their individual stream and river segments, often including their lakes and reservoirs (EPA 1994). A water body segment is a bounded part of a stream, river, lake, or reservoir that is regulated by a set of water quality standards. To establish these standards, states and tribes identify designated beneficial uses (for example, drinking water, recreational, agricultural) for each of their water segments, and then they set water quality criteria to ensure protection of its chemical, physical, and biological integrity (EPA 1994). A water quality criterion is an ambient concentration of an important parameter such as dissolved oxygen, pH, temperature, or heavy metals. An LD_{50} or other metric of these parameters is used to ensure that the designated use or uses for a given water segment are not impaired. Impaired water quality means that one or more of the criteria adopted to protect the designated use or uses of an individual water body segment are not being met. Leading causes of water quality impairment in our nation are excess nutrients (nitrogen and phosphorus), sediment/siltation, pathogens, and metals (USGS 1999). The U.S. Environmental Protection Agency (EPA) National Water Quality Inventory 2000 report states that approximately 40 percent of the nation's assessed streams are impaired (EPA 2006). This water quality indicator is an important measure of water resource sustainability and is an important factor for meeting rangeland sustainability objectives. Water resources must be of adequate quality to support a variety of uses such as human and livestock consumption, wildlife habitat, agricultural and industrial supply, and recreation (Heinz 2002). Water quality is important to rangeland sustainability because wildlife, livestock, downstream water users, recreationists, and others depend on clean water, particularly in arid and semiarid rangelands.

Geographic Applicability

Water quality standards vary geographically. For a particular water body, the water quality parameters that are deemed important, as well as the appropriate criteria or thresholds, depend on the designated uses. Also, states and tribes consider natural ranges of variation when designating uses and developing water quality standards. Water quality impairment assessments are local decisions because our nation's waters do not naturally exhibit the same characteristics. However, states and tribes regularly monitor and assess water quality and identify their water bodies that do not meet their standards. These impaired water bodies are reported on a Clean Water Act Section 303(d) list that is updated biennially (EPA 2003).

Scale in Time and Space

States and tribes have flexibility in how they determine designated uses, which water quality parameters to monitor, which monitoring methods to use, and which methods are used to assess water quality. Also, to meet management and compliance objectives, most water quality monitoring is conducted at "fixed" stations, and the resultant data are not necessarily representative of the whole water body or watershed. National reports on water quality do not yet provide an assessment of all the watersheds in the United States. For these reasons, scaling water quality parameter data up to a regional or national reporting level would be very difficult. Assessing comprehensive regional or national trends of important water quality parameters would present similar challenges. However, the Section 303(d) impairment lists, updated by states and tribes using local water quality data, provide national information on deteriorated water quality and its causes (EPA 2003). Reporting of Section 303(d) lists began in 1998, and states are required to update their lists every two years. As part of their Section 305(b) requirements, states have for the last 30 years been monitoring and reporting water quality information into EPA's national data repository, STORET (Storage and Retrieval).

Data Collection and Availability

Under Section 305(b) of the Clean Water Act, the EPA, other federal agencies, states, and tribes are required to monitor their waters for water quality and report that information into EPA's national water quality database, STORET. Additionally, a National Water Quality Inventory is required biennially, which summarizes water quality reports submitted by states, territories, interstate commissions, and tribes. For reasons stated above, this report cannot be used as a regional or national assessment or to measure national trends in water quality. Also required is a biennial Section 303(d) list of impaired waters (EPA 2003). These impaired waters are required to develop a total maximum daily load (TMDL). TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and it allocates components of that total to the various polluters. The biennial Section 303(d) list of impaired waters is probably the best information we have on impaired water quality and should initially be the data sources for this water quality indicator.

Another potentially useful data source is U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. To help support local decision makers in developing TMDLs and to provide long-term, nationwide information on water quality, the USGS NAWQA Program is starting its second decade of intensive water quality assessments. These assessments will cover 42 large hydrologic systems representing about 60 percent of the nation's waters used for drinking and irrigation. These assessments include a broad list of physical, chemical, and biological measures including 1) streamflow and stream habitat, 2) water, 3) sediment and tissue chemistry, and 4) characterization of algae, invertebrate, and fish communities. However, NAWQA data coverage on rangelands is limited because at least half of the 40-percent non-coverage area is rangeland. (Appendix 2-F).

Clarity to Stakeholders

The concept of a water body meeting or not meeting a water quality standard is an easily understood concept to stakeholders.

Changes in Groundwater Systems

Description and Importance of the Indicator

Because groundwater is a crucial source of fresh water (Alley et al. 2002), supplying the major source of drinking water for more than 50 percent of the U.S. population and 96 percent of the rural domestic supply of water (Solley et al. 1998), a case could be made that groundwater has a direct connection with social, economic, and ecological sustainability of rangelands. Groundwater is used for irrigated pastures that supply winter forage for livestock in many regions of the country. Many of the streams, rivers, and wet meadows in rangeland depend on groundwater and the connection between groundwater and shallow water tables (Taylor and Alley 2001). Drops in groundwater levels may eventually influence stream flows in two common ways: through water moving from the stream into the groundwater system, which recharges removals made elsewhere in the system, or through input reductions at seeps, springs, and wetlands (Alley et al. 1999). Streamflow is expected to decline as a result of woody plant encroachment in landscapes dominated by subsurface flow regimes. Similarly, encroachment of woody plants can be expected to produce an increase in the fractional contribution of bare soil evaporation to evapotranspiration in semiarid ecosystems, whereas such shifts may be small or negligible in both subhumid and arid ecosystems (Huxman et al. 2005).

Water-level monitoring of wells remains the best method for detecting fluctuations in groundwater levels (Taylor and Alley 2001). These measurements may relate to changes in land use and water use, but these relationships require a large array of monitoring stations. Unfortunately, only a limited portion of this array exists (Alley et al. 2002).

The appearance of increased groundwater discharge can be related to a reduction of net primary productivity (NPP) on some ecological sites. Changes in rangeland vegetation can be measured (Vogelmann et al. 1998a, 1998b) and in some cases related to changes in stream base flow. Changes in the distribution of phreatophytic vegetation can be measured using remote sensing techniques, and these changes can be related to changes in streamflow, spring discharge, and increased salinization in lowland areas. Downcutting of mountain meadows can lower water tables and cause the replacement of water-loving vegetation with upland species.

Water-level data will also show areas where surface-water and groundwater interactions may play an important role in sustaining riparian habitat. Changes in water depth in wells over regional areas can be related to phreatophyte control but much less clearly to removal of general amounts of upland range vegetation. The groundwater eventually discharges from aquifers to springs, streams, wetlands, playas, plants, and adjacent basins. All this can influence the natural rangeland vegetation associated with these features. Clearing of native vegetation has led to an order of magnitude increase in recharge rates in areas such as the Niger Basin in Africa (Favreau et al. 2002).

When drawdown exceeds recharge, the result is a loss of available groundwater supply, land subsidence, degradation of water quality, and a loss of riparian habitat. Lowering of the water table (mining of the groundwater) and reduction in groundwater flows and storage are continually changing in response to human and climatic stress. Emphasis must be given to the relationship between groundwater and surface water, so this indicator would mostly be influential near springs and seeps and in the drainages and floodplains.

Geographic Applicability

This indicator integrates groundwater levels over relatively large land areas as defined by the size and structure of the aquifers. This indicator is potentially of importance on almost any rangeland area. The USGS annually monitors groundwater levels in thousands of wells in the United States.

Scale in Time and Space

About 9,000 locations in the United States have gauging stations. The rangelands in the western U.S. have limited coverage. Enhanced coverage is needed for this indicator to become a useful early-warning indicator (Alley et al. 2002).

Data Collection and Availability

The USGS Groundwater database contains groundwater site inventory and groundwater level data (Appendix 2G). The USGS annually monitors groundwater levels in thousands of wells in the United States and conducts a groundwater site inventory of more than 850,000 wells, springs, test holes, tunnels, drains, and excavations. These data are compiled into the USGS Groundwater database. Available site descriptive information includes well location information (latitude and longitude), well depth, site use, water use, and aquifer. Groundwater level data are collected and stored as either discrete groundwater measurements or as a continuous record. Water-level data for groundwater monitoring sites in the study area have been compiled from USGS databases and other sources. Hydrographs that illustrate the water-level changes in most aquifer systems have been plotted. Geographic Information System data sets that represent pre-development or recent groundwater levels are being created, where possible.

Clarity to Stakeholders

The public understands water levels as they relate to wells for drinking water, but the connection between groundwater and surface water is not well understood. Also, the possible influence of groundwater on vegetation characteristics is not easily comprehended by the public.

Changes in the Frequency and Duration of Surface No-Flow Periods in Rangeland Streams

Description and Importance of the Indicator

This indicator originated in Heinz (2002, 2008) and was retained by the SRR. This indicator annually measures the percentage of rangeland streams with at least one day of no-flow (also referred to as zero-flow) in a year, and, of those, the percentage that have a duration of zero-flow for a given period that is substantially longer or shorter compared with a long-term average. Together, these two variables describe the frequency and duration of surface no-flow periods.

Streamflow is critical in sustaining the habitat necessary for many rangeland plants and animals. Increasing no-flow periods can lead to loss of streamside vegetation and wildlife habitat for many rangeland species. No-flow periods can lead to loss of fish and aquatic animals. Conversely, decreasing no-flow periods can also lead to shifts in rangeland plants and animals and their habitats.

Surface no-flow periods can occur naturally. Surface no-flow periods can also occur because of increased water use for domestic, irrigation, or other purposes. Other causes of no-flow periods are changes in land use (for example, a transition from rangeland to urban development or a transition from no livestock grazing to livestock grazing) and changes in vegetation that modify the flow of surface water and the recharge of groundwater (for example, expansion of deep-rooted vegetation such as pinyon or juniper, which can draw down surface aquifers). Changes in surface no-flow periods also can be attributable to changes in weather and/or climate, such as periods of drought and wet periods.

Geographic Applicability

This indicator has been reported for ecoregions (Heinz 2002, 2008) using the ecoregion approach of Bailey (1995), specifically for the desert shrub, grassland/steppe, and California/Mediterranean ecoregions, which represent the majority of rangelands in the lower 48 United States. Trends in the frequency and duration of surface no-flow periods are discernible over time at the division level of Bailey's ecoregions, and spatially between divisions.

Scale in Time and Space

The USGS has collected flow rate data since the end of the 19th century on stream gauges across the United States (USGS stream gauge data, http://waterdata.usgs.gov/nwis/sw. Accessed 15 January 2009).

Data Collection and Availability

Methods and procedures exist for data collecting and reporting of this indicator at a regional to national level. Data sets of useable quality exist (Appendix 2-H). Data sets are maintained by the USGS and are available at http://waterdata.usgs.gov/nwis/sw. Accessed 15 January 2009.

Clarity to Stakeholders

Stakeholders can understand that streams that are changing from perennial to ephemeral or intermittent, with decreasing streamflow, will affect habitat of wildlife and plant species and will affect availability of water for agricultural, municipal, energy production, and other uses.

Percent of Stream Miles in Rangeland Catchments in Which Stream Channel Geometry Significantly Deviates From the Natural Channel Geometry

Description and Importance of the Indicator

This indicator tracks changes in stream channel geometry (that is, in cross section, in profile, and in channel bed materials) from a baseline condition. Changes in cross section are defined by the width/depth ratio at "bankfull" stage. Changes in profile are defined by sinuosity and channel slope. Changes in bed material are defined by the particle-size distribution of materials comprising the streambed. Measurements of these attributes of stream channel geometry comprise the indicator. Baseline conditions can be defined by natural, historic, or reference channels located in the same hydro-physiographic position on the landscape.

Changes in width, depth, width/depth ratio, slope, sinuosity, meander characteristics, and substrate materials are indicative of changing conditions of water and sediment yield in a watershed. Changes in channel pattern (for example, straight, meandering, braided, riffle-pool, step-pool, or cascade) are also good indicators. Where such changes are observed over time and space, the cause of channel adjustment should be explored to determine if management practices are contributing to channel degradation and if the stream system is presently out of balance with the water and sediment being supplied by the watershed.

Stream channels are constantly adjusting to the water and sediment load supplied by the watershed. Changes in channel conditions in a rangeland watershed correspond to changes in streamflow and sediment supply in the basin, as well as human manipulation of the channels, and therefore are a good indicator of sustainable rangeland management.

Geographic Applicability

This indicator should be meaningful in virtually all regions provided the baseline condition is adequately and correctly defined. Regional differences will exist in what is considered natural and baseline. Primary influencing factors will be climate and its associated influence on vegetation composition along the channel, as well as parent materials of watershed sediments available for transport and deposition along the channel.

Scale in Time and Space

Temporally, channel adjustments may be identified for a particular stream reach by evaluating a sequence of aerial photos covering several years or decades. Alternatively, upstream and downstream reaches may provide a descriptive history of channel adjustments using a "space for time" substitution. Because most channel evolution occurs in an upstream direction (that is, channel features like nickpoints, gullying, and widening tend to work upstream rather than downstream), earlier conditions for a stream reach likely resembled present conditions upstream of the reach. Similarly, channel evolution at a site would be expected to produce a future condition similar to that presently observed in downstream reaches. Thus, channel geometry measurements should be evaluated with respect to both temporal and spatial considerations.

The indicator is most useful and meaningful at the reach scale; however, it likely is amenable to aggregation on a watershed or sub-basin scale. Spatial scale also must be considered when assessing whether changes in channel geometry are local or system-wide in nature. Local site-specific changes in channel geometry result from erosion and deposition processes that are not symptomatic of a disequilibrium condition in the watershed. Common displays of local channel adjustment include instability along the concave bank of a meander bend as part of natural channel meandering or in isolated locations as a result of channel constrictions or flow obstructions (for example, ice, debris, and structures). In contrast, system-wide changes in channel geometry and substrate often reflect changes in runoff and sediment yield from the watershed or changes in resistance to flow and erosion in the channel corridor. Both could be indicative of non-sustainability of management practices. However, even system-wide adjustments can result from natural channel evolution, and care must be used when interpreting the measurements associated with this indicator.

The greatest utility of the channel geometry indicator would result from repeated measurements over a period of time. Time trends of channel narrowing, widening, flattening, steepening, fining, or coarsening would be less susceptible to misinterpretation than single measurements at a moment in time. Repeated measurements over several spatial scales (that is, both reaches and sub-basins) would also allow consideration of natural channel evolution processes versus rapid channel response to non-sustainable watershed practices. Single measurements of channel geometry at a single location in a basin would be most susceptible to misinterpretation and misunderstanding of channel processes.

Data Collection and Availability

The data for evaluating this indicator exist for some areas; however, data likely occur in a variety of formats. No national data sets exist, and any regional data sets likely include information only for a single state or federal agency. However, standardized procedures for sampling and analyzing these data do exist.

Clarity to Stakeholders

Detailed understanding of this indicator probably is not intuitive for all stakeholders; however, it might be possible to make it that way. Accurate interpretation of channel geometry and substrate measurements requires an understanding of fluvial geomorphology. Communication of this indicator will require a skilled presentation to achieve understanding by a broad cross-section of stakeholders.

A Look Ahead

Several of the indicators pose challenges regarding their applicability over broad geographic areas. Sampling schemes have not yet been designed for some of the indicators to achieve an objective of regional- to national-level reporting of change over time. Some indicators represent "outside the box" thinking and would require more understanding among stakeholders before they would widely accept the indicators as credible.

We are discovering that regional- and national-level data sets are not available for most of the indicators. More data sets are often available for smaller geographic areas, with various methods used for measurement. Elaborating on the quality of data sets has been challenging because quality-control information is scant in the literature.

Of the 10 indicators, some of the five water-based indicators might also be identified by the Sustainable Water Resources Roundtable, which is ongoing. Within SRR, there has been some overlap in indicator identification between the Soil and Water Resources Criterion Group and the Plant and Animal Resources Criterion Group. Integration, both within the SRR and between the various Roundtables, is critical to minimize overlap. In some cases, more than one indicator appears to be indexing similar rangeland components. For example, organic matter, aggregate stability of the soil surface, bare ground, and soil erosion each affect or influence assessment of soil erosion. Therefore, an obvious question is: do we require all of these soil indicators to adequately assess the role of soils and soil change in the reporting of rangeland sustainability?

Soil and water are natural capital and, as such, represent an accumulated wealth that if squandered will cause decline in rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water can provide an approximation of rangeland sustainability for our nation and a blueprint for evaluating rangeland sustainability worldwide.

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Wright, J.F. 1995. Development and use of a system for predicting macroinvertebrate fauna in flowing waters. Australian *Journal of Ecology* 20:181-197.

Wright, J.F., M.T. Furse, and P.D. Armitage. 1994. Use of macroinvertebrate communities to detect environmental stress in running waters, p.15-34. *In:* D.W. Sutcliffe (ed.). Water quality and stress indicators in marine and freshwater ecosystems: linking levels of organization (individuals, populations, communities). Cumbria, UK, Freshwater Biology Association.

Appendices. Information on data sets associated with soil and water indicators. Information is not available for the microbial activity soil indicator and the stream channel geometry water indicator.

Appendix 2-A. Area and percent of rangeland with significantly diminished soil organic matter and/or high carbon:nitrogen (C:N) ratio.

	Data Set #1
Brief Title for Data Set	Organic Matter from NRI (using Statsgo).
Contact Person/Agency/Group	
Citation (if published)	
Website (if available)	
Additional information on data set	
For what years are data available, and how often are data collected?	1982 to 1992 in 5-year intervals.
In what format is the data set available?	Data points.
Are data nominal, ordinal, or interval?	Continuous.
What will be the approximate cost of collecting data?	$1,000/point (estimate for all NRI, not just soil organic carbon).
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	None.
What is the spatial grain of these data?	3 random plots per 160 acres (65 ha) per Primary Sampling Unit.
What is the spatial extent of these data?	Non-federal rangeland nationwide.
At what spatial scales can these data be aggregated and reported?	County?, Major Land Resource Area (MLRA), state, or nation.
What is the temporal grain of these data?	Every 5 years.
What is the temporal extent of these data?	1982 to 1992.
At what temporal scales can these data be aggregated and reported?	Every 5 years.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, published in NRI protocol.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Given standard protocol, should be very repeatable (no p-values available).
Quality: how biased are the sampling methods?	Limited bias; adequate statistical sampling design applied.
Quality: how precise are existing data? (Give standard error, if available)	Given protocol, should be very precise (no standard error available).
Quality: how valid are existing data?	Measures soil organic matter. Must use 58% conversion to get soil organic carbon.
Quality: how responsive are existing data?	A lag would likely occur before this measurement would show change attributable to human impacts.
Quality: how much statistical power to detect change does this data set have?	Unknown.
Quality: how well does this data set meet the data needs for this indicator?	It measures soil organic matter, thus requires a 58% correction factor to obtain soil organic carbon.
Other comments: (Include any other relevant aspects of the data set that should be included)	

Appendix 2-B. Extent of rangelands with changes in soil aggregate stability.

	Data Set #1
Brief Title for Data Set	Soil Aggregate Stability
Contact Person/Agency/Group	
Citation (if published)	
Website (if available)	
Additional information on data set	This data set does not yet exist at the national or regional level.
For what years are data available, and how often are data collected?	
In what format is the data set available?	
Are data nominal, ordinal, or interval?	Nominal. Observations of 6 to 8 mm diameter soil surface fragments during immersion and subsequent wet-sieving are compared with criteria, which results in the assignment of the soil surface fragment to 1 of 6 stability classes (stability classes 1 through 6; 1 being slakes immediately, and 6 being 75% remains on a 1.5 mm screen after sieving) (Herrick et al. 2001b; Herrick et al. 2002).
What will be the approximate cost of collecting data?	
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	
What is the spatial grain of these data?	No specific spatial grain has apparently been established for soil aggregate stability data. Most data that have been collected and reported in the literature have been collected at a patch scale, within sites (for example, ecological site).
What is the spatial extent of these data?	
At what spatial scales can these data be aggregated and reported?	Herrick et al. (2005) recommends aggregation of spatial data collected within functionally similar landscape units. They recommend a hierarchy of landscape geographic areas be used to guide the identification of monitoring units. An ecological site (USDA NRCS 2003), which represents a soil-landscape unit, would represent the largest geographic landscape area recommended for use as a monitoring unit. Ecological sites can be further subdivided into vegetation-similar landscape areas, representing soil-landscape-vegetation units (typically areas with dominant plant species that define the plant community), and these soil-landscape-vegetation units can serve as monitoring units. Vegetation-similar landscape areas within ecological sites can be further subdivided into landscape areas within which current management is similar, or soil-landscape-vegetation-management units. These soil-landscape-vegetation-management units would be expected to respond similarly to management changes. Spatial data could be aggregated to large areas by using these monitoring units.
What is the temporal grain of these data?	Herrick et al. (2005) recommend a temporal grain of 1 to 5 years.
What is the temporal extent of these data?	At the regional or national level, there is no temporal extent because soil aggregate stability data have not been aggregated to the regional or national level yet.
At what temporal scales can these data be aggregated and reported?	

Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, if the field soil aggregate stability kit (Herrick et al. 2001b) is used repeatedly over time, data can be reported in a consistent form over time.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	
Quality: how biased are the sampling methods?	
Quality: how precise are existing data? (Give standard error, if available)	Herrick et al. (2001a) present coefficient of variation statistics for soil aggregate stability measurements, but standard errors of means were not presented. Coefficients of variation increased dramatically when data collected from different vegetation types were combined. In addition, coefficients of variation were greater in shrub-dominated sites compared with grass-dominated sites, with the shrub-dominated sites being comparatively more degraded. Herrick et al. (2002) recommend that soil aggregate stability be calculated separately for plant canopy versus intercanopy spaces to help decrease variation.
Quality: how valid are existing data?	Using the field soil aggregate stability kit (Herrick et al. 2001b), this indicator measures what is intended with a high degree of accuracy. Herrick et al. (2001b) report that there is high correlation between the qualitative evaluation of soil stability class using the field soil aggregate stability kit and the quantitative measurement of soil aggregate stability done in the laboratory. The qualitative and quantitative comparisons were performed on the same soils. Aggregate stability percentage obtained from the quantitative lab procedure was within the range associated with the stability class (from the qualitative soil stability test) about ¾ of the time, and all of the aggregate stability percentages were always within 1 class of each other. Although the field soil aggregate stability kit method cannot replace careful laboratory-based measurements of soil aggregate stability, it can provide valuable information when these more intensive procedures are not possible.
Quality: how responsive are existing data?	Existing data are responsive to differences in management, disturbance levels, plant community composition, biological soil crust cover, sometimes arbuscular mycorrhizal fungi, most soil textures, and sometimes organic matter content (Herrick et al. 2001b; Rillig et al. 2003; Chaudhary et al. 2009). Soil aggregate stability apparently is not responsive in wetland and extremely coarse-textured (coarse sand to fine gravel surfaces) soils because soil aggregates do not readily form in these soils (Herrick et al. 2001b). Soil aggregate stability is relatively insensitive to intensive short-term disturbances such as trampling by horses, humans, and vehicles but is more sensitive to longer-term changes in soil structure (Herrick et al. 2002). This relative insensitivity to intensive short-term disturbances is critical to ensure that repeated measurement (monitoring) of soil aggregate stability can pick up or track actual changes, rather than being simply reflective of normal variability in the system (Herrick et al. 2002). The 1.5 mm sieve size of the field soil aggregate stability kit method increases the probability of detecting change at an early stage because aggregation at this size is generally controlled by rapidly cycling organic matter (Tisdall and Oades 1982; Herrick et al. 2002; Bird et al. 2007), and degradation of this size is likely to occur before smaller aggregates are destabilized (Bird et al. 2007).

Quality: how much statistical power to detect change does this data set have?	The answer depends on what sample size is used and what the alpha level is set at. Across 3 different sites in southern New Mexico, at an alpha level of 0.05, sample sizes ranging between 9 and 54 were necessary to achieve a power of 0.8, whereas to achieve of power of 0.9, at an alpha level of 0.05, greater sample sizes were required, ranging between 12 and 74. In this context, the power was applied to the ability to detect a difference in soil aggregate stability of 1 class. At an alpha level of 0.2, sample sizes ranging between 4 and 25 were necessary to achieve a power of 0.8, whereas to achieve a power of 0.9, at alpha level of 0.2, sample sizes ranged between 7 and 39 (Herrick et al. 2001a).
Quality: how well does this data set meet the data needs for this indicator?	
Other comments: (Include any other relevant aspects of the data set that should be included)	As reported in Bird et al. (2007), approximately 5,000 locations between 2003 and 2006 were sampled for soil aggregate stability in the western United States with the field soil aggregate stability kit, as part of the Natural Resources Conservation Service's National Resources Inventory program.

Appendix 2-C. Area and percent of rangeland with a significant change in extent of bare ground.

	Data Set #1	**Data Set #2**
Brief Title for Data Set	NRI administered by NRCS	Indian Remote Sensing (IRS); also a consideration of SPOT, IKONOS, QuickBird, Radar Satellite Data, and other fine-grained imagery of various kinds including very-large scale aerial (VLSA) (Booth et al. 2003).
Contact Person/Agency/ Group	NRCS State Offices	Satellite data: EOSAT Corporation, Thornton, CO. For protocol, Paul T. Tueller, University of Nevada, Reno, ptt@unr.edu. VLSA: Terry Booth, ARS, Cheyenne, WY, terry.booth@ars.usda.gov.
Citation (if published)		1. Booth, D.T., D. Glenn, B. Keating, J. Nance, S.E. Cox, and J.P. Barriere. 2003. Monitoring rangeland watersheds with very-large scale aerial imagery. Proceedings of the First Interagency Conference on Research in the Watersheds. 28-30 October 2003, Benson, AZ. 2. Tueller, P.T., P.C. Lent, R.D. Stager, E.A. Jacobse, and K. Platou. 1988. Rangeland vegetation changes measured from helicopter-borne 35mm aerial photography. Photogrammetric Engineering and Remote Sensing 54:609-614.
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/. Accessed 28 September 2004.	http://www.geoeye.com/CorpSite. Accessed 6 April 2009 http://www.digitalglobe.com/product/index.shtml. Accessed 6 April 2009 http://rrru.ars.usda.gov/. Accessed 6 April 2009
Additional information on data set	NRCS has been working with other agencies, including ARS, BLM, USGS, and USDA Forest Service, to develop an interagency list of data elements that could be used for national-level inventories.	Considerable imagery at various scales and types available throughout the United States. Analysis and interpretation is required to use these data and accumulate bare ground estimates over large areas of rangeland.
For what years are data available, and how often are data collected?	1982 to 1992; every 5 years.	Satellite data: Numerous dates from 1972 onward. IRS has been available since 1983, and the other satellites are more recent. VLSA: Data collected since 2002 and are collected as needed for specific research projects.
In what format is the data set available?	Data points. Primary sampling units (PSUs).	Satellite data: Multispectral and panchromatic digital image data from satellite and large-scale video and digital multispectral images. VLSA: 70 mm color film and 11.1 megapixel color digital images.
Are data nominal, ordinal, or interval?	Nominal.	Satellite data: Interval—spectral brightness values. VLSA: Images are spectral; subsequent bare ground measurements are nominal.
What will be the approximate cost of collecting data?	$1,000 per PSU.	Satellite data: Variable; imagery now available for $400 per image for the digital data/date. VLSA: Costs averaged $0.07 per ha ($0.03 per acre) for a 2003 survey of Cottonwood Creek watershed (Casper Field Office of BLM) that included 559 aerial and ground photographic samples (unpublished report to BLM Wyoming State Office).

What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Summarized reporting only.	Satellite data: Biggest problem is the classification and interpretation of the data. VLSA: The method is new and data sets are few in number.
What is the spatial grain of these data?	Plot size, 160 acres (65 ha) in a primary sampling unit (PSU) with 3 random plots per PSU.	Satellite data: Variable; 5 m multispectral and 5 m panchromatic pixels for the IRS data. VLSA: A resolution as fine as 2.2 mm per pixel from 100 m above ground level.
What is the spatial extent of these data?	A number of random PSUs on non-federal rangelands.	Satellite data: Available for numerous cloud-free dates over large areas since the early 1970s; for example, each Landsat TM scene covers an area about 115 miles (185 km) on a side. VLSA: Limited to selected research sites in Wyoming, Colorado, Idaho, Nevada, and New Mexico.
At what spatial scales can these data be aggregated and reported?	MLRA, state, or national.	For any area in which the cost of the data can be provided.
What is the temporal grain of these data?	5 years.	Satellite data: Multiple dates annually. VLSA: Can be acquired as desired.
What is the temporal extent of these data?	Every 5 years from 1982 to 1992.	Satellite data: Since 1972. VLSA: Since 2002.
At what temporal scales can these data be aggregated and reported?	5 years.	Satellite data: Seasonally and annually over the years since 1972.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes.	Satellite data: Yes, a recent protocol has been developed to calibrate older with more recent satellite data. VLSA: Yes, image acquisition and analysis methods lend themselves to consistency.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Repeatable but some dependency on different data collectors.	Satellite data: The repeatability is good because image data are available for numerous cloud-free dates. -VLSA: To be determined. Bennett et al. (2000) reported a standard deviation of 1.3 for cover estimates in a test designed to measure precision of their image-analysis method.
Quality: how biased are the sampling methods?	Somewhat biased because they are estimates.	Satellite data: The data quality is excellent because of the georeferencing along with radiometric and geometric corrections. VLSA: Systematic aerial sampling avoids human bias in sample acquisition and inadvertent bias attributable to site inaccessibility. Human bias in the measurement of bare ground is reduced by using a calibration procedure for image analysis and by using computers to make automated measurements.

Quality: how precise are existing data? (Give standard error, if available)	Somewhat precise, yet the level of precision is based on the experience of the estimators; in practice and with training the estimates are quite repeatable.	VLSA: Bennett et al. (2000) reported a standard deviation of 1.3 for cover estimates in a test designed to measure precision of their image-analysis method.
Quality: how valid are existing data?	Validity is high, but the data set is sparse.	Validity can be determined based on image processing classification accuracy. Images are storable data that allow the validity of image interpretations to be reassessed as needed.
Quality: how responsive are existing data?	The data are reasonable based on the experience of those who are doing the interpretation.	These data can measure differences in bare ground on an annual basis.
Quality: how much statistical power to detect change does this data set have?	The statistical power is not high since much of the data consist of estimated values.	Satellite data: These data can have high statistical power because, based on the number of pixels, a very large sample size can be quickly obtained for any site. VLSA: See discussion in Booth and Cox (2008a). This method exceeds other rangeland-survey methods as a tool to detect change. This is attributable to the high resolution that is possible in the images and to a capability for greatly increased sampling intensity with minimal increases in image-acquisition costs. The cost to get 10 digital images per km of flight line is almost equal to the cost of getting 1 image per km as long as capacities for frame-rate capture and on-board image storage are not exceeded.
Quality: how well does this data set meet the data needs for this indicator?	The data set has the potential to meet the needs and can be summarized by MLRA.	Satellite data: The development of a bare ground category can serve as a surrogate for bare ground although it may not be possible to spectrally separate out such features as biological soil crusts or other cover features. VLSA: Bennett et al. (2000) reported most of their images showed excellent discrimination between soil and plant material. The more expensive point sampling on the ground, by a single person, at 1 point in time over a small area, is likely to best meet the data needs for this indicator. On large areas, over time, and where multiple technicians are involved, imaging methods are likely to give more satisfactory results than conventional on-the-ground sampling.
Other comments: (Include any other relevant aspects of the data set that should be included)	Such data sets often are dependent on level of annual funding appropriations available to do these inventories.	Remote sensing data are strongly dependent on the protocol to extract a bare ground category, the accuracy of the category, and its interpretation.

Appendix 2-D. Area and percent of rangeland with accelerated soil erosion by water and wind.

	Data Set #1	**Data Set #2**
Brief Title for Data Set	NRI administered by NRCS.	Fine-scale (small geographic extent) color photography for erosion evaluations.
Contact Person/Agency/Group		Terry Booth, High Plains Grasslands Research Station, ARS, Cheyenne, WY, terry.booth@ars.usda.gov; Paul Tueller, Professor Emeritus of Range Ecology, University of Nevada, Reno, ptt@unr.edu.
Citation (if published)		Tueller, P.T. and D.T. Booth. 1975b. Large scale color photographs for erosion evaluations on rangeland watersheds in the Great Basin, p. 708-752. *In*: Proceedings of the American Society of Photogrammetry, 28-31 October.
Website (if available)	http://www.nrcs.usda.gov/technical/NRI/	http://www.r-s-c-c.org/rscc/Volume4/tueller/mod4.html. Accessed 6 April 2009. There are examples here of large-scale imagery and the use of imagery for rangeland applications.
Additional information on data set	NRCS is now working with other agencies, including ARS, BLM, USGS, and USDA Forest Service, to develop an interagency list of data elements that could be used for national-level inventories.	Data sampled on 8 sites in the Great Basin. Numerous additional sites have been sampled on rangelands around the world using fine-grained aerial imagery but in no systematic manner.
For what years are data available, and how often are data collected?	1982 to 1992; every 5 years.	Two years; sampling of this kind can be done quickly and efficiently from a light aircraft or helicopter with sampling done at random locations and at sites with difficult on-the-ground access, far from roads.
In what format is the data set available?	Data points. Primary sampling units (PSUs).	Images upon which measurements can be made are usually expressed as a percent of the scene in a given erosion class or, in the case of this study, a range and mean rating for soil surface factors. These factors are flow patterns, gullies and rills, litter movement, and bare ground. Categories are stable, slight, moderate, critical, and severe with interval values for each.
Are data nominal, ordinal, or interval?	Nominal.	Ordinal and interval.
What will be the approximate cost of collecting data?	$1,000 per PSU.	Highly variable; fine-scale (small geographic extent) flight transects cost between $200 to $1,200 depending on the number of transects per flight and the distance between transect locations.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	There is only summarized reporting of estimated erosion.	Primarily a cost consideration to acquire the imagery and a sampling problem to obtain imagery that represents the rangeland areas to be inventoried.

What is the spatial grain of these data?	Plot size is 160 acres (65 ha) in a PSU with 3 random plots per PSU; commonly 3 PSUs are sampled per township stratum.	Variable with scales ranging from 1:600 to 1:5,000 (1:1,000 in this case). Pixel sizes vary from millimeters to about 5 m.
What is the spatial extent of these data?	A number of random PSUs on non-federal rangelands. At last sample in 1992 there were 14,368 NRI points that represented 4 million acres (1.62 million ha) on rangelands nationwide, excluding Alaska.	Very narrow with sampled flight transects. New high-resolution satellite data potentially will be useful over all rangelands in the United States now that 0.6 m pixels are available with the new QuickBird satellite. See: http://www.digitalglobe.com/product/index.shtml. Accessed 6 April 2009.
At what spatial scales can these data be aggregated and reported?	MLRA, state, or national.	Variable from the plant community level to the MLRA or nationwide.
What is the temporal grain of these data?	5 years.	Variable from daily, to seasonally, to annually.
What is the temporal extent of these data?	Every 5 years from 1982 to 1992.	Can be any extent depending on the sampling scheme. Most existing data are not temporally extensive.
At what temporal scales can these data be aggregated and reported?	5 years.	At any temporal scale for which images can be obtained; this is dependent on data acquisition protocols.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Subjective; an estimated level of erosion varying from none-slight, to moderate, to severe, or gullies, concentrated flow, etc.	Very consistent spectral and spatial attributes.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Depends on the experience and training of the estimator.	High quality and excellent repeatability based on geometric and radiometric corrections of the data sets.
Quality: how biased are the sampling methods?	Somewhat biased because they are estimates.	Very objective although some subjectivity is used during interpretation. Image processing of digital data can be highly objective.
Quality: how precise are existing data? (Give standard error, if available)	Somewhat precise, yet the level of precision is based on the experience of the estimators; in practice and with training the estimates are quite repeatable.	Very precise; comparisons of photo interpretations with ground data produced regression coefficients varying from 0.83 to 0.99.
Quality: how valid are existing data?	Valid as reported; in the 1992 sample, it was reported that 30.5% of the non-federal acreage had wind or water erosion that exceeded soil loss tolerances.	Very valid but once again based on the level of interpretation; image-processing techniques will provide greater validity to the data sets.
Quality: how responsive are existing data?	Since the NRI data are somewhat subjective, the value of the data is dependent to a large extent on the experience of trained individuals.	Highly responsive based on careful interpretation and analysis of the photos.
Quality: how much statistical power to detect change does this data set have?	Has not been tested, but the number of samples is sufficient for reasonable statistical power.	High statistical power. With satellite images the statistical power may not be relevant because complete samples can be obtained.

Quality: how well does this data set meet the data needs for this indicator?	Potentially very useful since the data are to be continuously obtained on a 5-year basis.	Quite well depending on the interpretation of the aerial images.
Other comments: (Include any other relevant aspects of the data set that should be included)	Such data sets often are dependent on level of annual funding appropriations available to do these inventories.	This and other remote sensing procedures have very high potential for measuring changes in erosion features on rangelands, but cost would be great for complete sampling of all rangelands in the United States.

Appendix 2-E. Percent of water bodies in rangeland areas with significant changes in aquatic biota assemblage composition.

	Data Set #1
Brief Title for Data Set	Aquatic Invertebrate Assemblage
Contact Person/Agency/Group	BLM National Aquatic Monitoring Center, Utah State University, Logan, UT.
Citation (if published)	Hawkins, C.P., R.H. Norris, J.N. Hogue, and J.W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10:1456-1477.
Website (if available)	http://www.usu.edu/buglab/. Accessed 16 January 2009.
Additional information on data set	Aquatic invertebrate assemblage data for >30,000 samples collected at more than 12,000 sites in the western U.S. More than 80% of the sites are geographically referenced.
For what years are data available, and how often are data collected?	1992 to present.
In what format is the data set available?	Electronic database.
Are data nominal, ordinal, or interval?	The raw data are interval. Data are species composition reported for a sample at a site or for a group of sites across a user-defined region, for example, a county, watershed, state, or ecoregion. Raw interval data can be manipulated and reported as ordinal (e.g., good, fair, poor classes), and nominal (e.g., presence or absence of a particular taxa).
What will be the approximate cost of collecting data?	$800 to $1,200 per site, depending on travel.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	None; data are public and easily accessible. EPA's national water quality database—STORET, is an example of a public database with this information.
What is the spatial grain of these data?	Individual site data are for a stream reach, typically 100 m in length that characterizes the upstream and upslope watershed. Data can be aggregated to evaluate larger hydrologic units, ecoregions, or political regions. Monitoring units based within similar environmental areas (e.g., similar in elevation, latitude, ground cover, stream size) and under similar management would be expected to respond similarly to management changes.
What is the spatial extent of these data?	Western U.S. predominantly.
At what spatial scales can these data be aggregated and reported?	Subbasin and larger, e.g., ecoregions or physiographic regions (e.g., Great Basin or Colorado Plateau), or political geographic areas such as counties or states.
What is the temporal grain of these data?	Wide variation from seasonal, annual, to single-moment-in-time sampling events. The data appear to have good temporal stability.
What is the temporal extent of these data?	Primarily 1992 to present. Some pre-1992 data are available, but these data were collected using different protocols and these data are often not in electronic format.
At what temporal scales can these data be aggregated and reported?	Most commonly annual, but it depends on the sampling frequency; an analysis of temporal trends across broad landscapes is certainly possible.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, most of the samples were collected and treated similar in the laboratory.

Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Should be high because temporal variability is low for aquatic macro-invertebrate assemblages sampled in areas with absence of human impairment.
Quality: how biased are the sampling methods?	Likely low if sampling methods are consistent. Several studies have shown low variability (error associated with methodology) among different data collectors.
Quality: how precise are existing data? (Give standard error, if available)	Good; quality assurance and quality control studies have shown high precision.
Quality: how valid are existing data?	Data are valid for evaluating impairment of rangeland aquatic habitats across much of the western U.S.
Quality: how responsive are existing data?	Aquatic invertebrate assemblages have been shown to be responsive to many management actions occurring on rangelands.
Quality: how much statistical power to detect change does this data set have?	Very high statistical power based on the size and geographic coverage of the data set.
Quality: how well does this data set meet the data needs for this indicator?	The data set provides a straightforward measurement of the difference between the species expected to occur at a site and those collected.
Other comments: (Include any other relevant aspects of the data set that should be included)	

Appendix 2-F. Percent of surface water on rangeland areas with unacceptable levels of chemical, physical, and biological properties.

	Data Set #1	**Data Set #2**	**Data Set #3**
Brief Title for Data Set	CWA 303(d) list of Impaired Water Bodies	STORET—Storage and Retrieval System for Water and Biological Monitoring Data	National Water-Quality Assessment (NAWQA)
Contact Person/Agency/ Group	EPA Office of Water	EPA Office of Water	USGS National Headquarters, Reston, VA.
Citation (if published)			
Website (if available)		http://www.epa.gov/storet/. Accessed 28 September 2004.	http://water.usgs.gov/nawqa/. Accessed 28 September 2004.
Additional information on data set		STORET is EPA's main repository of water quality monitoring data. It contains water quality information from a variety of organizations, from volunteer watershed groups to state and federal environmental agencies.	
For what years are data available, and how often are data collected?	1998. Lists are updated biennially. States submit lists to EPA on April 1 in even-numbered years.	"Legacy STORET" is the original STORET Water Quality File and has data from 1965 to 1998, but it requires a mainframe user ID and specialized training. STORET Data Warehouse was created to replace Legacy STORET and has data from 1999 to present. The system is refreshed with new data at the end of each month. Data are submitted to STORET from the monitoring groups at varied rates (that is, monthly, quarterly, etc.).	1991 to present. Data are typically collected monthly. The rest of the data are synoptic.
In what format is the data set available?	State lists designate water bodies that fail 1 or more standard(s) and list the water quality parameter(s) that fail to achieve standards. States are directed to identify the location of impaired waters. EPA's Reach File Version 3.0 is a database that identifies and provides a unique address for 3.2 million stream segments.	STORET Data Warehouse uses a UNIX/Oracle database server, and its contents may be browsed or downloaded by the public using a standard web browser such as Netscape.	Computer databases generally employing the Oracle format.

Are data nominal, ordinal, or interval?	Nominal—water bodies that fail to meet standard(s).	Mostly interval data with some ordinal data—monitoring site location data, water quality parameter data, and biological data and index results.	Mostly interval data, that is, continuous random variables.
What will be the approximate cost of collecting data?	Unknown.	A multi-million dollar federal, state, local, tribal, and private water quality monitoring program.	$63 million annual appropriation, and approximately $700 million over the life of the USGS NAWQA Program. $7.2 million is spent on each study unit over their 10 year life (in total).
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Available for public use.	Data from 1999 to present are available on EPA's website. Older data require mainframe ID and special training.	Access to Internet.
What is the spatial grain of these data?	Water bodies, first order streams.	All national water bodies from first order streams to rivers including lakes, reservoirs, wetlands, and estuaries.	Water bodies down to the 10 digit Hydrologic Unit Code (that is, watersheds) of the USGS.
What is the spatial extent of these data?	National; however, agencies have great latitude in deciding what water bodies are impaired.	National; however, agencies and organizations inputting into the system have a great deal of flexibility on what parameters they monitor and how they conduct the monitoring, making aggregation to the national level difficult if not impossible.	Limited to 59 major river basins in 1991, 52 basins in 1997, and 42 basins in 2001. In 2001, 13 study units were eliminated. Study areas were selected to focus on the nation's most important river basins, that is, those supplying drinking water and irrigation, under a 10-year study cycle. So coverage is limited for rangelands.
At what spatial scales can these data be aggregated and reported?	National; however, there is no explicit assessment protocol for determining water quality impairment.	Most of the parameter data are collected for regulatory or compliance objectives, and use for local assessment is appropriate. Aggregating to watershed, regional or national level will be difficult and possibly not appropriate.	National.
What is the temporal grain of these data?	Two years.	Daily, monthly, and quarterly monitoring depending on the monitoring station and type of water quality parameter.	Continuous, daily, and monthly depending on the parameter or constituent.
What is the temporal extent of these data?	1998 to present.	Realistically, 1999 to present.	The period of record for NAWQA data is 1991-present; however, the period of continuous record for select water quality data is in 3-year intervals.

At what temporal scales can these data be aggregated and reported?	Two years.	Monitoring design is for regulatory objectives, not for developing time series. Reporting over time will be difficult if not impossible.	Annually.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Jurisdictional variation in methodology used to determine impairment and listing. Individual jurisdictions have latitude in interpretation of data, types of data used, threshold selection, and monitoring methods.	Not at the present time.	Yes. Whereas each basin study includes core water quality parameter data, each basin study is tailored to water quality issues within the study unit. Data are collected and analyzed using consistent methodology.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	NA	Parameter data that go into the STORET Data Warehouse must meet EPA QA/QC guidelines; repeatability is 1 of those requirements.	Yes, they are repeatable and they are also verifiable.
Quality: how biased are the sampling methods?	NA	NA	They are basically unbiased. That is a key objective of the design and implementation of NAWQA study units.
Quality: how precise are existing data? (Give standard error, if available)	NA	NA	Very difficult to answer. Consider that in Fiscal Year 2004 alone there were 155 sampling stations, which involved the measurement of tens of thousands of water quality constituents. The question is only meaningful in terms of a specific constituent record.
Quality: how valid are existing data?	Some water bodies on state lists were placed there without the benefit of adequate water quality standards or data.	Parameter data in the STORET Data Warehouse are valid.	Very difficult to answer. Consider that in Fiscal Year 2004 alone there were 155 sampling stations, which involved the measurement of tens of thousands of water quality constituents. The question is only meaningful in terms of a specific constituent record.
Quality: how responsive are existing data?	Not very responsive. Lists reported biennially.	Water quality parameter data are responsive at local assessment areas.	Not very responsive except where the data are being measured on a continuous temporal scale.
Quality: how much statistical power to detect change does this data set have?	NA	NA	NA

Quality: how well does this data set meet the data needs for this indicator?	As a gross indicator that water quality problems exist it has value. As an indicator of rangeland sustainability in a region it is not specific or responsive enough.	It is unlikely that STORET will provide timely and consistent reporting of the key water quality parameters applicable to rangelands.	Very well. These data are collected so that use attainability analyses can be determined for waters in the involved study unit.
Other comments: (Include any other relevant aspects of the data set that should be included)			The closest parallel database in USGS to STORET is the National Water Information System (NWIS), which is 1 of several data sets used within the NAWQA Program. It may be that the name of the data set here should be NWIS rather than NAWQA because NAWQA is a bit broader than just a data set. NAWQA data address both surface and groundwater quality.

Appendix 2-G. Changes in groundwater systems.

	Data Set # 1
Brief Title for Data Set:	Changes in Groundwater Systems
Contact Person/Agency/Group (email, phone, address):	The project chief for the Southwest groundwater study is Stanley A. Leake, saleake@usgs.gov, at the Tucson office of the Arizona District, USGS. The study area includes aquifer systems in the arid to semiarid basins in the southwestern states of California, Nevada, Utah, Arizona, and New Mexico; USGS (see website below).
Citation (if published):	Alley, W.M., R. W. Healy, J.W. LaBaugh, and T. E. Reilly. 2002. Flow and storage in groundwater systems. Science 296:1985-1990.
Website (if available):	http://waterdata.usgs.gov/nwis/gw. Accessed 6 April 2009.
Additional information on data set:	Measurements of changes in well depth, spring discharge, and other variables can be done very accurately although not a lot of data are available for many watersheds on western rangelands.
For what years are data available, and how often are data collected?	Variable, but many wells are measured every year, often more than once per year.
In what format is the data set available?	Depth of well above mean sea level and depth of water in the well in feet.
Are data nominal, ordinal, or interval?	Interval.
What will be the approximate cost of collecting data?	For well depth data from 850,000 sites in the United States the data are free; developing relationships with range vegetation parameters may be costly.
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	The cost of relating groundwater data or spring discharge data to changes in the rangeland vegetation may be somewhat difficult and take a number of years. Some of the well data are 30 to 40 years old or more.
What is the spatial grain of the data?	The groundwater site inventory of the USGS consists of more than 850,000 records of wells, springs, test holes, tunnels, drains, and excavations in the United States. Available site descriptive information includes well location information (latitude and longitude, well depth, site use, water use, and aquifer). See http://waterdata.usgs.gov/nwis/gw. Accessed 6 April 2009.
What is the spatial extent of the data?	Numerous wells in each state and hydrological region.
At what spatial scales can these data be aggregated and reported?	Primarily by hydrological region and/or drainage basin.
What is the temporal grain of the data?	Once or twice per year or more often.
What is the temporal extent of the data?	Variable; some wells have long term records while others are quite limited with only 1 or 2 years of data.
At what temporal scales can these data be aggregated and reported?	Annually or semiannually. Under natural conditions, the travel time of water from areas of recharge to areas of discharge can range from less than a day to more than 1 million years (Bentley et al. 1986).
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes, all measurements of well depth are in feet.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	Repeatable. Meaningful trends are best provided over relatively long time periods, probably decades of measurement.
Quality: how biased are the sampling methods?	Unbiased.

Quality: how precise are existing data? (Give standard error, if available)	Precise.
Quality: how valid are existing data?	Quite valid.
Quality: how responsive are existing data?	Responsive in certain hydrologic units.
Quality: how much statistical power to detect change does this data set have?	Reasonable especially where there may be several wells representing an area of rangeland and/or floodplain with forage.
Quality: how well does this data set meet the data needs for this indicator?	Only partly; the fluctuations in well data must eventually be related to phreatophytic or other vegetation on rangelands.
Other comments: (Include any other relevant aspects of the data set that should be included.)	Data are scarce on springs and their discharge; such data would be important as rangeland vegetation and management changes. This is likely a very important potential indicator over the long term and is of intense interest in the west on rangelands. Much of the concern is at the urban fringe where many new wells are being drilled for culinary water causing a mining or potential mining of the water table.

Appendix 2-H. Changes in the frequency and duration of surface no-flow periods in rangeland streams.

	Data Set #1
Brief Title for Data Set:	USGS Surface-Water Data for USA
Contact Person/Agency/Group (email, phone, address):	USDI USGS, http://waterdata.usgs.gov/nwis/feedback. Accessed 15 January 2009
Citation (if published):	Slack, J.R. and J.M. Landwehr. 1992. Hydro-climatic data network (HCDN): a U.S. Geological Survey streamflow data set for the United States for the study of climate variations. U.S. Geological Survey, Open-File Report 92-129.
Website (if available):	http://waterdata.usgs.gov/nwis/sw, Accessed 15 January 2009
Additional information on data set:	Data are retrieved by category, such as surface water, groundwater, or water quality; and by geographic area. Of the 1.5 million sites with data, 80% are wells; 350,000 are water quality sites; and 19,000 are streamflow sites, of which more than 5,000 are real-time.
For what years are data available, and how often are data collected?	Years of data availability depend on the site (stream gauge). The earliest data were collected in 1857. Real-time data on streamflow in ft^3/sec typically are recorded at 15-60 min intervals, stored onsite, and then transmitted to USGS offices every 4 hours. Recording and transmission times may be more frequent during critical events. Data from real-time sites are relayed to USGS offices via satellite, telephone, and/or radio and are available for viewing within minutes of arrival.
In what format is the data set available?	Data can be presented in graph or table form. Streamflow data for the United States and Puerto Rico are presented in map form also, for these objectives: 1) showing real-time streamflow comparisons to historical on a daily basis using point data (individual stream gauges); 2) showing monthly-average streamflow comparisons to historical, on a hydrologic unit basis.
Are data nominal, ordinal, or interval?	Streamflow is a continuous variable, can be measured, and can be analyzed and reported in various ways. Streamflow measurements can be reported as interval data in graphs or tables. Map data are reported as percentile classes, which are then converted to nominal categories (dry, normal, and wet).
What will be the approximate cost of collecting data?	
What barrier(s) prohibit access or use of data? (Restricted use, exorbitant cost, technical or legal barriers, confidential barriers, etc.?) Or are data easily accessible?	Information presented on the website is considered public information and may be distributed or copied. USGS strongly recommends that data be acquired directly from a USGS server and not through other sources that may change the data in some way.
What is the spatial grain of the data?	Stream gauge, point data.
What is the spatial extent of the data?	The streamflow data are collected across all 50 states and Puerto Rico. Within state, spatial extent varies, with some states having few stream gauges and none in certain sections of the state, and other states having numerous stream gauges well dispersed.
At what spatial scales can these data be aggregated and reported?	Heinz (2002, 2008) performed data analyses of streamflow data at stream gauges by subbasin, with subsequent aggregation and reporting of the data at 3 divisions of Bailey's ecoregions. Reporting by aggregation of streamflow data by hydrologic units, to the national level, can be seen online. Streamflow data can be reported as point data, too.

What is the temporal grain of the data?	As short as 15 min.
What is the temporal extent of the data?	Temporal extent of the data varies by individual stream gauge.
At what temporal scales can these data be aggregated and reported?	Users of the website can view daily streamflow data by stream gauge in graph or table form, daily streamflow statistics, monthly streamflow statistics, and annual streamflow statistics. Heinz (2002, 2008) opted for different approaches and analyzed data and reported daily streamflow data by averaging to decadal increments (Heinz 2002) and 5-year increments (Heinz 2008) to show trend.
Quality: can data be adequately reported over time in a consistent form? (Consistent methodology)	Yes.
Quality: how repeatable are existing data? (Include p value of differences in estimates of independent observers if available)	
Quality: how biased are the sampling methods?	
Quality: how precise are existing data? (Give standard error, if available)	All real-time data are provisional and subject to revision. Recent data provided by the USGS in the United States—including stream discharge, water levels, precipitation, and components from water quality monitors—are preliminary and have not received final approval. Most data relayed by satellite or other telemetry have received little or no review. Inaccuracies in the data may be present because of instrument malfunctions or physical changes at the measurement site. Subsequent review may result in significant revisions to the data.
Quality: how valid are existing data?	
Quality: how responsive are existing data?	Because the temporal grain of streamflow data can be as short as 15 min, data can rapidly show a response. However, this only explains the responsiveness attributable to temporal grain. Therefore, although streamflow response can be detected from a visual perusal of data (for example, from a graph of trend), the responsiveness of streamflow data to management changes or climate or weather is not interpretable in the data set.
Quality: how much statistical power to detect change does this data set have?	
Quality: how well does this data set meet the data needs for this indicator?	The data set meets the data needs for this indicator very well if data are continually collected with no interruption. However, data collection at stream gauges is dependent on sustained funding, which is not a certainty for all stream gauging stations.
Other comments: (Include any other relevant aspects of the data set that should be included.)	

CHAPTER 3
Criterion II: Indicators for Conservation and Maintenance of Plant and Animal Resources on Rangelands

Linda A. Joyce,[1] William Fox,[2] Paul Geissler,[3] Rodney Heitschmidt,[4] Lori Hidinger,[5] Duncan Patten,[6] John Spence,[7] Laurence L. Strong,[8] Robert Unnasch,[9] and Robert A. Washington-Allen[10]

Keywords: biodiversity, rangeland health, rangeland sustainability, Sustainable Rangelands Roundtable

Abstract: Five criteria were established by the Sustainable Rangelands Roundtable to be used to assess rangeland sustainability on a national scale. One of those criteria is the conservation and maintenance of plant and animal resources. Within this criterion, 10 indicators were developed through the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. These indicators are not inclusive but provide a suite of variables that, when complemented with indicators from the other four criteria, produce a viable system to monitor the biophysical, social, and economic characteristics of rangeland sustainability at the national level.

Authors are [1]Range Scientist, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO, 80526, USA; [2]Assistant Professor, Texas AgriLife Research – Blackland Research & Extension Center, Temple, TX,76502, USA; [3]Assistant Program Coordinator, U.S. Geological Survey, Fort Collins, CO, 80526-8118,USA; [4]Research Leader and Superintendent (retired), USDA Agricultural Research Service, Miles City, MT, 59301,USA; [5]Managing Director, The Consortium for Science, Policy and Outcomes, Arizona State University, Tempe, AZ, 85287, USA; [6]Research Professor, Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, 59717-3120, USA; [7]Botanist, USDI National Park Service, Glen Canyon NRA, Page, AZ, 86040, USA; [8]Wildlife Biologist, U.S. Geological Survey, Jamestown, ND, 58401, USA; [9]Director, Monitoring and Adaptive Management, The Nature Conservancy, Boise, ID, 83702, USA; and [10]Assistant Professor, Dept of Ecosystem Science & Management, Texas A&M University, College Station, TX, 77843-2138, USA (names are alphabetical after Joyce).

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At the time of the research, Lori Hidinger was Program Manager, Sustainable Biosphere Initiative, Ecological Society of America, Washington, DC, 20006, USA; and Robert A. Washington-Allen was Research Staff Scientist, Environmental Sciences Division, Oak Ridge National Laboratory, PO Box 2008, Bethel Valley Rd, Oak Ridge, TN, 37831, USA.

Correspondence: Linda Joyce, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO, 80526, USA; Phone: 970-498-2560; Fax: 970-498-1212; email: ljoyce@fs.fed.us

Introduction

Within the Sustainable Rangelands Roundtable (SRR), a group identified, developed, and adopted standardized indicators that would characterize the conservation and maintenance of plant and animal resources, one of the five criteria for assessing sustainable rangelands. Within this criterion, 10 indicators were developed. The development of these indicators is a reflection of the expert opinions of rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, practitioners, and other interested stakeholders. Associated concepts and ideas evolved from lively discussions at the SRR workshops, as well as electronic correspondence between meetings. These indicators are not inclusive but provide a suite of variables that, when complemented with indicators from the four other criteria, produce a viable system to monitor the biophysical, social, and economic characteristics of rangeland sustainability at the national level.

The 10 indicators identified here reflect multiple factors relevant to the conservation and maintenance of plant and animal resources, from location and area of rangeland to detailed information on population dynamics of species of concern (Table 3.1). The development of these indicators built upon previous work in the refereed literature and work such as the Criteria and Indicators of the Montreal Process (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests 1995) and The State of the Nation's Ecosystems (Heinz 2002, 2008).

Table 3.1. Indicators for conservation and maintenance of plant and animal resources on rangelands, Criterion II.

Indicator	What the indicator describes	Status of data availability[1]
1. Extent of land area in rangeland	Over several measurements, changes in the total amount of land that fits the definition of rangeland.	B
2. Rangeland area by plant community	Changes in the area of plant communities on rangeland.	B, C
3. Number and extent of wetlands	Changes in wetland abundance.	A
4. Fragmentation of rangeland and rangeland plant communities	Changes in spatial patterns on rangeland and on plant community types.	C
5. Intensity of human uses	Changes in the densities of roads and human structures over time.	A
6. Integrity in natural fire regimes on rangeland	Changes in characteristics associated with the natural disturbance of fire, such as fire frequency, intensity, and extent.	C, D
7. Extent and condition of riparian systems	Condition of riparian vegetation and watershed health.	C
8. Area of infestation and presence/absence of invasive and non-native plant species of concern	Displacement of native plants and habitat.	C
9. Number and distribution of species and communities of concern	Changes in species and communities that are threatened, endangered, or of concern for some identified reason.	A
10. Population status and geographic range of rangeland-dependent species	Finer scale information, such as population levels and current geographic range, on select plant and animal species.	A, C

See Appendix 1-E.

Criterion 1 from the Montreal Process is "Conservation of Forest Biological Diversity." It includes indicators of forest type area, fragmentation, status of species at risk, and population dynamics of representative species. Similarly, national-level indicators proposed for grasslands and shrublands by The Heinz Center included extent of land area in rangelands, integrity of natural fire regimes, extent and condition of riparian systems, fragmentation, the area of infestation, and presence/absence of invasive and non-native species of concern (Heinz 2002, 2008). These indicators are identified here as important factors related to plants and animals on rangelands. West (1993) identified components of biodiversity such as landscape, community, population, and genetics. These components are reflected in our indicators associated with fragmentation, plant communities, presence of species and communities of concern, and population levels of representative species. With the exception of a few shrubs and grasses, few studies have been performed on the genetic diversity of rangeland plants. Therefore, no indicator was identified in this area.

Additional concepts related to rangeland health and biodiversity have been identified under the two other biophysical criteria identified by the SRR: "Maintenance of Soil and Water Resources on Rangelands" and "Productive Capacity and Conservation." Taken together, these three criteria of the SRR and their associated indicators will be a valuable tool in assessing the biophysical sustainability of rangelands on a national scale.

Extent of Land Area in Rangeland

Description and Importance of the Indicator

This indicator quantifies the amount of land area defined as rangeland at any given time. The amount of rangeland at any instant and the associated changes over time are important metrics because they provide information on one of the important global land types as well as inform the spatial and temporal framework from which all other indicators will be considered.

Analysis of this indicator requires a nationally accepted definition of rangeland that encompasses a definition of land cover. We define "land cover" as the ecological state and physical appearance of the land surface, e.g., grassland, savanna, or shrubland (Dale et al. 2000). Change in land cover converts land of one type of cover to another (Dale et al. 2000). Nearly 300 definitions of "rangeland" have been proposed (Lund 2007), including agglomerative (Society for Range Management 1994; IPCC 2007, glossary; Lund 2007; Heinz 2008) and biophysical (UNEP 1992; UNEP 1997; Reynolds 2001; Lepers et al. 2005; MEA 2005; Lund 2007). The common thread for the agglomerative approach is that "rangeland" is a "natural" vegetation complex dominated by grasses, grass-like plants, forbs, and/or shrubs. Thus, by definition, rangelands include indigenous grassland, savanna, shrubland, desert, tundra, alpine, marsh, and meadow ecosystems as well as introduced pasture systems, such as crested wheatgrass, that are managed as "natural" ecosystems. A biophysical definition of "dryland" was developed and accepted internationally by the 192 signatories' of the United Nations Convention to Combat Desertification (UNCCD). The recent Millennium Ecosystem Assessment (MEA 2005) adopted the term "drylands" as a reporting category. "Dryland" is defined as those lands where the ratio of mean annual precipitation to mean annual potential evapotranspiration ranges between 0.05 and 0.65 (UNEP 1992; UNEP 1997; Reynolds 2001; MEA 2005). Within the MEA (2005), rangeland, which encompasses much but not all of the dryland category, is a land-use category. The 10 reporting categories used in the MEA (2005) are not mutually exclusive: their areas can and do overlap (MEA 2005). Recent interest in assessing the amount of carbon stored in ecosystems has led to a set of proposed guidelines of carbon inventories (IPCC 2006). Within these guidelines, the land-area categories are defined on the basis of land use: forest, cropland, grassland, wetlands, settlements, and other land uses. The guidelines suggest that shrublands may be included within the grassland reporting category. Consistency in terminology is critical to assess the sustainability of rangelands. The SRR recommends the Society for Range Management agglomerative definition: rangelands are areas dominated by self-propagating vegetation comprised predominantly of grasses, grass-likes, forbs, shrubs, and dispersed trees (Society for Range Management 1994).

Information has been compiled about the area of rangeland, but little can be concluded about total rangeland area or change in rangeland area over time as estimation methods have varied or are non-existent. Lepers et al. (2005) conducted a global assessment of land cover change from 1981 to 2000 using multiple data sources including national statistics, expert opinion, local field studies, and remote sensing. They conclude that land cover change data were insufficient for the United States. The Heinz Center (Heinz 2008) used the National Land Cover Dataset (NLCD) 2001 to estimate grassland and shrubland area at 332 million ha (830 million acres) for the lower 48 states including pasture, and 82 million ha (205 million acres) for Alaska using the 1992 NLCD. The 1992 and 2001 NLCD thematic maps are derived from LANDSAT satellite data at 30-m spatial resolution for a pixel. An acceptable standardization between the 1992 and 2001 data sets has not yet occurred but will be available in the future (Fry et al. 2008). Despite this ongoing work, The Heinz Center concluded that data were insufficient to estimate changes in shrubland-grassland cover in the U.S. The most consistent and commonly used assessment of non-federal rangeland area and change has been the USDA Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI), collected since the 1970s (Nusser and Goebel 1997). Of interest here are the reported changes in rangeland area between the five-year periodic inventories (USDA Soil Conservation Service 1987; USDA NRCS 1995; Mitchell 2000, table 26). However, no periodic inventory of federally owned rangelands is available (Lepers et al. 2005; Heinz 2008). Further, the extent of federal rangeland has not been consistently determined across agencies and over time (Mitchell 2000). A consistent methodology assessing the area of rangeland over time should be implemented across all U.S. lands, offering a repeatable method to track rangeland area. Current technologies, discussed below, are available to accurately assess rangeland area extent and change in a spatial context.

The area of rangeland at any point in time and the changes over time have major consequences for the availability of ecosystem services from rangelands such as purification of air and water, generation and preservation of soils and renewal of their fertility, detoxification and decomposition of wastes and pollutants, pollination of crops and natural vegetation, dispersal of seeds, cycling and movement of nutrients, control of the vast majority of potential agricultural pests, maintenance of biodiversity, and provision of aesthetic beauty and intellectual stimulation that lift the human spirit (Daily et al. 1997; MEA 2005). The area of rangeland provides an estimate of the availability of forage for livestock in the production of meat, milk, and fiber and to a lesser extent forage for draft animals, as well as the potential gene stock for monocot crops such as wheat, barley, rye, and oats (Sala and Paruelo 1997). Given that 84 percent of mammals and 74 percent of the bird species within the United States (inhabitants or common migrants) use rangeland habitats (Flather et al. 1999), changes in rangeland area have implications to the sustainability of these species and populations. Assessing the capacity of ecosystems to stored carbon as a mitigation practice for climate change has generated the need to quantify the area of rangeland (Joyce 2000; IPCC 2006).Therefore, it is important that we know the extent of land area in rangeland and how that is changing over time. This indicator will allow us to track the amount and location of this important resource.

Geographic Variation

This indicator is meaningful for different geographic regions (e.g., Great Plains, Southwest). All major assessments and environmental reports use land area as an indicator across different geographic regions. For example, Mitchell (2000) reported that privately owned rangeland accounted for 160 million ha (399 million acres) of the total U.S. land base in 1992. And given the common definition of rangeland in the U.S. Department of Agriculture (USDA) NRCS (1995) inventory, Mitchell (2000) could then contrast the amount of rangeland within 4 different regions in the United States. MEA (2005) used the reporting category of drylands with a biophysical definition to compare and contrast the land area of drylands with other reporting categories such as forest/woodlands and mountains globally, in addition to summarizing the relative share of dryland in developing countries and industrial countries. Land area of major ecosystems (i.e., grasslands, deserts) established the basis for comparison of potential climate change impacts in Intergovernmental Panel on Climate Change (IPCC 2007). It should be noted, however, that estimates of area of rangeland vary across these assessments as a result of the way they are defined and subsequently sampled. And thus, the capacity to compare across these studies is limited. A consistent definition of rangelands would address this issue.

Scale in Time and Space

This indicator is meaningful at different spatial (i.e., counties, states, regions, and nationally) and temporal scales. The NRI (USDA NRCS 2010a) reports on the area of rangeland at the national level and, because the definition and sampling techniques are consistent, compares rangeland area across the 50 states. The NRI is a longitudinal sample survey, thus changes in major categories can be compared over time and the shifts between different reporting categories can be summarized (USDA NRCS 2000). For example, the largest loss of rangeland area was to cropland (Table 3.2) as nearly 7 million acres of rangeland were converted to cropland between 1982 and 1997.

Table 3.2. Changes in land cover/use between 1982 and 1997 (USDA NRCS 2000).

	Land cover/use in 1997 per 1,000 acres								
Private land cover/use in 1982	**Cropland**	**CRP land**	**Pasture land**	**Rangeland**	**Forest land**	**Other rural land**	**Developed land**	**Water areas & federal land**	**1982 total**
Cropland	350,265.3	30,412.1	19,269.4	3,659.2	5,606.5	3,158.9	7,097.5	1,485.1	420,954.0
Pasture land	15,347.0	1,329.6	92,088.3	2,567.9	14,091.4	1,619.0	4,230.0	732.8	132,006.0
Rangeland	6,967.5	728.5	3,037.2	394,617.4	3,021.6	1,702.7	3,281.3	3,383.2	416,739.4
Forest land	2,037.1	128.8	4,168.2	2,098.8	380,343.3	1,754.8	10,279.2	2,528.0	403,338.2
Other rural land	1,386.8	93.1	1,013.6	719.1	2,767.7	42,713.3	726.9	227.8	49,648.3
Developed land	196.7	1.2	78.6	110.8	227.0	12.0	72,618.7	0.8	73,245.8
Water areas & federal land	797.5	2.7	336.6	2,204.0	897.7	180.8	18.1	443,760.6	448,198.0
1997 total	376,997.9	32,696.0	119,991.9	405,977.2	406,955.2	51,141.5	98,251.7	452,118.3	1,944,129.7

Notes: 1982 land cover/use totals are listed in the right hand vertical column, titled "1982 total." 1997 land cover/use totals are listed in the bottom horizontal row, titled "1997 total." The number at the intersection of rows and columns with the same land cover/use designation represents acres that did not change from 1982 to 1997. Reading to the right or left of this number are the acres that were lost to another cover/use by 1997. Reading up or down from this number are the acres that were gained from another cover/use by 1997. This table is Table 5 from http://www.nrcs.usda.gov/technical/NRI/1997/summary_report/table5.html

As stated earlier, estimates of rangeland area vary as a result of the definition and estimation techniques. For example, ground-based inventories estimate the amount of land area (in any classification) using a point-based sampling system – an extensive number of sample points where each point represents a certain amount of land area. To capture the heterogeneity of rangeland vegetation, field-based inventories require comprehensive environmental and vegetation attribute data, stratification, and appropriate sample sizes per attribute and the associated person hours to produce statistically acceptable results. The number of samples needed in field-based inventories is typically determined by the desired variation in the estimate. For example, in the 1992 NRI, 800,000 sample points were needed in order to obtain the objective of a coefficient of variation of less than 10 percent for any estimate of surface area within a particular resource (Nusser and Goebel 1997).

Major Land Resource Areas (MLRAs) are geographic areas, usually several thousand acres in extent, which are characterized by a particular pattern of soils, climate, water resources, and type of land use. They are nested within Land Resource Areas (Soil Survey Staff 1981). This classification system is based on the concept that landscapes are hierarchically structured discrete entities that can be mapped at different spatial scales. A number of other federal agencies also use or have developed ecophysical or ecoregional maps that use this hierarchical concept (Bailey 1995; Omernick 1987; Hargrove and Hoffman 2004). These ecoregion maps have been delineated using both expert opinion and/or quantitative procedures, such as Hargrove and Hoffman (2004).

When using remote sensing methods, scale issues arise in association with the pixel size of the remotely sensed imagery. As pixel size increases, the estimates of rangeland area have the potential for increasing bias due to boundary and inclusion effects (Konarska et al. 2002). Still, the argument is often made for qualitative rapid field assessments, even though results are less reliable than desired (e.g., Rasmussen et al. 1999). West (2003) discussed the limitations of field-based data sets and recommended expanded research on the use of Geographic Information System (GIS) and remote sensing technologies within rangeland. It is likely that the future land inventories will use a combination of remotely sensed information in a GIS- and ground-based information (Washington-Allen et al. 2006).

Data Collection and Availability

The available data for this indicator are best described by B (Table 3.1, Appendix 1-E). Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. The data sets that currently exist for this indicator, though not descriptive of the entire United States, are based on inventory or monitoring systems that were designed at the national level.

At least three sources of extant data at the national level could be evaluated for this indicator: 1) the Landsat derived 1992, 2001, and 2006 National Land Cover Data (NLCD) Sets (Vogelmann et al. 2001; Homer et al. 2007) the remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) Global Land Cover Product (Friedl et al. 2002; USGS 2010a), and 3) the ground survey NRCS NRI data for non-federal lands, which is currently the most commonly used assessment data for U.S. rangelands (Nusser and Goebel 1997;USDA NRCS 2010a). The current NRI sampling and analysis procedures have evolved over time (USDA NRCS 2010a) and now incorporate the use of aerial photography and GIS along with ground-based inventories. The USDA Forest Service also conducts inventories of public and private lands, primarily focusing on forestland attributes through the Forest Inventory and Analysis (FIA) program (Smith et al. 2009).

A partnership of six federal agencies called the Multi-Resolution Land Characteristics Consortium (MRLC; http://www.mrlc.gov/. Accessed 20 April 2011) was formed in 1992 to reduce the cost to any one agency of the purchase of Landsat satellite data (Vogelmann_et al.

2001). Two national land cover maps have been produced from the MRLC program, including the 1992 NLCD (USGS Land Cover Institute 1992; Loveland et al. 2000) and the 2001 NLCD (Homer et al. 2007). While the MRLC Consortium supported the 1992 and 2001 NLCD products, substantial differences in imagery, legends, and methods between these two products inhibit a direct comparison (Fry et al. 2008). The NLCD 1992-2001 Land Cover Change Retrofit product allows for the analysis of land cover change over time and documents an estimated 3 percent change in land cover between 1992 and 2001 with an increase of 30,417 km^2 of grass/shrubland cover in the U.S. As previously discussed, the 1992 and 2001 NLCD has been used to estimate total rangeland (grassland-shrubland) cover (Heinz 2002 and 2008) (Fig. 3.1). An updated National Land Cover Database (2006 NLCD) is being produced using data from the 2001 NLCD and 2006 Landsat imagery (Xian et al. 2009).The development of methods to map land cover change at continental scales using moderate spatial resolution imagery such as available from the Landsat satellites is an active area of research. For example, the National Aeronautics and Space Administration (NASA) Landsat Ecosystem Disturbance and Adaptive Processing System program is conducting research to develop algorithms that can be extended in time and space to map forestland cover change for North America (Masek et al. 2008).

DeFries et al. (1998) began development of a remote sensing-based data set that could detect changes in land cover overtime using the International Geosphere-Biosphere Programme (IGBP) definition of land cover types. This concept has been extended to MODIS (Reeves et al. 2001; Zhang et al. 2000), which has been functional since July 2000. Value-added algorithms developed for MODIS-generate land cover characteristics (Justice et al. 2002), including fire anomalies, land cover conversion, and vegetation continuous fields (e.g., phenology, Zhang et al. 2009; biomass, Baccini et al. 2004). The MODIS Land Cover Type product (MCD12Q1) contains multiple classification schemes (USGS 2010b). The primary land cover scheme identifies 17 land cover classes defined by the IGBP, which include 11 natural vegetation classes, three human-altered classes, and three non-vegetated land classes. Evaluation of the primary land cover scheme identified that a portion of the cropland/natural vegetation mosaic cover type will also contain an unknown proportion of rangeland (Friedl et al. 2002). The MODIS Terra + Aqua Land Cover Type Yearly L3 Global 500 m SIN Grid product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method: IGBP global vegetation classification scheme, University of Maryland scheme, MODIS-derived LAI/fPAR scheme, MODIS-derived Net Primary Production scheme, and Plant Functional Type scheme.

A comparison of the estimates of rangeland area from the 1992, 2001, and 2006 NLCD (Landsat imagery with 0.09 ha spatial resolution), MODIS Global Land Cover Product (100 ha spatial resolution), and NRI (ground survey point sample on non-federal lands) would be informative. The NLCD and MODIS data sets have the advantage of providing a map product that is needed for other SRR criteria and indicators. However, the maps will likely have omission and commission errors, and accuracy assessment of the products are needed to calculate unbiased estimates of the area of rangeland. The NRI estimates of the area of rangeland should be unbiased but are only available for non-federal lands (Table 3.2). However, the NRI estimates offer the opportunity to assess the accuracy of satellite thematic classifications of rangeland area or change in the same way the FIA and Southwest Regional GAP Analysis Project (Lowry et al. 2007) field data were used to look at the accuracy of MODIS-derived continuous forest cover (White et al. 2005). This type of comparison would identify the most efficient method to assess land area change in rangeland. Other indicators may require a different approach; Thematic Mapper (TM) imagery may be better for calculating rangeland fragmentation than a map from MODIS imagery.

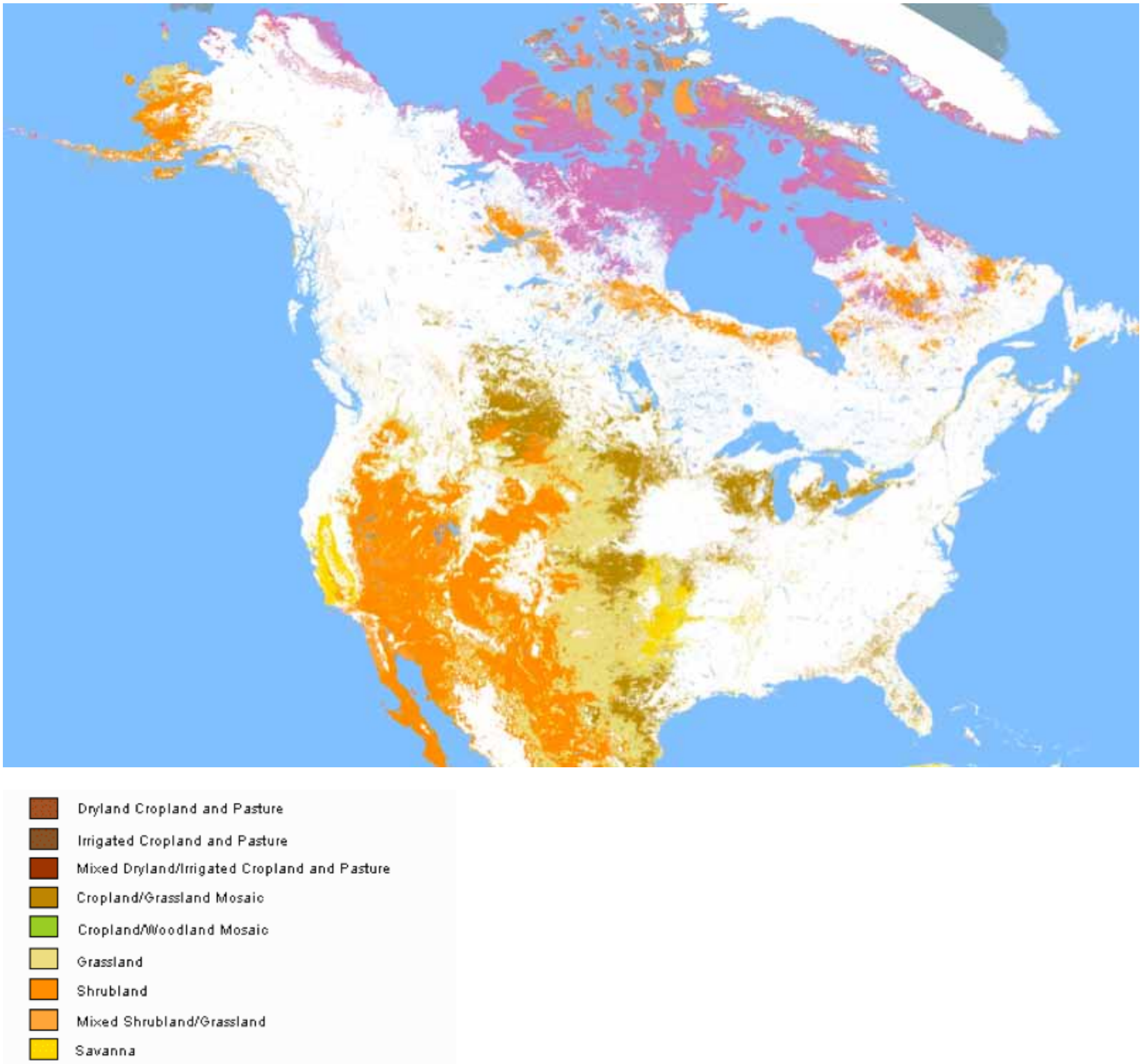

Figure 3.1. Extent of land area in rangeland as determined using remote sensing data. Source: Adapted from http://www.nationalatlas.gov/landcvm.html USGS 1992 and 1993 AVHRR 1-km U.S. land cover (USDI 2009).

Clarity to Stakeholders

Total area of rangeland and changes in the total area of rangeland would likely be one of the more easily understood and accepted indicators by the public. The possibility of mapping rangeland area and change would enhance understanding by the public.

Rangeland Area by Plant Community

Description and Importance of the Indicator

This indicator describes rangeland plant communities and their area at any given time, with the difference between times being a reflection of temporal changes. This indicator has a classification component—how stakeholders name and/or describe the plant community—and an inventory component—where they are found and what area they cover. This indicator is the hierarchical subcomponent of the "Extent of Land Area in Rangeland" indicator.

Plant communities are loosely assembled collections of plant species (Mueller-Dombois and Ellenberg 1974), with the mix of species affecting community structure and function and ultimately its capacity to support a wide range of plants and animals including rare, threatened, and endangered species. Description and classification of plant communities are challenging because the distribution of plant species over time and space is influenced by many factors operating at a number of scales. Classification systems are artificial constructs developed to simplify the variability of vegetation; therefore, numerous methods to classify vegetation have been developed (Whittaker 1973; Mueller-Dombois and Ellenberg 1974; Shiflet 1994; ESA 2004; Grossman et al. 2008).

Vegetation can be described in terms of potential vegetation, existing vegetation, physiognomy, floristics, or varying combinations of these descriptors. Resource conservation and land management agencies and organizations have often developed classification systems that facilitate decision-making for resource management and planning. The Ecological Site classification system is a single level classification system developed by the NRCS and used by both the NRCS and the U.S. Department of the Interior (USDI) Bureau of Land Management (BLM) (USDA NRCS 2010b) and now with a recent memoranda of understanding, the USDA Forest Service (Brown and Bestelmeyer 2008). Bestelmeyer et al. (2009) noted that ecological site classifications are based on the premise that difference in potential plant communities and their resilience are governed by subtle differences in soil, geomorphology, and climate. Knowing the suite of potential plant communities possible at a given site can help place the existing vegetation in a historical and environmental framework. Other federal agencies (U.S. Fish and Wildlife Service [FWS], U.S. Geological Survey [USGS], Department of Defense) and non-governmental organizations (among them, The Nature Conservancy [TNC]) have developed land and plant community classifications for institution specific management and planning needs. The challenge in developing a nationally consistent vegetation classification system is to recognize the role that these historic systems have played in management and planning decisions and to identify methods to continue to provide such information to meet management needs.

A fundamental goal of SRR is to facilitate the adoption of standardized assessment and monitoring technologies by all rangeland resource agencies and users in order to enhance interpretation of these data regardless of land ownership or stewardship responsibilities. To accomplish this goal and to enhance the utility of this indicator, a nationally consistent definition of rangeland ("Extent of Land Area in Rangeland" indicator) is needed as well as accepted definitions and descriptions of associated rangeland plant communities ("Rangeland Area by Plant Community" indicator). Descriptions must be clear and complete so resource managers, scientists, and technicians can unambiguously identify the specific plant communities occupying any given rangeland. Further, a consistent classification system should be implemented across the United States within the context of an inventory system that samples plant communities on rangeland. Technology is available to perform a national inventory and monitoring program for rangeland plant communities and to enhance these direct measurements with a probability-based sample design. The integration of remote sensing, abiotic data, GIS technologies, and ground sampling in a probability-based sampling design would capitalize on the strengths of each approach (e.g., Franklin et al. 2000). The challenge is to recognize the strengths of all assessment and monitoring approaches and then use the best combination of them.

The varieties of rangeland vegetation reflect the variety of benefits and values that rangelands provide. The extent of these communities indicates the current capability of rangeland to produce these benefits and values for society. Changes in certain plant communities could result in changes in resource outputs, ecosystem services, non-market values, and habitats for plant and animal species. Examples of endangered or critically endangered rangeland ecosystems include the native shrub and grassland steppe in Oregon and Washington, the Palouse prairie in eastern Oregon and Washington, and the tallgrass prairie of the eastern Great Plains (Flather et al. 1999; Noss et al. 1995). Presence of a plant community can also serve as a loose proxy for environmental characteristics, disturbances, and ecosystem processes. Changes in plant communities over time may suggest changes in underlying environmental factors such as climate and nutrient availability, changes in ecosystem functioning, or changes in disturbances. Flather and Sieg (2000) reported that the simplest measure of ecosystem diversity is the number and area of rangeland plant communities that occur nationally. They state that maintaining a sufficient area of each plant community is necessary to sustain ecosystem components and processes, as well as the species dependent on them. Information on the number and extent of rangeland plant communities over time is fundamental for resource management and planning decisions, as well as providing the basic information on vegetation for scientific research. Further, this information is critical to ensuring the sustainability of rangelands.

Geographic Variation

While different plant communities will occur in different regions, if communities are classified and named using the same protocols and methodology, this indicator is useful in and across different regions.

Scale in Time and Space

If a standard classification system of rangeland plant communities is nationally accepted, it will be necessary to define the spatial scale and hierarchal level within the classification system when indicator data are collected. This is because the field implementation of the definition is influenced by spatial scale. Estimations of the areal extent of plant communities through either ground-based inventories or remotely sensed techniques are often less sensitive than desired, but as technology advances, we may be able to improve our ability to determine plant communities more efficiently, in a less costly manner, and with greater spatial resolution. Granted, direct discrimination of the taxonomic composition of rangeland vegetation using satellite data have proven quite elusive. Still, newer sensors of high spectral and spatial resolution may dramatically improve our capability to remotely determine botanical composition. That said, of far greater promise is the process of context modeling. Context modeling technology predicts the taxonomy of vegetation from remotely sensed physiognomic and structural vegetation maps in conjunction with other landscape variables such as soil type and elevation within a geographic information system (Franklin et al. 2000; Wulder et al. 2008; see Guisan and Zimmermann 2000 for cautions).

Data Collection and Availability

In terms of the classification component and the inventory component of this indicator, the data availability is categorized as both B and C (Table 3.1, Appendix 1-E). Standardized methods and procedures for data collecting and reporting exist at the regional-national level, but useable data set(s) do not exist at the regional-national level. There is no single agency responsible for classifying, describing, and/or mapping the vegetation of the United States (FGDC 2008), and there are many agencies for which information on vegetation is critical and, therefore, have been developed independently at national or regional levels. Hence, some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level.

In 2008, Version 2 of the U.S. National Vegetation Classification Standard (NVCS) was formally approved by the Federal Geographic Data Committee (FGDC 2008; Jennings et al. 2009; Faber-Langendoen et al. 2009). The development of this revision occurred through a partnership of the Ecological Society of America (ESA) Panel on Vegetation Classification, NatureServe (http://www.natureserve.org/. Accessed 15 November 2008), and federal partners of the FGDC. Critical changes from Version 1 include a restructuring of the overall hierarchy, development of new standards for the lower levels of the classification (alliance and association), and the formation of a dynamic approach to maintaining the classification (Faber-Langendoen et al. 2009). Perhaps the most important revision is the development of a process, referred to as "successive refinement," to create a consistent national vegetation classification. Vegetation types must be defined and characterized using appropriate data where the classification and data are publicly accessible. The classification system is dynamic in that the content will evolve as data continue to be collected, analyzed, and correlated over time and new vegetation types are defined and previously defined types refined. Developing and revising these plant communities under the NVCS will be a peer-reviewed process. FGDC (2008) notes that the standard shall be followed by all Federal agencies for vegetation classification data collected directly or indirectly (through grants, partnerships, or contractors) using federal funds. Widespread use of NVCS by county and state governments, research institutions, and the private sector could facilitate information needs on vegetation across ownerships and landscapes.

The National Vegetation Classification (NVC) has eight levels in the hierarchy for natural and cultural vegetation with differently defined criteria for natural versus cultural. Cultural vegetation is defined as "vegetation with a distinctive structure, composition, and development determined by regular human activity" (FGDC 2008). It includes one or more physiognomic and structural attributes, such as growing in rows, substantial cover of bare soil for significant periods of the year, highly-manipulated growth forms usually determined by mechanical pruning or mowing, and/or species not native to the area intentionally introduced to the site by humans. The upper levels of the hierarchy for natural vegetation are based on broad growth form patterns that reflect ecological relationships (Faber-Langendoen et al. 2009) (Table 3.3). Physiognomy (life form, cover, structure, leaf type) plays a predominant role in Levels 1-3, whereas both floristics and physiognomy influence the criteria of the middle levels 4-6. The role of floristics increases as one steps down into the hierarchy. The upper physiognomic levels of the NVCS hierarchy are based on factors that could be discernible from aerial photography or fine spatial resolution satellite imagery.

Table 3.3 Summary of NVC-revised hierarchy levels and criteria for natural vegetation (FGDC 2008)

Hierarchy level	Criteria
Upper	Physiognomy plays a predominant role.
L1 – Formation Class	Broad combinations of general dominant growth forms that are adapted to basic temperature (energy budget), moisture, and substrate/aquatic conditions.
L2 – Formation Subclass	Combination of general dominant and diagnostic growth forms that reflect global macroclimatic factors driven primarily by latitude and continental position, or that reflect overriding substrate/aquatic conditions.
L3 – Formation	Combinations of dominant and diagnostic growth forms that reflect global macroclimatic factors as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions.
Middle	Floristics and physiognomy play predominant roles.
L4 – Division	Combinations of dominant and diagnostic growth forms and a broad set of diagnostic plant species that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbances regimes.
L5 – Macrogroup	Combinations of moderate sets of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and subcontinental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbances regimes.
L6 – Group	Combinations of relatively narrow sets of diagnostic plant species (including dominants and co-dominants), broadly similar composition, and diagnostic growth forms that reflect regional mesoclimate, geology, substrate, hydrology, and disturbance regimes.
Lower	Floristics plays a predominant role.
L7 – Alliance	Diagnostic species, including some from the dominant growth form or layer, and moderately similar composition that reflect regional to subregional climate, substrates, hydrology, moisture/nutrient factors, and disturbance regimes.
L8 – Association	Diagnostic species, usually from multiple growth forms or layers, and more narrowly similar composition that reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes.

Table 3.4. Hierarchy for natural vegetation with example (from FGDC 2008)

Hierarchy for Natural Vegetation	
Upper Levels	
1 – Formation Class	Scientific Name: Mesomorphic Shrub and Herb Vegetation Colloquial Name: Shrubland and Grassland
2 – Formation Subclass	Scientific Name: Temperate and Boreal Shrub and Herb Vegetation Colloquial Name: Temperate and Boreal Shrubland and Grassland
3 – Formation	Scientific Name: Temperate Shrub and Herb Vegetation Colloquial Name: Temperate Shrubland and Grassland
Mid Levels	
4 – Division	Scientific Name: ***Andropogon – Stipa – Bouteloua*** Grassland and Shrubland Division Colloquial Name: North American Great Plains Grassland and Shrubland
5 – Macrogroup	Scientific Name: ***Andropogon gerardii – Schizachyrium scoparium – Sorghastrum nutans*** Grassland and Shrubland Macrogroup Colloquial Name: Great Plains Tall Grassland and Shrubland
6 – Group	Scientific Name: ***Andropogron gerardii – Sporobolus heterolepis*** Grassland Group Colloquial Name: Great Plains Mesic Tallgrass Prairie
Lower Levels	
7 – Alliance	Scientific Name: ***Andropogon gerardii – (Calamagrostis canadensis – Panicum virgatum)*** Herbaceous Alliance Colloquial Name: Wet-mesic Tallgrass Prairie
8 – Association	Scientific Name: ***Andropogon gerardii – Panicum virgatum – Helianthus grosseserratus*** Herbaceous Vegetation Colloquial Name: Central Wet-mesic Tallgrass Prairie

The floristic levels of the classification hierarchy require more detailed field plot data to characterize the composition, structure, and cover of the vegetation. An example of the hierarchy for a grassland type is shown in Table 3.4. As identified by FGDC (2008), the initial NVC types are the current set of provisional NVC alliances and associations for natural vegetation (FGDC 1997), upper-level types developed by the Hierarchy Revision Working Group (Faber-Langendoen et al. 2009), and cultural vegetation types developed by USDA NRCS (2003). The original list of plant communities published by TNC, in conjunction with the Natural Heritage Network (Anderson et al. 1998), provided a comprehensive compilation of literature and field observations for each community. This list is now maintained by NatureServe. To date, the number of NVC nationally described associations is 5,516 (NatureServe 2008). Data to define new vegetation types must be archived and publicly accessible (Jennings et al. 2009). The ESA Panel on Vegetation Classification maintains VegBank as a repository to facilitate archiving, discovering, viewing, citing, and disseminating plot data (Duke et al. 2006), and the archive meets FGDC-recognized standards (Jennings et al. 2009). FGDC (2008) states that a vegetation classification system is not synonymous with a map legend. Tart et al. (2005) state that vegetation classification must be done first to identify the entities to be mapped.

Several projects have attempted to use Version 1 of the NVC to map vegetation (Comer et al. 2003). The USGS National Gap Analysis Program (GAP) is a first attempt to map existing rangeland vegetation of the nation using floristically defined classes and a common vegetation classification system. State GAP projects attempt to map existing vegetation at the alliance level of the NVCS using Thematic Mapper imagery and ancillary data with a per-class accuracy of 80 percent or greater (Fig. 3.2). The USGS/NPS Vegetation Mapping Program is using manual interpretation of aerial photography to map vegetation of National Parks at the alliance and association levels of the NVCS with a classification accuracy goal of 80 percent for each map class. However, attempts to attain the desired classification categories and accuracy have proven difficult. Mapping at the alliance level includes challenges such as not all alliances occur in large and distinctive patches, many alliances comingle in small areas, and some alliances remain indistinguishable using remotely sensed imagery (Comer et al. 2003). Mapping projects have often used a broader classification such as ecological systems (Comer et al. 2003) and associated the alliance information with the mapping unit.

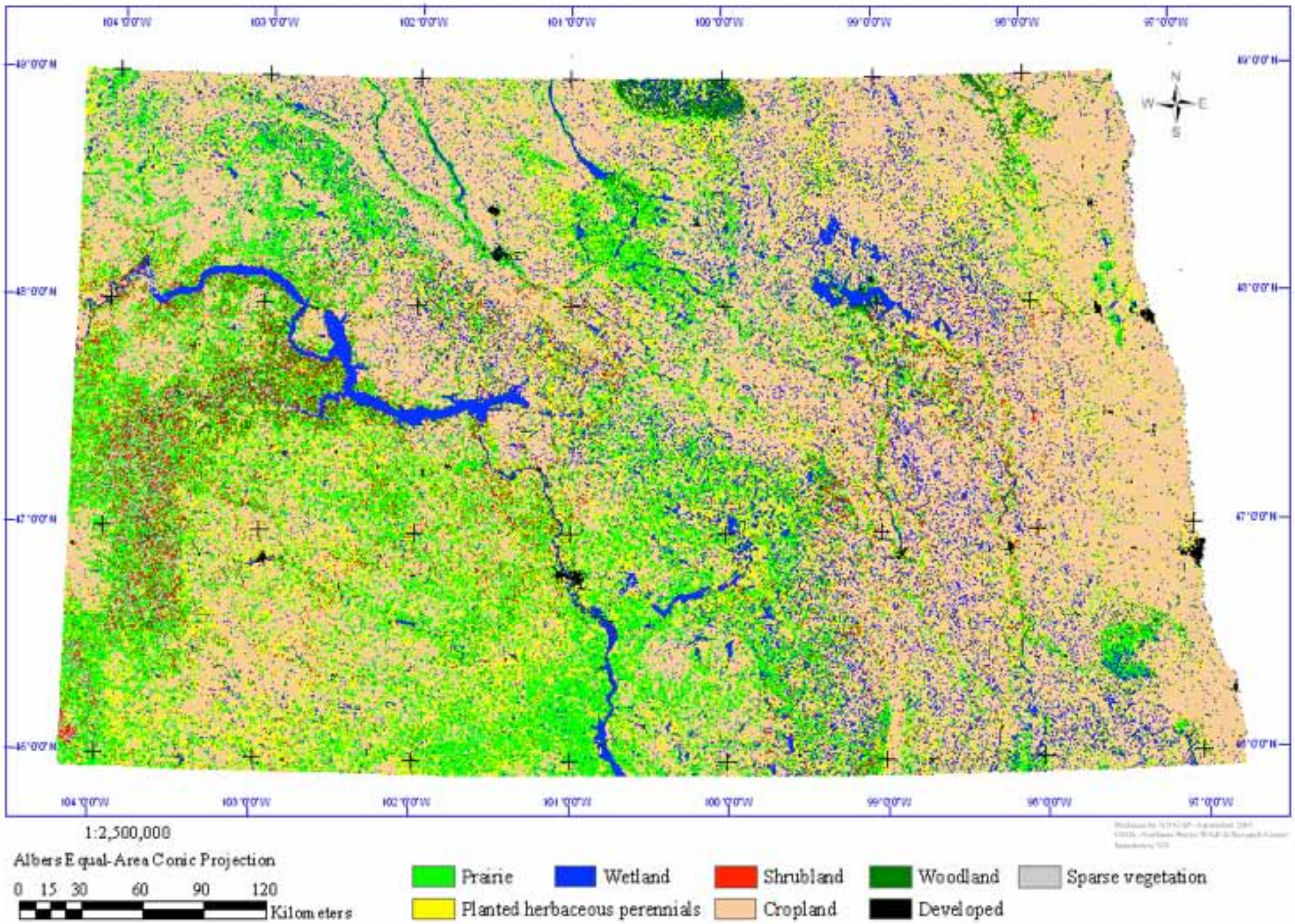

Figure 3.2. North Dakota Gap Analysis land cover map, circa 1997. Eight general land cover categories at the upper level of the land cover classification system (Strong et al. 2005).

The NVC describes existing vegetation. Historically, vegetation management on rangeland has depended upon ecological sites or similar potential-based land classification systems to provide information on the ecological integrity of the management unit (Brown and Bestelmeyer 2008; Bestelmeyer et al. 2009). The National Vegetation Classification emphasizes vegetation traits, whereas ecological sites bring in the additional influential factors associated with climate, geomorphic setting, and soils. For example, an NRCS Ecological Site, as defined in Boltz and Peacock (2002), is the product of all environmental factors responsible for its development. As such, an NRCS Ecological Site description attempts to incorporate the effects of soils, hydrology, herbivory, and disturbance regime on vegetation community (Ecological Site Information System, USDA NRCS 2010b). Soil series and slope are the primary variables for determining, correlating, and differentiating NRCS Ecological Sites. Brown and Bestelmeyer (2008) describe the many challenges that face the ongoing and future development and application of ecological sites including the influence of invasive species and climate change on individual ecological site dynamics and the possibility that interactions among individual plant communities in a landscape context may be just as important as the interactions of species within the plant community. Further, given the widening interest in ecological sites, assumptions underlying ecological site behavior associated with livestock grazing may no longer be valid or may be too limited to meet the increasing diversity of users (foresters, wildlife biologists, hydrologists). Opportunities may be present as scientists and managers refine current thinking on ecological sites to capitalize on the data collection and classification standards outlined in the National Vegetation Classification. The challenge within the rangeland community will be to merge these efforts so that there is the capacity and capability to compare vegetation data across temporal and spatial scales and to describe our understanding of plant communities and landscapes so that this information forms the platform for policy and management decisions.

Clarity to Stakeholders

While detailed understanding of this criterion by the public is questionable, use of the National Vegetation Classification has been attempted by many groups interested in rangeland conservation, such as the state GAP projects and The Nature Conservancy. The ESA Panel on Vegetation Classification efforts to establish descriptions for alliance and the VegBank database have also broadened the awareness of these approaches to vegetation classification. Although rangeland management has focused on ecological site, it may be that the public may have more of an awareness of existing vegetation and concern for changes in existing plant species and communities over time.

Number and Extent of Wetlands

Description and Importance of the Indicator

The indicator relates to abundance of wetlands in the rangeland landscape. Wetlands for this indicator include depression (e.g., prairie potholes and playas) and slope wetlands but do not include riverine or floodplain wetlands that are covered under the "Extent and Condition of Riparian Systems" indicator. Wetlands are transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. We have defined "wetland" as having one or more of the following three attributes: 1) the land at least periodically supports predominately hydrophytes, 2) the substrate is predominately undrained hydric soil, and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979).

This indicator measures the number and total area of wetlands within all or portions of the rangeland system. The metric may be either a) numbers of individually identifiable wetlands and acreage for a particular region, or for the entire rangeland region, or b) numbers and percent of landscape occupied by wetlands. Most wetlands occurring on rangeland will fall into the riverine, lacustrine (subsystem Littoral), or palustrine systems. They can be further described by class and subclass as well as by modifier for dominance type (vegetation), water regime, water chemistry, and soil (order or suborder as well as hydric criteria). Within the Cowardin et al. (1979) classification system, riverine systems are distinguished from riparian areas—the riverine system is bounded by the channel or stream bank while riparian areas typically begin at the stream bank. Within this criterion, riparian condition and extent are treated as a separate indicator (see discussion in "Extent and Condition of Riparian Systems").

Wetlands are a unique feature of rangeland in which maintenance of biodiversity requires connection among many wetlands as well as linkages to neighboring uplands. Reduction of wetland areas, often a consequence of hydrological or land-use changes, reduces the potential for sustaining the diverse assemblage of rangeland organisms that depend on wetlands for all or part of their life cycles. Wetlands also offer feeding sites for migratory waterfowl and other species, a connection that may be used for evaluating functionality of wetlands. Wetlands also function as buffers or filters of runoff, helping to maintain water quality in aquatic systems.

Geographic Variation

This indicator can be measured at a local, state, or regional scale. The presence of wetlands is connected directly to the hydrogeomorphic characteristics of the regional landscape. For example, prairie pothole wetlands, which are depressional, are found primarily in the region of the Dakotas. Vernal pool wetlands, also depressional, occur within portions of California (and other areas in the United States). Playas and mineral soil flats are found in the arid Southwest, and coastal wetlands and estuarine fringe wetlands are found along low oceanic coast lines. Recognition of these regional and hydrogeomorphic differences can be included in presentation of the indicator.

A wetland indicator can also be developed relative to the different climatic regimes often associated with different regions of the country's rangeland. If response to changing climate is an important factor in rangeland sustainability, wetlands may be more sensitive to changes in many hydrological components of climate than other indicators. The timing of a wetland inventory is important so that the data can be placed in the context of seasonal distribution of precipitation as it normally occurs and in the context of the natural variability of climate.

Changes in wetlands area can be associated with regional hydrogeomorphic characteristics and regional climate. For example, wetland areas in the Southwest and in the Southern Great Plains are closely tied to changes in water availability (e.g., groundwater depletion, water diversion), whereas in other regions, such as the Northern Great Plains, natural hydrologic variability strongly influences changes in wetland area. Human activities alter wetlands on some scale in most regions.

Scale in Time and Space

The spatial scale of wetlands ranges from tens of meters to several kilometers. If wetland delineation is done on an individual wetland basis, the data can be scaled up to any spatial scale desired, whereas wetland identification done by satellite on a regional basis may not be able to be scaled down to a local level. Changes in wetland numbers and areas can occur in decadal or smaller time frames, time frames sufficiently short to allow measurements to be used for management purposes.

Data Collection and Availability

The data for this indicator are best represented by A (Table 3.1, Appendix 1-E). Methods and procedures exist at the regional-national level for data collecting and reporting, and data sets of useable quality exist at the regional-national level. The data set being developed by the FWS under its National Wetlands Inventory (NWI) Program may be the most comprehensive and applicable to the Sustainable Rangelands project (FWS 2010a).

In 1982, the NWI produced its first estimate of the status of the nation's wetlands and wetland losses. The Emergency Wetlands Resources Act of 1986 (Public Law 99-645, 100 Stat. 3582) required the FWS to complete mapping of wetlands in the contiguous United States and, as soon as practicable, maps of Alaska and other noncontiguous portions of the United States and produce, by September 30, 1990, and at 10-year intervals thereafter, reports to update and improve in the 1982 "Status and Trends of Wetlands and Deepwater Habitat in the Coterminous United States, 1950s to 1970s." The NWI Program has focused on map or digital databases of wetlands and reporting on national wetland trends using a probability-based sampling design.

Using data from 3,635 four-square mile plots, the National Wetland Status and Trends Study analyzes the trends of major wetland types (Tiner 2009). Updates on status and trends of wetlands were produced in 1990 (Dahl and Johnson 1991), 2000 (Dahl 2000), and 2006 (Dahl 2006). For each plot, aerial imagery is interpreted and annotated in accordance with procedures published by the FWS. The results are compared with previous era imagery, and any changes are recorded. The differences between the data sets are analyzed, and a statistical estimate of the change is produced.

One hundred percent coverage for wetland mapping by the FWS does not exist (Tiner 2009), but the mapping continues and eventually all rangeland areas will be covered. It is unknown whether remapping will occur on a regular basis to allow for comparisons of changing wetland coverage. To date NWI, maintained by the National Wetlands Inventory Center, has mapped 90 percent of the lower 48 states and 34 percent of Alaska. About 60 percent of the lower 48 states and 27 percent of Alaska are digitized. Examples of the protocols used are presented in Dahl and Bergeson (2009). Online mapping capability is available on its website (FWS 2010b). The Federal Geographic Data Committee (FGDC Wetlands Subcommittee 2009) recently adopted the techniques used by the NWI as the federal wetland mapping standard, thus insuring that all federally funded wetland mapping can be added to the NWI's wetlands master geospatial database (Tiner 2009).

Baseline, or reference, conditions published in "Status and Trends of Wetlands in the Conterminous United States 1998-2004" (Dahl 2006) may be useful for future evaluation of wetland changes (Fig. 3.3). The report provides the most recent and comprehensive estimates of the current status and trends of wetlands in the 48 conterminous United States on public and private lands. Ninety-five percent of the nation's wetlands are freshwater; this number includes upland wetlands associated with rangelands. A major finding of the report is that the nation's estimated wetlands showed a 0.2 percent increase in freshwater wetlands between 1998 and 2004 compared to a continued declining wetland loss in the prior decade. Urban and rural development account for most recent freshwater wetland losses, while agricultural lands and rangelands experienced wetlands gains, in part through management or modification of shrublands and prairies (Dahl 2006).

The NRCS NRI also inventories wetlands using a statistically based sample of land use and natural resource conditions and trends on U.S. non-federal lands (USDA NRCS 2010a). Analyses of the inventory results over time provide data on land use, soil erosion and soil quality, water quality, wetlands, and other issues regarding the conservation and use of natural resources (USDA NRCS, not dated). See Table 3.5 for NRI information that can be found online.

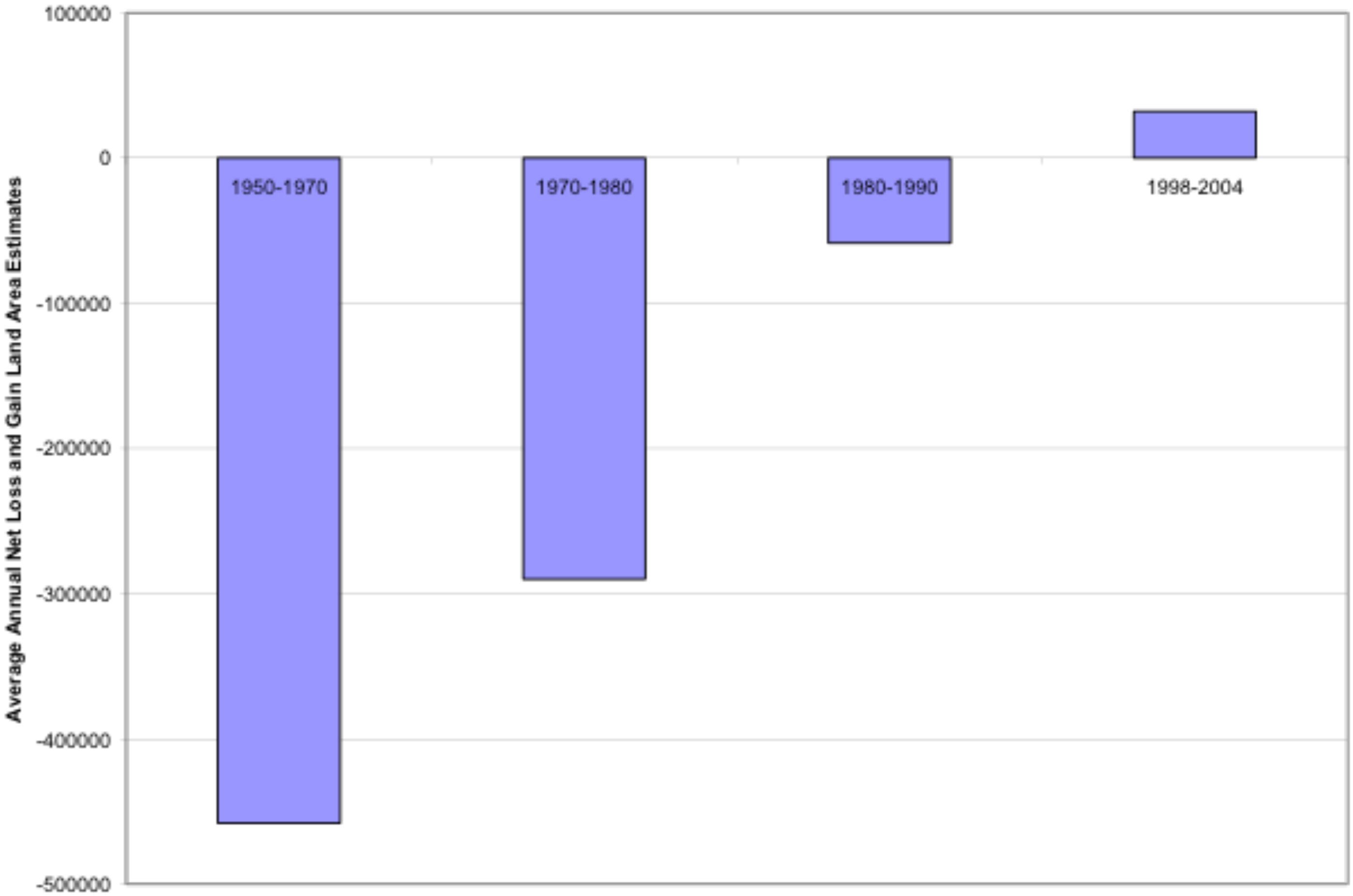

Figure 3.3. Average annual net loss and gain estimates for the conterminous United States, 1954-2004. These data, taken from Dahl (2006), indicate that wetland area gains were achieved through restoration and creation. The Dahl (2006) report does not draw conclusions regarding trends in the quality of the nation's wetlands.

Table 3.5. Online resources from the National Resources Inventory.

Data Resources	http://www.nrcs.usda.gov/technical/dataresources/ Links to NRCS base map coverages, status maps, the NRI database, and databases on soil, water and climate, plants for conservation, and other subjects. This site is a node of the National Spatial Data Infrastructure.
NRCS Geospatial Data Gateway	http://datagateway.nrcs.usda.gov/data.html Provides natural resources or environmental data at anytime, from anywhere, to anyone. Data themes listed on the Gateway Data Management page include orthoimagery, soils, cultural, and demographics (census tract boundaries, census of population and housing, census of agriculture, economic census), governmental units and place names, elevation, hydrography, cadastral, transportation (roads), Digital Raster Graphic (DRG) Scanned USGS quads, land cover/vegetation/plants, watershed boundaries (10-12 digit hydrologic units), wetlands, wetland and floodplain easements, climate (precipitation and temperature), and flood hazards
Imagery	*Aerial Photography*: http://www.apfo.usda.gov/ *Orthoimagery*: http://www.ndop.gov/index.html The NRCS participates in the National Digital Orthophoto Program, which serves as a focal point for accessing aerial and orthophoto imagery.

Although the NRI coverage does not include federal lands (USDA NRCS 2010a), the data may be sufficiently focused on those lands where land-use change is most likely to allow interpretation of wetland change, especially when those data are combined with NWI information. Within the NRI, wetlands are present as an attribute that may occur on all other land cover/use categories, so the data can be queried by land cover/use (e.g., rangeland) for wetland estimates by any category. Each NRI sample point has multiple attributes (soil map unit component, soil descriptions, land cover/use, wetland type, etc.) associated with it for many kinds of analyses. Additionally, state, administrative region, ecoregion, and other geographically defined areas of interest can be used to summarize data within the NRI. An additional advantage is that since 1997 the NRI has gone to an annualized inventory, with annual reports beginning with a summary report in 1997 (revised in 2000). The NRCS has made maps of the area of non-federal wetlands in 1992 and 1997 available on the web (USDA NRCS 2010c)).

Flather et al. (1999) analyzed wetland trends from 1982 to 1992 using the NRI data and found a decline (70 percent) in the rate of wetland loss between the mid-1970s and mid-1980s similar to the 2000 FWS report (Dahl 2000). Zedler and Kercher (2005) evaluating wetland status, trends, and ecosystems services found similar changes. During the 1982-1992 period, the primary cause of wetland conversion on non-federal lands was urban development. Data from the 2006 FWS report (Dahl 2006) show similar losses to urban development. However, this report indicates an overall gain of 0.2 percent in freshwater wetlands in the 1980-2004 period.

The indicator can be monitored with existing remote sensing capabilities (see NWI above). These monitoring data are repeatable and can be collected over time to present a picture of changing abundance of wetlands in the rangeland landscape. If NWI was to be repeated periodically and compared with NRI data, a more complete picture of changing wetland abundance may emerge. The probability-based sampling design allows for calculation of errors associated with each measurement in time. Tiner (1997) points out that wetlands can be missed when using remote sensing because wetlands with similar spectral signatures as non-wetlands might not be identified as separate from the surrounding vegetation. Accuracy of NWI is based on how much of the area is ground-truthed (e.g., Kudray and Gale 2000).

The FGDC in 1996 passed standards for classification of wetlands and deepwater habitats of the United States (FGDC Wetlands Subcommittee 2009). These standards provide specific ecological and hydrological information for the identification, classification, and mapping of wetlands in the United States and its territories. Adoption of these FGDC standards will not change the current status of NWI maps produced by the FWS.

Clarity to Stakeholders

Stakeholders understand what wetlands are and that wetlands in the rangeland landscape have been greatly reduced in the 20th century. Consequently, an indicator that simply presents the number and total area of wetland for selected spatial scales (e.g., regions or states) will be understandable to stakeholders and the public. Data from the FWS NWI and from the NRCS NRI are also readily available to stakeholders and the public over the Internet. NatureServe Explorer (http://www.natureserve.org/explorer/. Accessed 20 April 2011) provides users with the ability to search for wetland communities within other plant communities.

Fragmentation of Rangeland and Rangeland Plant Communities

Description and Importance of the Indicator

This indicator is defined as the breaking up or loss of connectivity of rangeland or of a rangeland cover type. A cover type is a category within a classification scheme that distinguishes among the different habitats, ecosystems, or vegetation types on a landscape (see discussion above of "Area of Rangeland by Plant Community" indicator). While designation of a patch is subjective (McGarigal and Marks 1995), a patch is usually a discrete scale-dependent entity of interest (such as a cover type) used to categorize landscape heterogeneity (Pickett and Cadenasso 1995). Landscapes are characteristically a mosaic of heterogeneous patches, and this is true of rangeland (Senft et al. 1987; Belsky 1989; Coughenour 1991; Friedl 1994; Washington-Allen et al. 2008). For our purposes, a patch or cover type has both regional and national spatial extents delineated both by total rangeland area and rangeland plant communities. Using such information, fragmentation has been observed in rangelands over time (Fig. 3.4).

Fragmentation has been shown to impact plant and animal species and ecosystem function in western ecosystems. For example, in one of the first applications of diversity metrics at the landscape scale, Romme and Knight (1982) demonstrated the impacts of fire patch dynamics on different forest stand ages and associated bird species. While fragmentation studies have a long history in forested ecosystems, recent research has also described fragmentation as an interruptive process affecting the sustainability of rangeland ecosystems (Ludwig and Tongway 1995; De Soyza et al. 2000; Flather and Sieg 2000; Wu et al. 2000; Washington-Allen 2003; Peters et al. 2006; Rietkerk et al. 2004; Ludwig et al. 2007; Hobbs et al. 2008; Okin et al. 2009; Ravi et al. 2009). Fragmentation of community types is particularly critical for wildlife and some plant populations; sufficient habitat and niche size is required to sustain breeding, rearing, feeding, and shelter needs (e.g., Romme and Knight 1982). In addition, fragmentation, and thus loss of connectivity, can also affect the maintenance of ecosystem processes, in particular fire regimes and hydrological and biogeochemical processes (Romme and Knight 1982; Wu et al. 2000; Peters et al. 2006; Rietkerk et al. 2004; Okin et al. 2009; Ravi et al. 2009). Fragmentation measures the size of contiguous areas, spatial organization, and community type dispersion. These factors are important descriptors in terms of grazing use, habitat and niche, and ecosystem services. Recently, fragmentation of rangeland ecosystems has been shown to impact the social and economic systems associated with those arid and semiarid lands (Galvin et al. 2008; Hobbs et al. 2008).

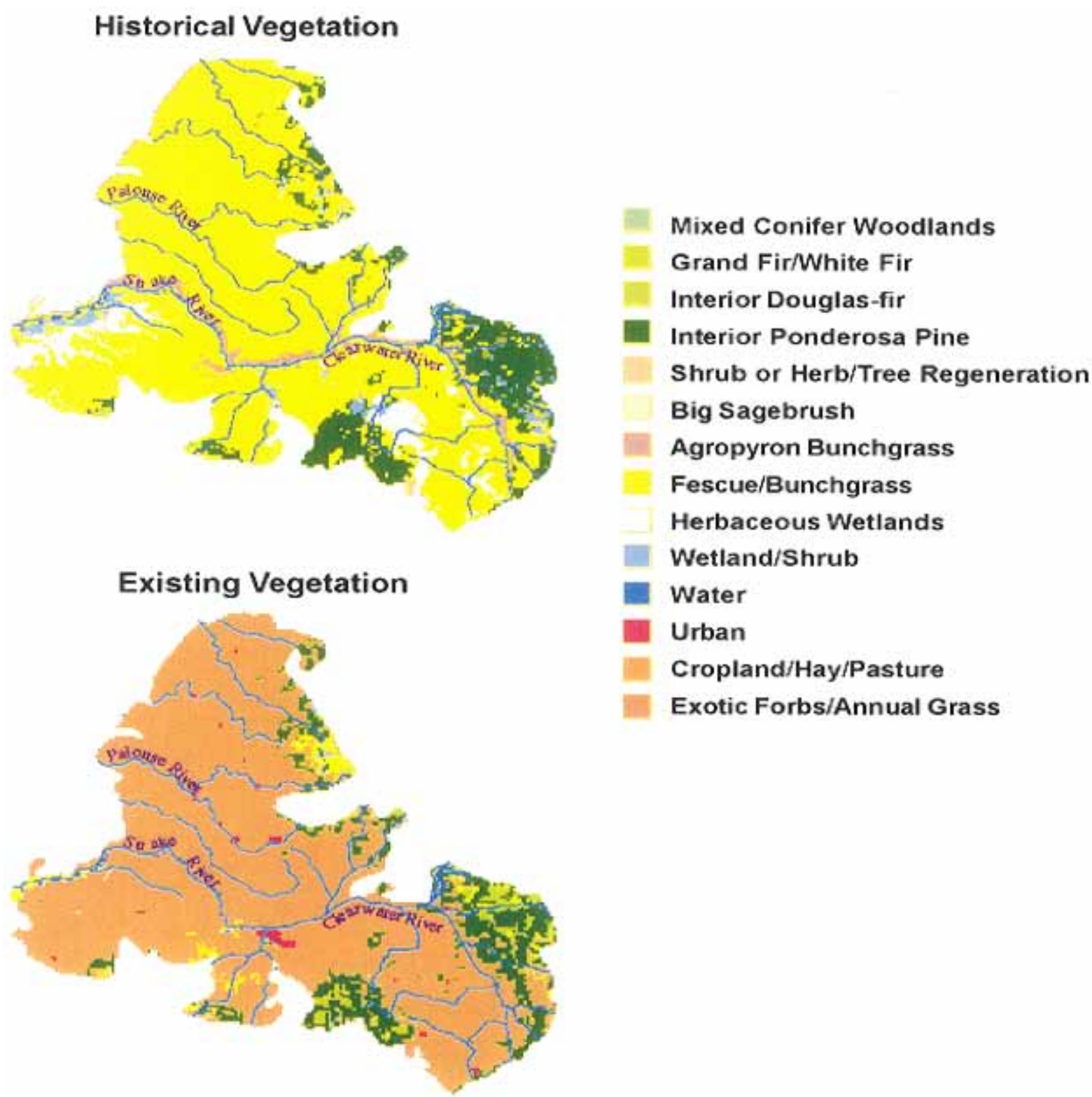

Figure 3.4. Fragmentation in rangeland vegetation communities. Palouse Prairie historical vegetation cover (circa 1900) and existing vegetation (circa 1990). Source: Quigley and Arbelbide 1997; Black et al. 1998.

Geographic Variation

The indicator would be meaningful in different regions. The changes in this indicator are nested within the total rangeland area of a region (see "Extent of Land Area in Rangeland" indicator) and within plant communities in the region (see "Area of Rangeland by Plant Community" indicator). The geographic extent may or may not change with loss or extinction of patches if the plant community shifts to another rangeland plant community. For example, ecological responses to abiotic or biotic changes at the local spatial scale, such as a shift to another plant community due to plant invasions, may not be apparent at the landscape scale where the total rangeland areal extent may not have been altered. However, at the local scale, fragmentation may have occurred. Thus, it is meaningful to speak of fragmentation of total rangeland area of a region and also fragmentation of particular plant communities.

Scale in Time and Space

Fragmentation has the capability of capturing spatial heterogeneity at varying spatial and temporal scales because it can be viewed hierarchically (Pickett and Cadenasso 1995). Fragmentation is a scale-dependent phenomena. For example, Washington-Allen (2003), Peters et al. (2006), Okin et al. (2009), and Ravi et al. (2009) demonstrated the effects that climate change, wind and water erosion, fire, and grazing have and could have on increasing bare ground patch connectivity, which can lead to loss of vegetation patch self-organization and increased dispersal across the landscape. Further, Fuhlendorf et al. (2002) demonstrated the importance of evaluating multiple scales (extents) when investigating relationships between landscapes and wildlife populations. They also demonstrated that changes in landscape structure over several decades influenced the lesser prairie-chicken, more so than the current landscape structure. They suggest that species exhibiting high site fidelity may show a lagged response to changes in landscape structure when compared to species that do not exhibit site fidelity. Scale in time and space are important considerations when exploring the impacts of fragmentation on rangeland.

Data Collection and Availability

The data currently available for this indicator are best represented by C (Table 3.1, Appendix 1-E). Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. Data sources for the analysis of fragmentation include federal agency repositories such as USGS (satellite imagery, digital elevation models, GAP analysis map data layers of land ownership, vegetation, and species distribution, and the NLCD), the Forest Service (LANDFIRE land cover map derived from 30-m Landsat data and associated 200,000 or more rangeland field data plots), the U.S. Environmental Protection Agency (EPA), and U.S. Census Bureau. Rangeland and rangeland community data sets identified in the "Extent of Land Area in Rangeland" and "Area of Rangeland by Plant Community" indicator sections could be used to calculate fragmentation matrices for rangeland.

In order to quantify fragmentation, metrics have been developed that identify the kinds of patches (e.g., cover type) and measure the size and area occupied, density, shape, connectivity, dispersion or clumping, number of patches, and the distance between patches (McGarigal and Marks 1995; Wu et al. 2000; Turner et al. 2001; Washington-Allen 2003). These metrics either directly analyze digital data or thematically/categorically classified digital data in one of two formats – raster or vector. Direct analysis have used such methods as lacunarity analysis (Wu et al. 2000) or Fourier analysis (Ares et al. 2003) with high resolution aerial photography and satellite imagery (1-m pixel resolution) including activity radar. The thematic data are usually imported to a spatial analysis program such as FRAGSTATS (McGarigal and Marks 1995). Table 3.6 lists indicators that have been used to measure fragmentation. Mean nearest neighbor is the distance (in meters) to the edge of the nearest neighboring patch of the same type. A small nearest neighbor standard deviation (NNSD) relative to the mean implies a homogenous distribution of patches across landscapes, whereas a large NNSD relative to the mean indicates a more heterogeneous distribution of patches (McGarigal and Marks 1995). Contagion measures the probability that two randomly chosen adjacent raster cells belong to different classes. Interspersion and Juxtaposition (IJI) is a measure of interspersion that is somewhat different from contagion because it measures individual patch types, and contagion measures individual pixels. IJI measures the juxtaposition of a focal patch type from all other types at the landscape and individual class type scales. IJI ranges from 0 to 100 percent with low values indicating low interspersion and high values indicating high interspersion or even distribution throughout a landscape (McGarigal and Marks 1995).

The Heinz Center (Heinz 2008) used the NLCD 2001 to aggregate selected cover types into a grassland-shrubland category. This analysis compared changes in grassland-shrubland core patch size between the West Coast, Southwest, and Rocky Mountain regions in the conterminous U.S. Core grassland or shrubland are patches of 0.1 ha that are surrounded by greater than 90-percent grassland or shrubland and other natural cover types. Heinz (2008) found that 22 percent of core shrubland was in patches of greater than 259 km^2 (or 100 square miles) compared to core grassland (13 percent within such patches). The West Coast, Southwest, and Rocky Mountain regions were dominated mostly by shrubland patches greater than 259 km^2 in size.

Another example of the use of such data to explore the impact of fragmentation on rangelands is the Rural Land Fragmentation Project in Texas. This study examined the status and recent changes in ownership size, land use, and property values of private farms, ranches, and forest lands in Texas (Wilkins et al. 2003). Data were from the U.S. Census Bureau, the USDA NRI, and the Bureau of Economic Analysis' Regional Economic Information System. Base maps of Texas were obtained from the Texas Natural Resources Information System. Changes in the size of the operation (e.g., ranch, farm) indicated that the amount of land in mid-size farms and ranches (500 to 2,000 acres) declined and resulted in mid-sized ownerships being fragmented into smaller ownerships. They suggested that over the next two decades, land in the south, central, and east-central portions of Texas would become increasingly fragmented, in contrast to trends suggesting that ownerships on the High Plains would increase in size. Coincident with these changes in ownership size were changes in native vegetation. Areas remaining in large ranches were more likely to stay in native vegetation, in contrast to smaller operations where conversions to non-native pastures was more likely. They noted that the ecological region strongly influenced these trends. They concluded that not only is native rangeland lost through conversion to improved pastures, but that the remaining native rangeland habitats are fragmented into increasing smaller patches as fragmentation progresses. The 2005 Land and Water Conservation plan (Texas Parks and Wildlife Department 2005) measured fragmentation by examining the division of single ownership parcels over time (Fig. 3.5). This index was combined with the percent of land converted to urban uses, population growth, and other metrics to assess the growing demand on land and water resources.

Table 3.6. The landscape metrics from the spatial analysis program FRAGSTATS (McGarigal and Marks 1995) that can be used to quantify landscape fragmentation.

Metric	Measure
Nearest Neighbor (meter)	Distance to nearest neighbor patch edge
Nearest Neighbor Standard Deviation	Dispersion of patches
Patch Number (PN)	Number of patches in landscape or the number of patches per class
Mean Patch Size (MPS)	Mean area of patches in landscape or the mean area of patches per class
Contagion (%)	Clumping, adjacency, and dispersion of pixels
Interspersion and Juxtaposition (IJI, %)	Interspersion and adjacency of patches

Flather and Sieg (2000) described the need to refine the use of remotely sensed satellite imagery to quantify fragmentation on rangeland and to identify the specific agents of fragmentation, such as intensive land uses, roads, and concentrations of exotic species. Such work is still needed. Thayn et al. (2008) establish that spatial pattern metrics are better predictors of rangeland stocking rates than spectral diversity metrics for Kansas grasslands. Ludwig et al. (2007) establish the link between landscape structure and function and the potential for landscapes to lose, or "leak," soil sediments. Such research establishes the potential for a new index for monitoring the health of rangelands using remotely sensed information. Hobbs et al. (2008) explore the ways in which humans contribute to fragmentation of rangelands, such as through fencing and potential adaptations that can mitigate harmful outcomes.

Clarity to Stakeholders

The public has been informed of the general subjects of habitat loss and species extinction and is more likely to associate the concept of fragmentation with forested habitat and the consequences of timber harvesting and land-use change on forested habitat. However, recent research (e.g., Galvin et al. 2008) and the widely accessible Heinz report (Heinz 2008) have quantified and demonstrated the implications of fragmentation in rangelands. Further, public support for the establishment of public lands and private conservation reserves indicate an understanding of the importance of rangeland habitat. The use of many easily calculated metrics could confuse the concept of fragmentation. Thus, it will be important to use metrics of fragmentation where they convey additional ecological information about underlying processes.

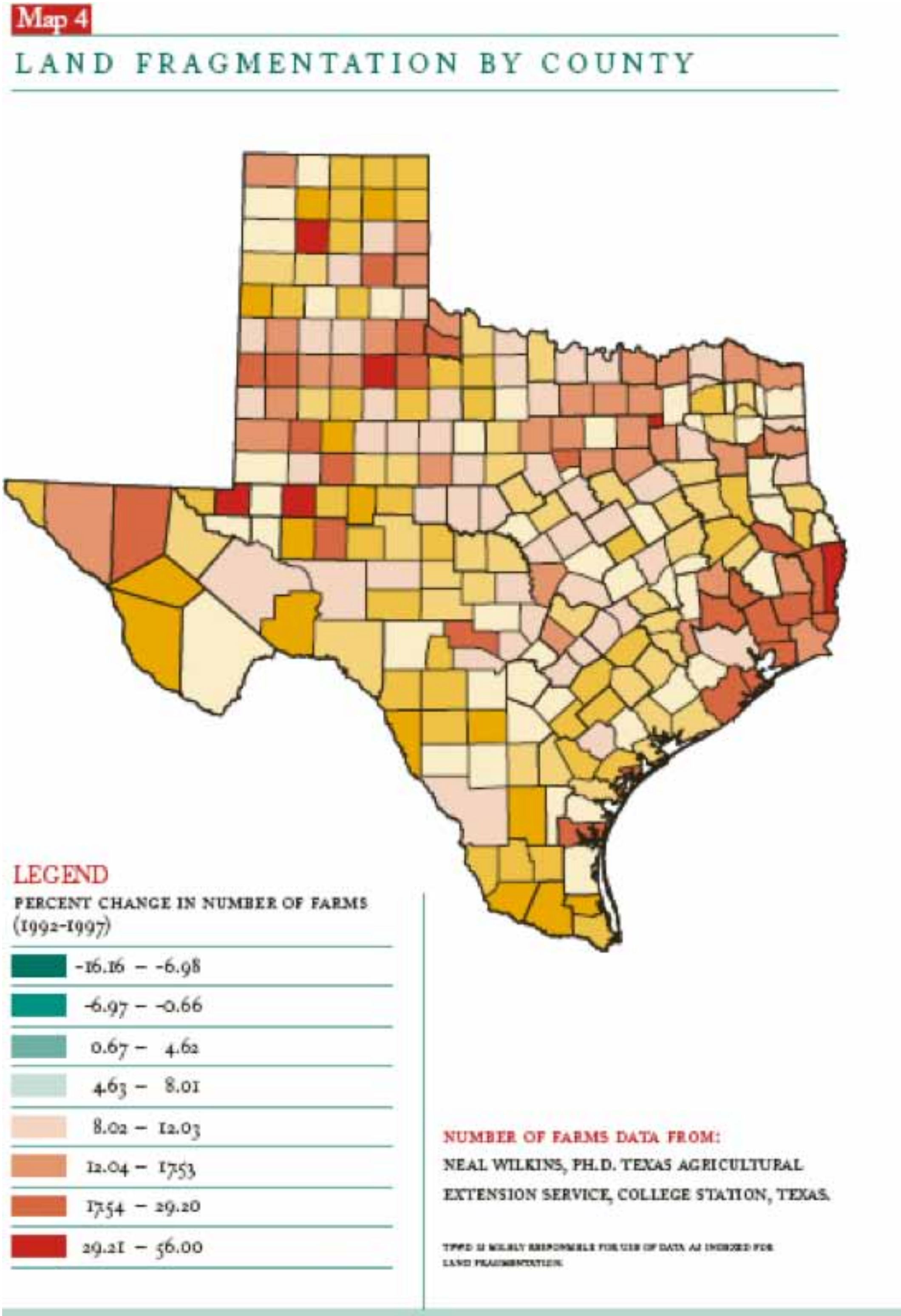

Figure 3.5. Fragmentation map by county of Texas where fragmentation was estimated by the change in the number of ranches over time, division of single parcel into one or more parcels (Texas Parks and Wildlife Department 2005).

Intensity of Human Uses on Rangeland

Description and Importance of the Indicator

This indicator provides a surrogate measure of intensive human uses of rangeland through the use of road density measures and housing densities. Many intensive uses of rangeland are often not represented in land cover maps because of their small individual spatial extents. Examples of these types of land uses of rangeland include low-density rural housing developments, power lines, off-road vehicle (ORV) uses, mines, and oil and gas wells, along with their associated transportation infrastructure. Although these activities have small individual spatial extents, their ecological impacts at both local and landscape scales and their cumulative impacts can be significant (Theobald et al. 1997; Forman and Alexander 1998; Leu et al. 2008). Recent examples of the use of road and housing density measures to examine land-use dynamics include those by Imhoff et al. (2000), Theobald (2001, 2003), Sanderson et al. (2002), Imhoff et al. (2004), Dale et al. (2006), and Radeloff et al. (2010).

The processes of land-use change are reasonably well understood and flow predictably from population growth, household formation, and economic development (Heimlich and Anderson 2001; Leu et al. 2008). Pressures on the interface between rural and urban landscapes are expected to increase from both rural and urban populations (Brown et al. 2005; Hansen et al. 2005; Theobald and Romme 2007). New technology lowers the cost of communication and transportation, resulting in higher land prices farther out into rural areas. As access to urban centers through communication and transportation technology increases, the development value of rural land exceeds the value for agricultural purposes. To adapt to rising land values and increasing contact with new residents, traditional rangeland users may change their operations to fit an urbanizing environment. This may include selling properties for development purposes or discontinuing their activity.

The potential ecological impacts of intensive human uses of rangeland include loss and fragmentation of rangeland, rangeland plant communities, and open space (Theobald et al. 1997), reduced primary and secondary productivity and biodiversity (Forman and Alexander 1998; Imhoff et al. 2004), increased soil disturbance and susceptibility to wind and water erosion (Iverson et al. 1981), disruption of material flows and ecological processes in the landscape (e.g., groundwater flow), fire spread (Forman and Alexander 1998), and enhanced opportunities for successful establishment of invasive plants and animals. The ecological impacts of intensive human uses of rangeland extend beyond the footprints of the land uses and vary with the spatial location and pattern of the intensive land uses (e.g., Leu et al. 2008).

Geographic Variation

Intensive human uses of rangeland are ubiquitous, and, thus, the indicator is meaningful in all geographic areas. Theobald (2003) examined spatial variability in “roadedness” in an assessment of the risk of habitat loss caused by development in Colorado. The proportion of the landscape impacted by roads varied widely among watersheds ranging from a low of 6.1 percent to high of 40.9 percent. The range of “roadedness” was even greater among counties. The relationship between percent roaded and the proportion of public land by county was weak. Three rangeland types, xeric upland shrub, tallgrass prairie, and foothills/mountain grasslands, were identified as threatened by forecasted development in 2020. They concluded that the “roadedness” and housing density indicators were useful for characterizing potential impacts from activities associated with human land use and for prioritizing where conservation efforts would be most effective. Sparsely populated states can be highly fragmented by roads. For examples, 90 percent of North

Dakota's land area is within 0.805 km (0.5 miles) of road, 99 percent is within 3.28 km (2 miles) of a road, and the maximum distance from a road is 4.82 km (3 miles; Fig. 3.6).

Scale in Time and Space

Interpreting "roadedness" and housing density images in the context of rangeland requires a spatially explicit map of rangeland or rangeland vegetation types. The need for such a map is discussed under the "Extent of Land Area in Rangeland" and "Area of Rangeland by Plant Community" indicator sections above and is likely needed by other criteria within the SRR as well. A "roadedness" image could be generated and intersected with a rangeland map, which would allow the amount of roads in rangeland or rangeland types to be calculated and the data aggregated by watershed, county, or other analysis units. Interpretation of the housing density image is more difficult because individual housing units are not spatially-explicit, which prevents determining if specific housing units occur within land designated as rangeland. Alternatively, the proportion of rangeland or rangeland types in different housing density classes (i.e., urban, suburban, exurban, and rural) could be tabulated and aggregated by county (Theobald 2001). Provided road and housing unit data are updated to reflect changes with time, the indicator could be used to examine trends in intensive human land uses of rangeland.

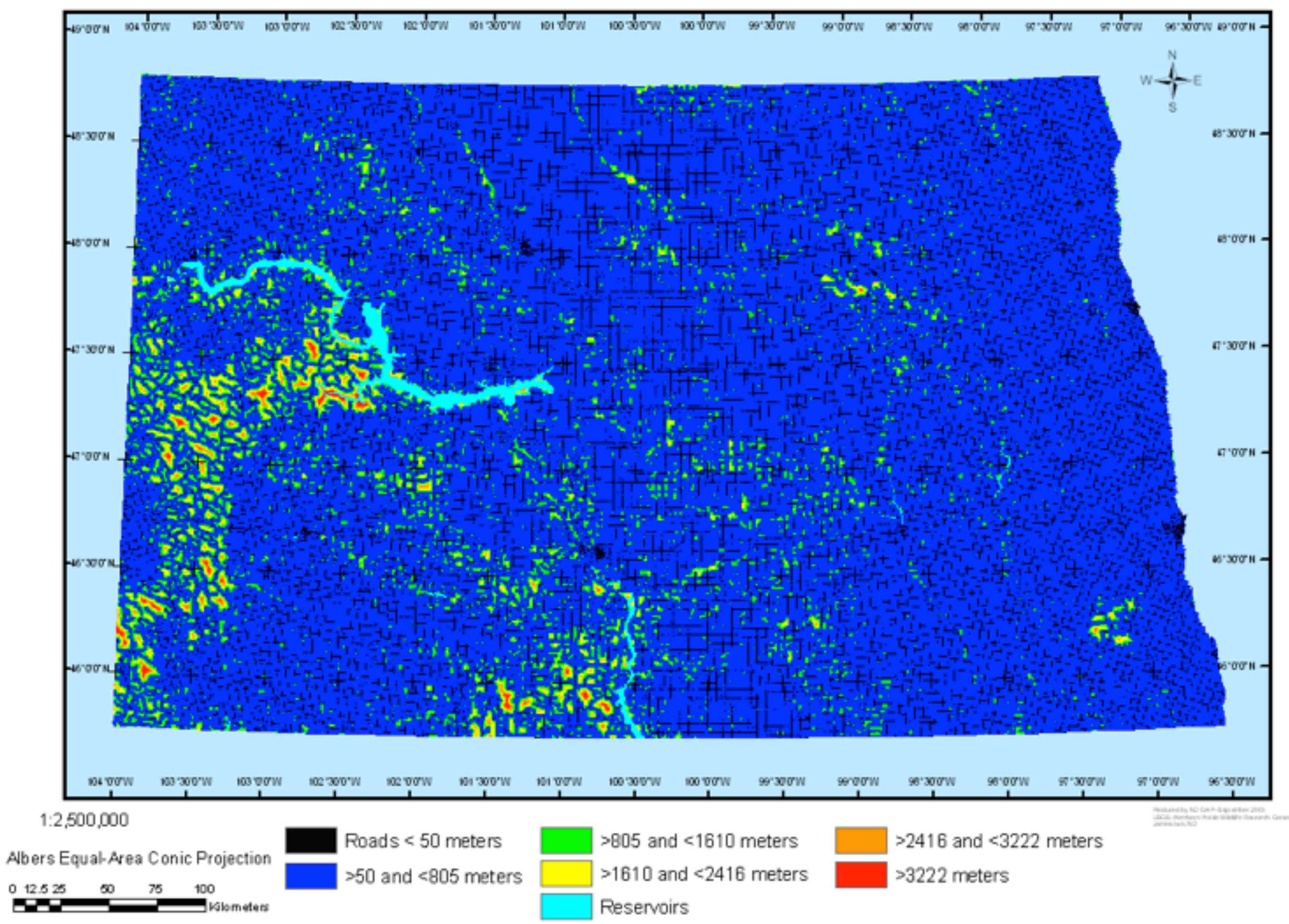

Figure 3.6. Distance from roads and trails in North Dakota. Road data from North Dakota Department of Transportation GIS Base Map Data version 1.0.

Data Collection and Availability

The data currently available for this indicator are best described by A (Table 3.1, Appendix 1-E). Methods and procedures for data collecting and reporting exist at a regional-national level, and data sets of useable quality exist at the regional-national level. This indicator would use digital road and housing data in a geographic vector model format within a GIS to calculate the density and spatial pattern of roads and housing units. Road density (km/km^2) is an overall index that averages patterns over an area. Road effects vary with road width and type, traffic density, location and spatial pattern (Forman and Alexander 1998). Because digital road data are spatially explicit, a "roadedness" image can be constructed that incorporates these factors (Davis et al. 1996; Stoms 2000). A "roadedness" image is constructed by buffering road arcs with a buffer width related to the class of road, e.g., a freeway is given a greater buffer width than an unimproved soil road.

Digital housing data are available for the nation in census block groups and blocks that are subdivisions of the familiar census tract (Theobald 2001). Although the census data are available at a relatively fine spatial grain for the nation, the location of individual houses is not spatially explicit. A housing unit density can be calculated for each polygon (block group and blocks) in the census data. Interpreting the "roadedness" and the housing density images in the context of rangeland requires a spatially explicit map of rangeland or rangeland types (see discussion of the "Extent of Land Area in Rangeland" indicator above). Roadedness, imperviousness, housing, and population density images have also each been derived from the Defense Meteorological Satellite Program (DMSP) night lights digital data (Elvidge et al. 1997; Imhoff et al. 1997; Sutton et al. 1997). The DMSP night lights time series is available from 1992 to 2003 (NGDC 2008).

The U.S. Census Bureau TIGER (Topologically Integrated Geographic Encoding and Referencing) and the National Imagery and Mapping Center databases are the most current sources of national data for roads and housing units. The USGS 1:100,000 scale Digital Line Graphs (DLG) were the initial source used to create most of the transportation lines in the TIGER database. Most of the 1:100,000 scale DLGs were constructed in the 1980s and have not been updated. The U.S. Census Bureau uses various internal and external procedures to update the TIGER database. There are issues with the completeness and location accuracy of the updated TIGER database (U.S. Census Bureau 2002). In preparation for the 2010 census, the U.S. Census Bureau and the USGS initiated discussions about the construction of spatially explicit road and structural data with 7.6 m positional accuracy (Broome and Godwin 2003). If road omissions in the TIGER database are identified as a serious problem, additional road data might be acquired from state departments of transportation, federal agencies (e.g., the USDA Forest Service), and local governments. However, the work required to prepare the road data for analysis would increase substantially. The road data do not provide information about ORV use on rangeland.

Clarity to Stakeholders

Roads and houses are common objects familiar to everyone. Consequently an indicator that presents the density of roads and houses will be understandable to stakeholders and the public.

Integrity of Natural Fire Regimes Across U.S. Rangeland

Description and Importance of the Indicator

This indicator, "Integrity of Natural Fire Regimes," spatially and temporally quantifies acres of rangeland burned annually. Analysis of this indicator requires a nationally accepted standard for reporting fire statistics. Burned acres would be identified annually by both location and season. This is necessary because frequency, intensity, seasonality, and type of fire depend on weather and climate in addition to the ecosystem structure and composition (Dale et al. 2001). Areas of both natural and prescribed (i.e., planned ignition) fires would be tracked.

Fire is a key ecological driver in many rangeland ecosystems, facilitating nutrient cycling, promoting recruitment of native grasses and forbs, and limiting encroachment of woody species. The dynamics of fire in rangeland ecosystems historically varied across the United States in terms of how frequent the fires were, the season that fires occurred, and the intensity and severity of the fires. In the desert grasslands of southwestern United States, highly variable rainfall coupled with a lack of fine fuels may have limited fire (Archer 1994). Regional climatic conditions such as the periodic meso-scale phenomena of El Niño-Southern Oscillation have been correlated with fire occurrence in the more mesic southwestern ecosystems (Swetnam and Betancourt 1990). Across the Central Great Plains, periodic fire was important for maintaining ecosystem structure and function (Engle and Bidwell 2001), and pre-European human management of fire to attract large grazers was an important component in the landscape dynamics there (Biondini et al. 1999). Fire return intervals may have varied from 7 to 30 years across the Great Plains (Brown and Sieg 1996; Perryman and Laycock 2000).

For many rangeland ecosystems, the introduction of domestic grazers, invasive species, conversion of rangeland to cropland, urbanization, fire suppression, and fragmentation of rangeland have significantly altered the natural fire regimes as well as landscape composition and structure (NRC Committee on Rangeland Classification, Board on Agriculture 1994; McPherson and Weltzin 2000; Rueth et al. 2002). Domestic livestock and wild ungulates graze a majority of both private and public rangeland in North America, altering the seasonal patterns of fine fuels availability (live and dead biomass), as well as species and physiognomic composition of vegetation on the landscape (Washington-Allen 2003). In many southwestern ecosystems with a history of frequent fire, the removal of fine fuels (grasses and forbs) by livestock and the resulting increase in bare ground caused a greatly extended fire-free interval (e.g., Savage and Swetnam 1990; Madany and West 1983).

In Texas, a combination of factors (reduced grass cover, fewer fires, a reduction in available moisture in the topsoil, and a change in rainfall patterns) over the past 100 to 200 years resulted in a shift from savanna with only scattered trees to a subtropical thorny woodland (Archer 1989). Throughout much of the Intermountain West, fire return intervals have decreased as a result of the livestock-facilitated invasion of cheatgrass. Because native sagebrush steppe communities do not have long evolutionary grazing histories of domestic livestock, do not survive the frequent fires facilitated by cheatgrass, and do not disperse effectively, the system moves toward a cheatgrass monoculture devoid of biodiversity or economic value (West and Young 2000). Indeed, the large majority of the West's arid rangelands have fire regimes that have been significantly altered from their natural patterns.

Because fire is such a dramatic disturbance, changes in its frequency or intensity results in significant changes in nutrient cycling, species richness, ecological integrity, and carbon stocks. Monitoring the integrity of fire regimes promises to significantly inform evaluations of rangeland health.

Geographic Variation

The areal extent of fire in rangeland ecosystems would be meaningful in different regions. Understanding the implications of changes in the area of rangeland annually burned will also require an understanding of the role of fire in different ecosystems. The role of fire would vary in rangeland ecosystems across the United States.

Scale in Time and Space

The areal extent of rangeland burned on an annual basis is available from a variety of sources (see below) and can be analyzed across both spatial and temporal scales. Changes in a fire regime, either in frequency or severity, can result from both natural (e.g., climate) and anthropogenic sources (e.g., grazing management, fire suppression). As a result, measures of change in a fire regime reflect important ecological changes at multiple scales ranging from sites to regions. However, changes in fire regimes must be interpreted with respect to the plant community being described and the spatial scale at which it is mapped. Past attempts to map changes in fire regimes have been spatially coarse and have not allowed for the analysis of separate, smaller community types.

Data Collection and Availability

The data currently available on acres burned are best represented by C and D (Table 3.1, Appendix 1-E). Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. Information on the precise location and season of fires are metrics that are conceptually feasible or initially promising, but no regional-national methods, procedures, or data sets currently exist.

Wildfire statistics are available through the National Interagency Fire Center (NIFC) at national and state levels over periods ranging from 1983 to 2009; however, fine spatial scale information on the historical fires is not available (http://www.nifc.gov/nicc/index.htm. Accessed 30 January 2010). Coarse-scale, national-level data on fire occurrence were developed for the 1986-1996 period (Schmidt et al. 2002). The national fire occurrence database includes spatial layers of federal and non-federal fire occurrences, as well as vegetation layers (Kűchler vegetation as well as current vegetation). Acres of fires within rangeland types could be assessed and mapped using such a system. However, these data represent a one-time coarse-scale assessment and mapping effort funded by the USDA Forest Service and the BLM, where data from several federal agencies and state agencies were compiled to produce a geographic information database (see also Brown et al. 2002). Schmidt et al. (2002) note that there are several potential problems with the fire occurrence data set, such as missing records, duplicate fires where the same fire may have been reported on federal and on non-federal lands, approximate locations of fires where county was the finest spatial identifier, and unreported fires. The most appropriate use of such an occurrence data set, according to the authors, is in illustrating trends in fire occurrence. Bartlein et al. (2008) used the database to assess the temporal and spatial structure of wildfires across the western United States. A national standardized reporting method is needed for all jurisdictions so that fire reporting at the national level can be dependable and consistent.

LANDFIRE, also known as Landscape Fire and Resource Management Planning Tools Project, is an interagency mapping project producing nationally consistent and comprehensive maps and data of vegetation, fire, and fuels characteristics (http://www.landfire.gov/index.php. Accessed 2 February 2010). Partners include the USDA Forest Service and the USDI. The principal purposes of the LANDFIRE Project are to: 1) provide national-level, landscape-scale geospatial products to support fire and fuels management planning, 2) provide consistent fuels data to support fire planning, analysis, and budgeting to evaluate fire management alternatives, 3) provide landscape-scale, cross-boundary strategic products for fire and land management activities, 4) supplement planning and management activities, including monitoring, that require consistent vegetation data, 5) supplement strategic and tactical planning for fire operations, and 6) supplement and assist in a variety of activities such as the identification of at-risk areas due to accumulation of wildland fuel, the prioritization of national hazardous fuel reduction projects, and modeling of real-time fire behavior to support tactical decisions to ensure sufficient wildland firefighting capacity and safety . LANDFIRE has produced geospatial data products that describe existing vegetation composition and structure, potential vegetation, historical fire regimes, and fire regime condition class (FRCC). Vegetation and disturbance dynamics models are used to simulate the historical vegetation reference conditions, and FRCC is the amount that current vegetation has departed from the simulated historical vegetation reference conditions (Rollins et al. 2006, 2007). Such information may provide insights into changes in fire regimes across the U.S., particularly as the information is updated over time.

Other methods of establishing acres burned annually are being developed. For example, using data from the MODIS project on NASA's TERRA satellite, scientists at the Goddard Space Flight Center are mapping fire activity worldwide (Kaufman et al. 1998). These data have been available since February 2000, can be summarized at a variety of geographic scales, and can be used to explore frequency and extent of fires (Fig. 3.7). Pu et al. (2007) used the Advanced Very High Resolution Radiometer (AVHRR) instrument to map fires on forest lands in North America. With additional information collected over time, these methods may begin to establish the spatial records of fire on rangelands. Eidenshink et al. (2007) reported on a six-year project whereby the Forest Service and USGS began mapping and assessing the burn severity for all large current and historical fires beginning in 1984. "Large" is defined as greater than 500 acres in the east and 1,000 acres in the western U.S. Landsat data will be used to assess burn severity and map the areal extent of the fire. As the fires are mapped, data become available on the web (http://www.mtbs.gov/. Accessed 20 April 2011). The intent of the project is to provide local, state, and federal land managers with information to evaluate the effectiveness of land management decisions and to establish a baseline from which to monitor the recovery and health of fire-affected landscapes over time (Eidenshink et al. 2007).

Clarity to Stakeholders

Total area burned is a concept readily understood by the public. Recent attention to large wildfires in the western U.S. has raised the level of discussion about the role of fire in ecosystems, but the importance of other measures (e.g., frequency, seasonality, severity, and intensity) are less well understood.

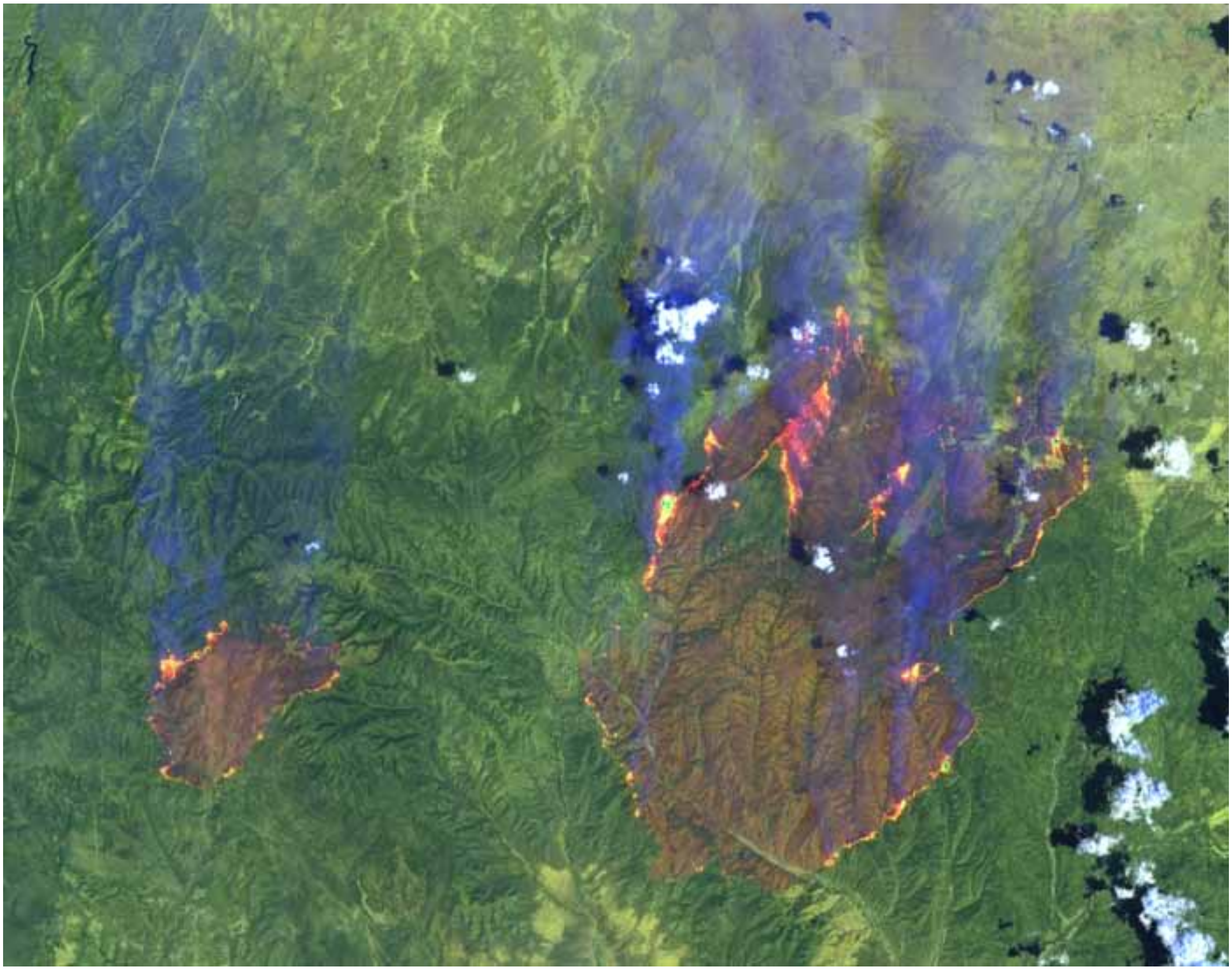

Figure 3.7. Area of Rodeo-Chediski Fire in Arizona on 28 June 2002, 18:06 UTC, identified using Landsat 7 ETM+ at 28 m resolution. From http://veimages.gsfc.nasa.gov//2936/Az_fires752.L720020621_lrg.jpg downloaded on 4 October 2010.

Extent and Condition of Riparian Systems

Description and Importance of the Indicator

This indicator measures the extent and condition of riparian plant communities along rivers and streams on rangelands. This indicator is separate from the "Number and Extent of Wetlands" indicator in that most riparian systems do not have all three attributes of a wetland (hydrophytic vegetation, hydric soils, and inundation frequency), and riparian systems have several distinct functions because they are primarily associated with lotic water in rivers and streams. This indicator is not a vegetation classification indicator but rather an indicator of vegetation condition or status regardless of composition.

The indicator will measure the status or condition of riparian vegetation on a linear basis measured in kilometers for 1st to 6th order streams within the rangeland regions. The status or condition may be evaluated on a quantitative basis using a numeric value. Possible numeric values could include a metric similar to the Index of Biotic Integrity (IBI) (Karr 1995), a hydrogeopmorphic (HGM) index (Brinson 1993), or a qualitative evaluation with a descriptor such as "fair condition" (e.g., Proper Functioning Condition [PFC]). No metric similar to the IBI has been thoroughly developed and tested, although several riparian researcher teams are working to create one that is ecologically-based and includes geomorphic, hydrologic, and biotic parameters. The HGM index is complex and has been applied to riparian areas only on a case-by-case basis. PFC is used by several agencies to evaluate riparian and stream bank conditions (Proper Functioning Condition Work Group 1993, 1994). By necessity, PFC depends on subjective evaluation by different personnel and is primarily based on physical parameters, which may limit its applicability on a national comparative basis. A quantitative index of condition built upon the concepts of PFC with more ecological parameters could perhaps become a measurement acceptable to most resource managers. When developed, an index score or indicator value (e.g., good or poor) will be applied to numbers of miles (or kilometers) of riparian community within a region. Riparian ecosystems respond to the "funnel effect" of changes in the associated upstream watershed. They respond readily to land use in adjacent floodplains but are very resilient and recover readily if perturbations are removed (Patten 1998). Riparian areas also function as buffers between the upland and the stream, helping to maintain water quality. They also control flood magnitudes and trap suspended sediment, altering channel configurations. Riparian ecosystems are used as habitat by a high percentage of animals for all or some portion of their life cycle and are known for supporting high biodiversity (Naiman et al. 1993). Consequently, sustainability of a watershed and all its components, including rangelands, can be evaluated in part through the condition of the riparian ecosystems within that watershed.

Geographic Variation

Riparian systems occur wherever there are streams and rivers. These systems tend to be linear, that is, following the course of the river, and are formed and maintained by similar hydrogeomorphic and biological processes throughout their range (Patten 1998; Scott et al. 1996). Consequently, an indicator metric or index developed for one region of the United States will be applicable to other regions.

Scale in Time and Space

Riparian systems can be related to watersheds, which can be aggregated into larger hydrological units. Measurements of riparian condition can be made locally or aggregated and evaluated on a larger scale such as a particular national forest, BLM unit, or region. The indicator relates to a system that is linear and characterized by disturbance (e.g., flooding). The temporal scale of riparian disturbance and resilience is normally within decades, and this is commensurate with the linear extent of the system, which is tens to hundreds of miles (or kilometers).

Data Collection and Availability

The data currently available for this indicator are best represented by C (Table 3.1, Appendix 1-E). Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. Several protocols exist that may be used on a local basis, e.g., the HGM index developed by U.S. Army Corps of Engineers (Brinson 1993; Smith 1993; Smith et al. 1995). Some protocols are generally used by several resource management agencies (e.g., PFC). The subjective nature of these data (e.g., PFC used by BLM and USDA Forest Service) could result in inconsistencies when aggregated and implemented at regional or national levels.

Clarity to Stakeholders

The importance of riparian systems is becoming more apparent to concerned stakeholders as issues with urban and agricultural intrusion into riparian buffer strips are often brought before city, county, and state planning entities. Riparian areas are also widely used by the public for recreational purposes, and the public recognizes their importance in maintaining the quality of rivers.

Area of Infestation and Presence/Absence of Invasive and Non-Native Plant Species of Concern

Description and Importance of the Indicator

Invasions of non-indigenous species can threaten native biodiversity, ecosystem functions, animal and plant health, and human economies (Carey 2003; Pimentel et al. 2005). Plant invasions are a serious threat to natural and managed ecosystems. The number of species involved and the extent of existing invasive species renders the problem almost intractable with the likelihood of the problem worsening in the future (Hobbs and Humphries 1995; Prentis et al. 2008; Crossman et al., in press). The optimal solution regarding invasive and non-native species is to prevent the introduction of these species into the ecosystem. However, in many rangeland situations, this option has already been lost, and a system must be developed to manage invaded areas, monitor exotic organisms, and attempt to minimize their impacts on other ecosystems. The proposed indicator is designed to track the area of infestation and the presence or absence of invasive or non-native species on rangeland over time. This information should help land managers to develop strategies to address the problem.

Biological invasions can be defined as the introduction, establishment, and spread of species outside their native range (Richardson and Pyšek 2006). Globally, "introduced species" are present in biological and geographic regions where they have not evolved and where they may be inadequately suited, but where potential exists for rapid adaptation (Richardson and Pyšek 2006; Facon et al. 2006; Novak 2007).

Invasive species typically have high reproductive rates, fast growth rates, and dispersal mechanisms that allow for swift movement across landscapes. Overall, these species have developed evolutionary-based adaptations that provide an added advantage in competing with other species (Prentis et al. 2008). Other non-native plant species, not officially defined as noxious or invasive, can also share some of these traits and can alter the functioning of rangeland ecosystems in ways similar to invasives. Hence, non-native species of concern are included in this indicator to be used at the discretion of those monitoring rangeland systems. Their inclusion provides the opportunity to monitor them through the indicator and to measure potential impacts they may be having on native rangeland systems. The implementation of this indicator requires that stakeholders define which species are to be monitored for their region. These species may be in addition to the federally designated species of concern in rangeland systems.

The indicator measures the area of infestation (acres/hectares) of identified invasive plant species to track their progress within the rangeland landscape over time. The areas of infestation can be inventoried or monitored at the county level and be scaled up to the state, regional, and national level. In association with the monitoring of infestation area, one could also develop a database that determines the presence or absence of an invasive or non-native species at both the state and county levels. This information would allow for efficient mapping to track the movement of identified species. Ultimately, the indicator can be used by policymakers and managers to monitor changes in the abundance and distribution of invasive or non-native species and make determinations on how to manage the species in question.

Invading nonindigenous species in the United States cause major environmental damages and losses adding up to more than $100 billion per year (Pimentel et al. 2000). There are approximately 50,000 foreign species in the U.S., and the number is increasing (Pimental et al. 2005). About 42 percent of the species on Threatened and Endangered lists are at risk primarily because of non-indigenous species (Pimentel et al. 2000). Invasive plant species make up approximately 10 percent of the 50,000 non-indigenous species in the U.S. that have escaped into natural systems (Morse et al. 1995). Non-indigenous, "weedy" species are spreading and invading approximately 700,000 ha/yr of U.S. wildlife habitat (Babbitt 1998). The 700,000 ha/yr of habitat refers only to wildlife habitat that is being lost. The total area of infestation due to invasive plants is much higher. Current rates of infestation on rangeland are increasing at approximately 14 percent per year (USDI BLM 1996). It is estimated that 100 million acres of land are moderately to heavily infested with non-native grasses such as cheatgrass, red brome, and medusa head (Westbrooks 1998).

One example of an invasive plant that is having significant impacts on natural ecosystems is purple loosestrife (*Lythrum salicaria*). Purple loosestrife, introduced in the early 19th century as an ornamental plant (Malecki et al. 1993), changes the basic structure of most of the wetlands it has invaded (Thompson et al. 1987) through altered decomposition rates and nutrient cycling and reduced wetland plant diversity and habitat suitability for specialized wetland bird species (Blossey et al. 2001). This plant alone is able to reduce critical habitat impacting 44 native plants and endangered wildlife species that rely upon native plants for survival (Gaudet and Keddy 1988). Loosestrife now occurs in 45 states (USDA Plants 2009). Other non-native grasses (*Aegilops cylindrical* – jointed goatgrass; *Bromus japonicas* – Japanese bromegrass, *Echinochloa crusgalli* – barnyard grass, etc.) have altered historical fire regimes in the Great Basin and at Hawaii Volcanoes National Park (Mack and D'Antonio 1998). Salt cedar (*Tamarix chinensis*, *T. parviflora*, and *T. ramosissima*) was introduced as an ornamental in the early 1800s and has spread into nearly every riparian community of the desert Southwest. Dense stands of salt cedar release salt accumulation from their tissues and make the site unsuitable for native species (Westbrooks 1998). Invasive species also have economic impacts on rangeland economic value and enterprise net returns (Masters and Sheley 2001).

"Healthy ecosystems" are often considered to be highly diverse. A system can have a high biological diversity but lack biological integrity if a number of exotic species make up a large proportion of the diversity (Karr and Dudley 1981). Ecosystem health can be assessed by the normality of the linked processes and functions that constitute ecosystems (Rapport 1995) and defined in terms of vigor, resilience, and organization (Mageau et al. 1995). A sure way to maintain ecosystem health is to maintain biological integrity (Karr 1995). The opposite is not necessarily true, however. Inclusion of multiple or even a single exotic species can influence the ecosystem functions and processes to the point that biological integrity can be lost and ecosystem health can be diminished.

Geographic Variation

The proposed indicator is meaningful throughout all regions of rangeland systems and could be integrated across regions to provide a national-level metric and standardized monitoring program. Many methods could be used to standardize the metric. One easy method would be to focus on the taxonomic relationships of the invasive or non-native plants. In such a manner, similar species could be tracked and compared across multiple scales. For example, plant species in the Poaceae family could be tracked together to determine the problems associated with invasive or non-native grasses both locally and at the regional to national scale. This arrangement could eliminate the comparison of "apples to oranges" in the plant world. Focusing on taxonomic criteria would allow distinct strategies to be developed for various problem species (grasses, forbs, shrubs, trees, etc.).

Scale in Time and Space

The indicator can be scaled from the local and county level up through the state, region, and national levels of reporting. County-level monitoring would most likely be used (and is being used) to develop a national database. The use of area as a monitoring metric allows for quantification across counties, states, and throughout the nation. Presence or absence is a measurement that could be used to develop maps and to track the plants at county and state levels. The presence or absence designation is not designed to implicate an area as "invaded" if only one or two plants are in a county. Instead, the presence or absence portion of the indicator is designed to monitor where problems have the potential to increase.

Data Collection and Availability

The data currently available for this indicator are best represented by C (Table 3.1, Appendix 1-E). Some data set(s) exist at the regional-national level, but methods and procedures are not standardized at the regional-national level. At this time, there are a multitude of invasive species databases (Table 3.7, Fig. 3.8). Several of these provide distribution information at various scales; however, most of them only include a list of the species. In order for data to be meaningful at a regional to national level, an effort would need to be made to develop a national framework of data collection similar to the FIA or NRI. At the very least, a set of national data standards and a consistent list of species should be developed that would allow data to be aggregated up from some common local level (e.g., county). At this time, an effort to standardize collection and analysis of invasive species information is being developed. According to Rita Beard, Invasive Species Coordinator, NPS, Fort Collins, CO (personal communication), a multi-agency task force is developing a scale-sensitive standardized monitoring system that is planned for implementation within the next five years.

Table 3.7. Selected invasive plant species databases (adapted from http://www.invasivespecies.gov).

Database name	Database host
APHIS Regulated Plant List http://www.invasivespecies.org/NewInitiatives.html	U.S. Department of Agriculture, Animal and Plant Health Inspection Service
Aquatic, Wetland and Invasive Plant Information Retrieval System (AIRS) http://plants.ifas.ufl.edu/	University of Florida, Center for Aquatic and Invasive Plants with Bureau of Invasive Plant Management, Florida Department of Environmental Protection Aquatic Plant Control Research Program, U.S. Army Corps of Engineers
CalWeed Database http://endeavor.des.ucdavis.edu/weeds/	California Department of Food & Agriculture; California Interagency Noxious Weed Coordinating Committee; Bureau of Land Management; University of California-Davis
Exotic Plant Database (The Florida Exotic Pest Plant Council [Florida EPPC]) http://www.eddmaps.org/florida/	Florida EPPC; Florida Department of Environmental Protection's Bureau of Invasive Plant Management
Federal and State Noxious Weeds in GRIN (Germplasm Resources Information Network) http://www.ars-grin.gov/npgs/html/taxweed.pll	U.S. Department of Agriculture, Agricultural Research Service, National Genetic Resources Program
Federal Noxious Weeds Database http://www.invasivespecies.org/fedweeds.html	U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology
Global Compendium of Weeds http://www.hear.org/gcw/	U.S. Geological Survey, Hawaiian Ecosystems at Risk project (HEAR)
Global Invasive Species Database http://www.issg.org/ http://gisp.org/ Document7	Invasive Species Specialist Group (ISSG); Global Invasive Species Programme (GISP)
Hawaiian Ecosystems at Risk (HEAR) http://www.hear.org/	U.S. Geological Survey; University of Hawaii
Invasive and Exotic Species of North America – Invasive.org http://www.invasive.org/	A joint project between The University of Georgia – Bugwood Network and the USDA Forest Service
INVADERS Database http://invader.dbs.umt.edu/	University of Montana
Invasive Plants Atlas of the United States http://www.invasive.org/weedus/index.html	
USDA National Invasive Species Information Center http://www.invasivespeciesinfo.gov/plants/databases.shtml	General Database
USDA National Invasive Species Information Center http://www.invasivespeciesinfo.gov/plants/pubs.shtml	Publications
North American Weed Management Association http://www.nawma.org/	

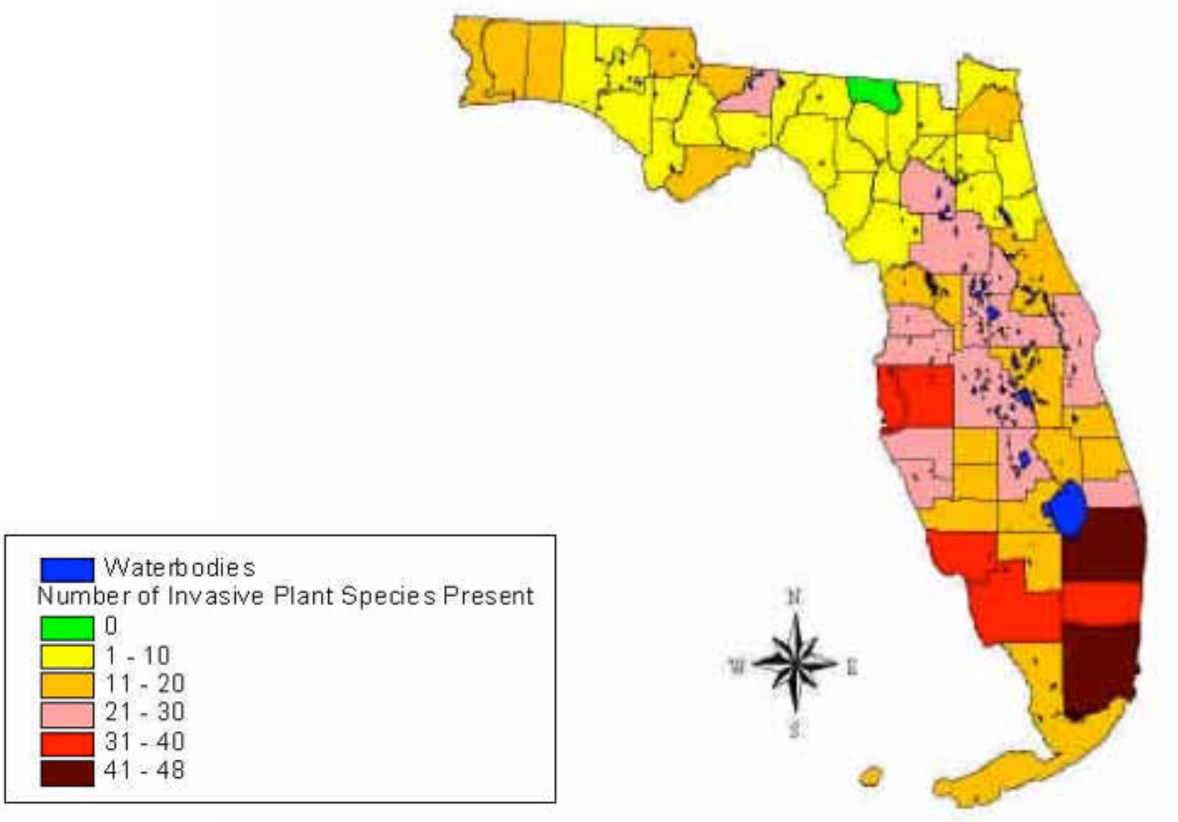

Figure 3.8. Example output from Florida Exotic Pest Plant Council's Exotic Pest Plant Database (http://www.eddmaps.org/florida/).

A standardized mapping procedure is also being proposed for each entry into the national-level data system (North American Weed Management Association 2002). Also, a National Early Warning and Rapid Response System for Invasive Plants in the United States has been proposed (FICMNEW 2002).

The University of Montana has developed the INVADERS database, which is a comprehensive database of exotic plant names and weed distribution records for six states in the Pacific Northwest (University of Montana 2008). Within this database, the spatial and temporal spread of weeds can be displayed using information on the historical distribution of the species. The database also contains a listing of all noxious weed species in the United States. The design structure is such that the database could be expanded to cover additional areas in the United States. Weed managers are invited to cooperate.

For the purpose of this indicator, the working group does not intend to develop a threshold value of area of infestation within an ecosystem. This will require local stakeholders to develop the levels to be monitored. The value of the indicator would be in the periodic resampling of the metric to develop trend data showing spread or decline of invasive or non-native species. The metric should be established to be repeatable, reliable, and accurate over time.

There are many potential uncertainties that have to be addressed in the development of a comprehensive invasive plant database program. These include, but are not limited to, misidentification of specimens, presence versus population estimates, irregularities in data collected, etc. The North American Weed Management Association (2002) is addressing these and other standardizing factors that could be used to reduce the level of uncertainty in the development of a national invasive database system.

Clarity to Stakeholders

Through a multitude of educational efforts, the impacts of invasive and non-native species are becoming increasingly well understood by the public. However, it will be necessary to continue educational activities to increase awareness and provide further understanding. The indicator itself is fairly straightforward and should be understood by the public.

Number and Distribution of Species and Communities of Concern

Description and Importance of the Indicator

This indicator measures the numbers and geographic ranges of rare or “at-risk” species that occupy rangeland habitats for a significant portion of their life cycle, as well as the presence and extent of rangeland plant communities of concern. Trends in the number of at-risk species and communities help identify potential loss of historical and natural rangeland ecological functioning, as well as the loss of associated values and benefits. This indicator is analogous to the “canary in the coal mine” when measuring ecosystem stress.

This indicator is related to the “Rangeland Area by Plant Community” indicator. Rare and at-risk communities will be identified in that indicator but are also included in this indicator because of the legal and biological importance of rarity and threatened status.

This indicator measures the number and geographic ranges of at-risk species and plant communities. Species of concern include those identified by TNC at the G1, G2, or G3 level, species listed under the Endangered Species Act or identified as candidates for listing, or species otherwise identified as being at risk, e.g., International Union for Conservation of Nature (IUCN) categories. Communities include those identified as G1, G2, or G3 by TNC, as well as those identified by other organizations such as the World Wildlife Fund (WWF 1999).

There are several metrics that could be used to describe the indicator. For species, metrics include the number of species, the number of populations per species, the abundance (number of individuals) per population, and the geographic range. For communities, metrics include the presence and number of at-risk communities, the number of stands of each community, the size of the stands, and the geographic range of the community.

The concept of at-risk communities is less well-defined in the ecological literature than at-risk species. “Plant community” is defined in the “Rangeland Area by Plant Community” indicator section above. At a coarse scale, TNC community-level measure of rarity (G1-G5) can be used, as it is well defined and widely applied. Areal extent (e.g., hectares or km^2) is also relatively easy to determine. The status of particular stands is more difficult to determine. Loss of native species, spread of exotics, and changes of ecosystem-level attributes such as nutrient cycling or pollination function could be used but are not currently well-defined or standardized.

An increasing number of at-risk species or communities, or a decline in their ranges, generally indicates regional or landscape-level ecosystem instability or degradation and the potential loss of critical components to maintain ecosystem function. The number of at-risk species or communities in a region is not as responsive an indicator as some other indicators because a species or community is probably in serious trouble before it becomes recognized or listed as threatened. It should be viewed more as a trailing than a leading indicator of ecosystem stress. Population demography or community-level functional attributes are more responsive measures but are more difficult to obtain than simple counts of species and communities.

Geographic Variation

Measures of the numbers of at-risk species and plant communities can be easily aggregated and compared among areas. However, as larger areas and more complex biomes are likely to have more species and communities, including rare and at-risk species, the numbers of at-risk species and communities should be considered relative to the total number of rangeland species and communities. In order for comparisons to be meaningful, the metrics used to describe conservation status should be uniform across taxonomic groups and between regions. Metrics and assessment tools developed by the FWS, TNC, NatureServe, WWF, and the IUCN are recommended as they are widely used and are applicable to U.S. rangeland.

Scale in Time and Space

The distribution of at-risk species and communities at the landscape level is generally patchy. However, the basic metrics are generally scale independent and can be aggregated from the local (county) and regional (state) levels to the national level. This indicator will also be comparable over time, if the criteria and assessment methods do not change.

Data Collection and Availability

The data for this indicator are best characterized as A (Table 3.1, Appendix 1-E). Methods and procedures exist for data collecting and reporting at a regional-national level, and data sets of useable quality exist at the regional-national level. There are extensive data available on at-risk vertebrate and vascular plant species and many plant communities at the local, state, ecoregional, and national levels. Most federally listed species will have either recovery plans or other documents that indicate status and distribution (USDI FWS 2010c). Other at-risk species and community data are available through state-level heritage programs, TNC, and NatureServe. These programs include data on both population locations and often species and community status. However, data are scarcer for some vertebrate groups (e.g., fish, small mammals, reptiles) than they are for large mammals and birds. Generally, much less is known about other taxonomic groups, such as lichens, bryophytes, invertebrates, fungi, algae, and bacteria. The identification and description of rare plant communities is at an earlier stage of development than for species. However, TNC, NatureServe, and WWF have attempted designations of rare communities. Some states also have relatively detailed community classifications and status. For example, the California Native Plant Society has published a list of plant communities at the alliance level, and it includes information on their status within the state (Sawyer and Keeler-Wolf 1995)

Although subjective judgment is often used in determining rarity, there are guidelines and extensive research available that can make these indicators both repeatable and reliable. Vascular plants and vertebrate animals have received closer scrutiny than other species, and charismatic species sometimes receive special emphasis, increasing the bias and decreasing the accuracy of the indicator. However, the numbers and ranges of at-risk species and communities remain valid despite these concerns because they measure the potential loss of critical rangeland components.

Clarity to Stakeholders

The concept of threatened and endangered species and communities is understood, and it forcefully communicates threats to rangeland sustainability. Almost everyone is familiar with endangered species through news reports. The concept of rare plant communities is understood in a very general sense by the public (e.g., loss of tropical rainforests), but a more detailed understanding is not widespread.

Population Status and Geographic Range of Rangeland-Dependent Species

Description and Importance of the Indicator

This indicator measures the population levels (abundance) and the current geographic ranges of rangeland-dependent plant and animal species, monitored across their known range. Species should be dependent on rangeland for most if not all of their life cycle, i.e., permanent residents. One cannot generally use the population level or range of one species to reliably infer traits about another species, so single species are not always useful as representatives of other species or communities. However, it is not possible to monitor the population levels and ranges of all species of animals, plants, and microorganisms, so some species must be selected for monitoring. If the selected species include keystone species and those that are sensitive to particular threats, such as overgrazing, irreversible soil erosion, or fire, and if the species are diverse with respect to their taxonomy, habitats, trophic levels, ranges, and life strategies, the indicator will have a higher likelihood of detecting trends in range ecosystems.

This indicator measures population levels (abundance) of rangeland-dependent species and the geographic area of their current ranges (Fig. 3.9). This indicator combines elements of the Montreal Process forest indicators 6, 8, and 9 (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests 1995). To a certain extent, it also measures genetic diversity on rangeland (for an alternative view see Flather and Sieg 2000). A reduction in the geographic range of a species often results in the loss of subspecies and locally adapted populations. It is a leading indicator of ecosystem stress and will respond to impacts before the indicator measuring the number of at-risk species. Stressed species will likely exhibit the stress through reduced population sizes, reduced geographic range or both, which will be detected by this indicator.

Rangeland-dependent species include widespread common plants and animals such as big sagebrush (*Artemisia tridentate)* or greater sage-grouse (*Centrocercus urophasianus*), or species from particular kinds of rangeland, such as saguaro cactus (*Carnegiea gigantea*) in the Sonoran Desert. Species may be categorized as umbrella, keystone, or guild indicator species (Landres et al. 1988; NRC 1986). The species thus categorized can indicate one of three factors: levels of contaminants in an ecosystem, changes in other species in the same guild, or changes in habitat quality that affects other species as well. An alternative to the use of particular species is to use community-level or ecosystem processes such as trophic relationships or species diversity as indicators of ecosystem function (Launer and Murphy 1994; Williams and Gaston 1994). The selection of the kinds of species or community-level attributes to measure is problematic for a variety of reasons (Landres et al. 1988). In the case of either species or ecosystem functions, ecological theory does not have the ability to precisely define the nature or quantity of species or community responses needed to maintain all the native elements of a regional biota or landscape.

At the species level, two terms are widely used: “indicator species” and “umbrella (keystone) species.” Indicator species are those that are representative of a particular ecological guild, trophic level, or ecosystem function. Indicator species do not necessarily have direct interactions or causal relationships with the species or groups they are supposed to represent. Umbrella or keystone species are over-arching species that need to exist in a community for a variety of other species to be present and persist as well. Implied in this are more direct causal linkages between an umbrella species and other species. For example, the presence of breeding woodpeckers in forested communities, through their propensity for cavity excavation, allows the presence of a wide variety of secondary cavity-nesting species. Another well-known indicator is the prairie dog, which is a keystone species because of its abundance and colonial and burrowing instincts. Many other rangeland species depend on the existence of the prairie dog colonies, such as black-footed ferrets, burrowing owls, and various plants, raptors and reptiles. More recently, Lambeck (1997) introduced the term “focal species,” defined as a multiple-species umbrella. He provides a conceptual model for selecting focal species. Although his emphasis was on rare and declining species in fragmented habitats, the method is also applicable to more common species.

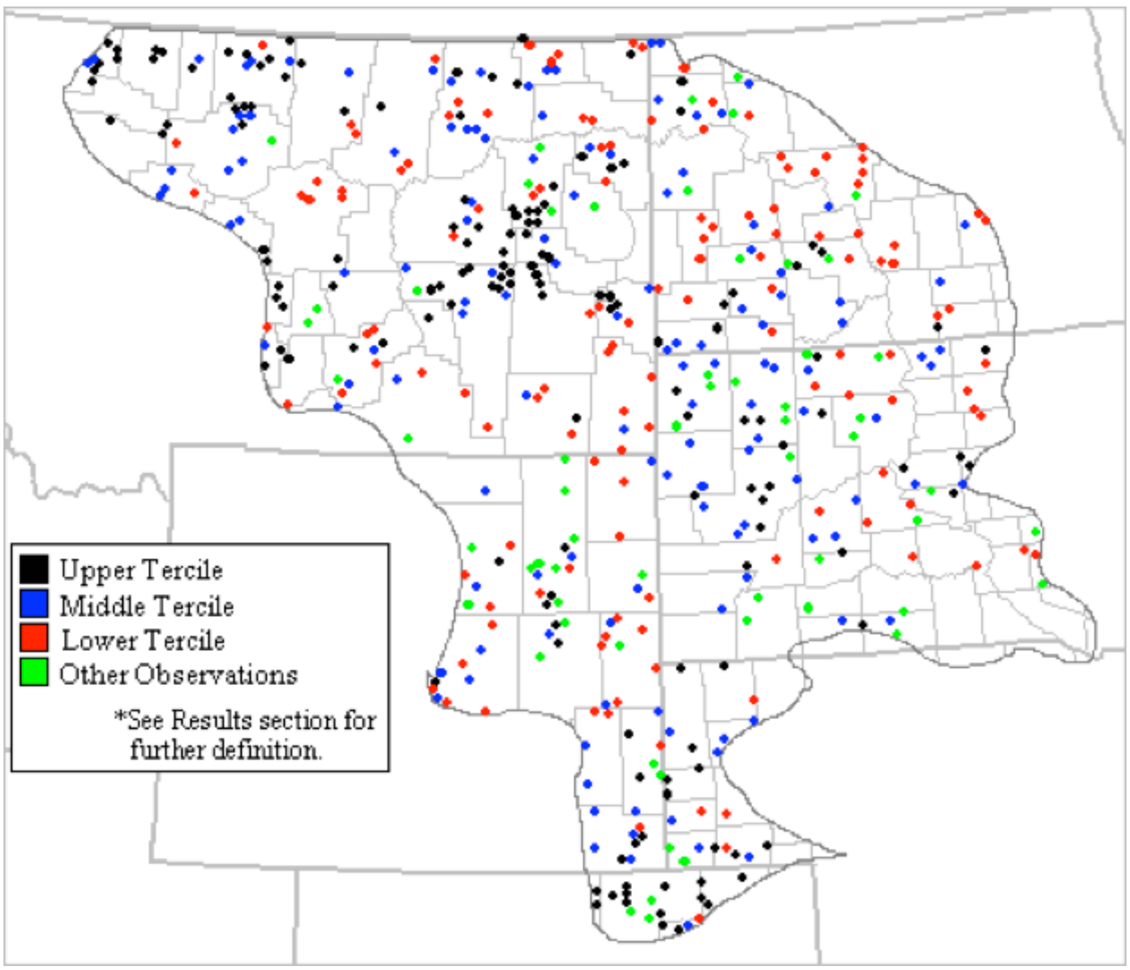

Figure 3.9. Population status and geographic range, breeding distribution of horned lark, a species dependent upon rangeland habitat in northern Great Plains. Source: Kantrud (1982).

Landres et al. (1988) point out the many pitfalls in using guild indicator species, suggesting that the method should be abandoned. If a species is to be used as an indicator of habitat change or quality, it must have a demonstrated relationship with the habitat attributes of interest. Because of the complex and multiple causality in natural ecosystems, it may prove difficult, if not impossible, to find a species that can be used to indicate habitat quality for any other species or group. Because of these problems, this indicator focuses on types other than guild indicator species and includes both "typical" representative rangeland-dependent species and umbrella species that are critical for maintaining subsets of a regional rangeland biota. Recognizing that we cannot monitor all species, some species selection is necessary. Careful selection of species can increase the likelihood of detecting threats to sustainability, but we cannot claim that the selected species are indicator or representative species.

Geographic Variation

Because of the wide diversity of vegetation on rangelands, any regionally-restricted rangeland species will not be a useful indicator outside the regional level (e.g., ecoregion or province). This makes it difficult to compare groups of species across various regions and at the national level, but trends in range and abundance can be compared in the abstract across regions and at the national level. For example, is there a widespread decrease in rangeland species, or are the decreases occurring primarily in particular areas or with particular types of species? The numbers of species can be aggregated from the local to the regional level.

Scale in Time and Space

The distribution of species and communities at the landscape level is often patchy. However, the population levels (abundance) of rangeland-dependent species, as well as trends in the geographic area of their current ranges can be aggregated from the local (county) to regional (bioregion, state) levels. It will be more problematic to aggregate this data to the national level. This indicator will be more meaningful if species trends can be extrapolated into the past to measure the loss of populations and contraction of geographic range over time up to the present. The basic metrics are population locations and overall status for representative species, repeated over space and time. This indicator will be comparable over time if the criteria and assessment methods do not change.

The number and geographic range of species in a region is a more responsive indicator than the number of at-risk species or communities. If a wide enough variety of species from different trophic levels and taxonomic groups are included, there is a greater probability of detecting early changes in communities and ecosystems that could lead to loss of function and sustainability.

Data Collection and Availability

The data for this indicator are best characterized for some vertebrate and vascular plant species as both A and C (Table 3.1, Appendix 1-E). Methods and procedures for data collecting and reporting exist at the regional-national level, and data sets of useable quality exist for some species at the regional-national level. Although data set(s) exist for many other species at the regional-national level, methods and procedures are not standardized at the regional-national level.

Data are available for a wide variety of vertebrate and vascular plant species that could be selected as representative or umbrella species. The data are primarily in the form of either local-focused research or as annual or other temporal counts of species abundance, such as the North American Breeding Bird Survey of the USGS (Sauer et al. 2002), the Christmas Bird Count of the Audubon Society (http://www.audubon.org/Bird/cbc/), the North American Waterfowl Breeding Population Survey (http://www.fws.gov/birddata/databases/mas/maydb/html), the Great Plains Flora Association county-level distributional data (Great Plains Flora Association 1977), and others.

Less is known about other groups, including invertebrates, reptiles, small mammals, bryophytes, fungi, algae, and bacteria. Lichens are known to respond to air pollution, and extensive research on their uses as indicators is available. Much of the available species-specific data are from local research sites that have little applicability at broader scales. Because of the site-specific nature of much of these data, it will be difficult to synthesize the available research and aggregate for regional or national assessments.

Species are typically characteristic of a particular climatic region; they are, therefore, extremely useful at the regional level. There are many different classifications of regional vegetation that local data could be aggregated toward, including but not limited to those developed by Brown et al. (1980), McLaughlin (1989), and Bailey (1995). However, the data cannot be easily aggregated beyond the regional level, as species-level comparisons are largely invalid across biome or ecoregional boundaries. However, patterns of similar species-groups (e.g., neotropical migrant birds) can be compared across regions.

Clarity to Stakeholders

Most people readily understand the concepts of population size, trends in abundance, and changes in geographic ranges of species. Rangeland-dependent as a concept may be less well understood by the public, except for a few large game or threatened species like the black-footed ferret, primarily because the public tends to lack the detailed ecological background needed to evaluate the concept.

Summary

The 10 indicators described here will contribute to a national system of monitoring the health and sustainability of U.S. rangelands. As noted in the “Soil and Water Conservation on Rangelands” criterion section, there is some overlap in indicator identification between the criterion groups. Integration, both within the SRR and between the various Roundtables (Forest, Mineral, Water), is critical to develop a suite of indicators that effectively and efficiently captures the factors necessary to monitor rangeland sustainability.

In the course of identifying key indicators of rangeland sustainability, we have also identified challenges for the rangeland scientific community. Measuring trends in the area of rangeland plant communities provides important information on the diversity of rangeland ecosystems and can serve as a loose proxy for environmental characteristics, disturbances, and ecosystem processes on rangelands. To be successful, a nationally accepted operational definition of rangeland and a standardized approach to classifying vegetation are needed, in addition to standardized inventory methodologies. The NVCS (FGDC 2008) and the Ecological Site Inventory (USDA NRCS 2010b) are two approaches moving toward standardized classification systems. Neither has had extensive implementation across a diversity of landowners. However, the collaboration efforts underway to improve the inventory, monitoring, and data management for these approaches should be encouraged.

The Federal Interagency Committee for the Management of Noxious and Exotic Weeds continues to refine and revise the development of a national invasive species database. This significant undertaking requires continued cooperation across political as well as scientific boundaries, as well as the necessary funding to bring such a massive undertaking to fruition. A centralized database is also needed with a query mechanism that will provide for the needs of managers fighting the problems in the field. Standardization of the data collected is the first step towards realizing a fully functioning program.

Enhanced spatial data would improve indicators. In addition to roads and residential land use, there are a number of additional uses of rangeland (e.g., commercial- and industrial-related land uses, oil and gas wells, wind energy developments, power lines, off-road vehicle uses) that would be useful but are more challenging to incorporate into the "Intensity of Human Uses on Rangeland" indicator. The development of spatially explicit data for human structures would be a significant improvement beyond the existing census block group data.

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CHAPTER 4
Criterion III: Maintenance of Rangeland Productive Capacity

G.R. Evans,[1] R.A. Washington-Allen,[2] R.D Child,[3] J.E. Mitchell,[4] B.R. Bobowski,[5] R.V. Loper,[6] B.H. Allen-Diaz,[7] D.W. Thompson,[8] G.R. Welling,[9] and T.B. Reuwsaat[10]

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Abstract: Maintenance of rangeland productive capacity is one of five criteria established by the Sustainable Rangelands Roundtable (SRR) to monitor and assess rangeland sustainable management. Within this criterion, six indicators were developed through the Delphi Process and the expert opinions of academicians, rangeland scientists, rangeland management agency personnel, non-governmental organization representatives, and other interested stakeholders. The indicators are standing aboveground biomass; annual net primary productivity; percent of suitable rangeland grazed by livestock; number of livestock on rangeland; presence and densities of wildlife functional groups on rangeland; and annual removal of native hay and non-forage plant materials, landscaping materials, edible and medicinal plants, and wood products from rangeland. A rationale for these six indicators is made.

Authors are [1]Director (retired), Natural Resource Distance Learning Consortium, Northern Virginia Campus, Virginia Tech, Alexandria, VA, 22314, USA; [2]Assistant Professor, Dept of Ecosystem Science and Management, Texas A&M University, College Station, TX, 77843-2138, USA; [3]Professor (deceased), College of Natural Resources, Colorado State University, Fort Collins, CO, 80523, USA; [4]Rangeland Scientist Emeritus, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO, 80526, USA; [6]Resource Manager, USDI National Park Service, Grant-Kohrs Ranch National Historic Site, Deer Lodge, MT, 59722, USA (presently stationed at Rocky Mountain National Park, CO, USA); [7]Rangeland Consultant, Wyoming State Grazing Board, Lander, WY, 82520, USA; [8]Associate Dean for Research, University of California, Berkeley, CA, 94720, USA; [9]National Grazing Lands Ecologist, USDA Natural Resources Conservation Service, Washington, DC, 20250, USA; 5Research Support Manager, Ridley Block Operations, Vaughn, MT, 59487, USA; and [10]District Manager (retired), USDI Bureau of Land Management, Medford, OR, 97504, USA.

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Correspondence: Dr. Gary Evans, 47503 Coldspring Place, Potomac Falls, VA, 20165; email: se4cnslt@msn.com.

Introduction

Rangelands have been a source of food and fiber for millennia, supporting generations of peoples from the tropics to the tundra. Maintaining the land's ability to produce these resources was critical to survival (Reader 1988). In his classical report *Conquest of the Land through 7,000 years*, Lowdermilk (1953) showed how empires stretching back to the beginning of civilization along the plains of present-day Iraq and the Nile River in Egypt met their demise in part because those living there could not retain the capacity to feed themselves.

For natural ecosystems like rangelands, productive capacity is an intrinsic process that, along with other processes such as biogeochemical cycling and biodiversity, provide the ecosystem goods and services essential to long-term sustainability (Christensen et al. 1996). Even economists tend to accept the premise that nature must be taken into account as both a vital factor of production and a source of our quality of life (Binswanger 1998). Productive capacity thus integrates all three components of sustainable management –economic, ecological, and social criteria – by focusing upon the ability of rangeland to produce goods and services. (For definitions of sustainable rangeland management, sustainable development and sustainability, see the introductory paper of this issue.)

Within the Sustainable Rangelands Roundtable (SRR), the Productive Capacity Criterion Group, comprised of academicians, rangeland scientists, natural resource agency personnel, non-governmental organization representatives, and practitioners, identified, developed, and adopted six standardized indicators that would characterize the maintenance of rangeland productive capacity (Table 4.1). The development of these six indicators reflects the expert opinions of the group as a whole. Associated concepts and ideas have evolved from discussions at the SRR workshops as well as the use of the Delphi Process between meetings. These indicators are not inclusive but, when complemented with indicators from the four other criteria, should provide a national monitoring system for assessing trends in rangeland sustainability. This paper outlines current thoughts toward developing standardized indicators for monitoring rangeland ecosystem productivity, based on today's information and research findings. As research and knowledge continue to evolve, the indicators will reflect new input and information.

Productive Capacity

Productive capacity can have different meanings, such as the maximum possible production on a site or the production possible given current conditions. Regardless, long-term sustainability requires that land uses do not change the resource or resource base, especially soils, to the point that the land is no longer capable of producing plant communities desired by society.

Although forests are the most productive biomes, rangelands rank second in Net Primary Production (NPP) worldwide (Lieth and Whittaker 1975). Globally, grasslands and savannas cover approximately 35 million km^2 or one-quarter of the earth's land area (Graetz 1994). Desert shrublands and tundra encompass a roughly equivalent land area (Shantz 1954). Because rangelands encompass such a broad diversity of ecosystems, the range of NPP is also broad, from less than 500 kg $ha^{-1}yr^{-1}$ to levels approaching 10,000 kg ha^{-1} yr^{-1} (Sala et al. 1988; Ehleringer 2001).

Table 4.1. The six productive capacity indicators and applicable data set.

Indicator	What the Indicator Describes	DS	Title of Data Set
Rangeland aboveground phytomass	A direct measure of total standing (aboveground) plant material.	1	VegBank
		2	NatureServe Explorer
		3	Ecological Site Description System
		4	Ecological Site Inventory System for Rangeland
		5	USGS/NPS Mapping
		6	USGS Gap Analysis Program
		7	Potential Natural Vegetation Groups, Version 2000
		8	USFS - NRIS (FSVEG Module)
		9	BLM - SVIM (Soil Vegetation Inventory Monitoring)
		10	NRCS - NRI
		11	IDS (Inventory Data System) - Ecological Status Inventory
		12	NASA Earth Observing System
Rangeland annual primary productivity	A direct measure of the rate of rangeland annual primary production.	1	U.S. Environmental Protection Agency
		2	NASA Earth Observing System (e.g., MODIS)
		3	DAAC - Distributive Active Archive Center
		4	AmeriFlux (part of DAAC)
		5	USGS/NPS Mapping
		7	Potential Natural Vegetation Groups, Version 2000
Percentage of available rangeland grazed by livestock	Information on use patterns of rangeland that could be grazed by livestock. Shows the shift in production from one commodity to another, based on climate, economic, and other variables.		
Number of domestic livestock on rangeland	A direct measure of rangeland secondary production.		
Presence and density of wildlife functional groups on rangeland	The presence and density of wildlife functional groups; provides an additional direct secondary production measure of rangeland.		
Annual removal of native hay and non-forage plant materials, landscaping materials, edible and medicinal plants, wood products	The removal of native hay and non-forage products are additional measures of rangeland productive capacity, as well as sustainability and biodiversity.		

Productive capacity includes more than primary production, however. To some extent, livestock and wildlife population sizes represent measures of secondary production. Even though they are secondary production, herbivore biomass and herbivore consumption of biomass are closely correlated with primary production in some ecosystems (McNaughton et al. 1989). Indicators tracking production and/or removals of other resources have been shown to be important for assessing sustainable management (USDA Forest Service 2004; Imhoff et al. 2000 and 2004).

We currently define productive capacity as the yield of plant and animal biomass (net annual primary and secondary productivity minus losses due to death and harvest) in response to abiotic and biotic factors such as climate and land uses (Reeves et al. 2001; Running et al. 2004). Other measures of productive capacity are manifested in other SRR criteria indicators, particularly rangeland area by plant community. Climatic phenomena, such as the periodic El Niño and La Niña events, cause changes in primary and secondary production having proximal and evolutionary implications that can be tracked over the long-term (Diaz and Markgraf 1992; Holmgren et al. 2006; Washington-Allen et al. 2006). For example, Craine et al. (2010) demonstrated in a recent 14-year study of 21,000 cattle fecal samples that forage quality, a factor in secondary productivity, declined nationally with temperature increases occurring since the mid-1990s. Projected "mega-droughts" due to warming and a lack of rainfall in the western U.S. rangeland states have the potential to deleteriously impact future productivity and water availability (Overpeck and Udall 2010). Drought, a product of these phenomena, will be considered in each of the indicators presented below.

Maintaining rangeland productive capacity implies that future generations will also obtain a mix of desired market and non-market goods and services. Thus, estimates for this criterion must consider both temporal and spatial scales across a wide variety of goods and services. It is important to understand that productive capacity ultimately embodies more than forage and livestock. It also impacts amenity and consumptive goods and services (e.g., wildlife habitat, landscape values, medicinal plants, and wood products).

Some components of productive capacity are mutually exclusive (competitive) while others are compatible (co-existing or mutualistic). This, however, is a fundamental principle of ecology. Seldom are different uses mutually exchangeable. For example, tradeoffs exist between the amount of forage available for use by livestock and by wildlife in critical areas such as elk winter range, as well as between forage grazed versus forage harvested through haying.

Identifying and monitoring key goods and services over long time frames requires monitoring capabilities at multiple geographic scales. Data must also be compatible over a relatively long time series in relation to natural fluctuations (Miles 1979; Magnuson 1990; Washington-Allen et al. 2006). While the need for long-term data has been identified, a set of solutions has not. As the six indicators to be presented reflect, some data do not exist or exist in such a disparate form that they provide little information about trends or changes. In order to understand the productive capacity indicators at the national scale, one must describe their dynamics at a regional level. As described in Criterion I, the mechanism of a system's function at one scale is manifested at the next finer scale of measurement. Consequently, data supporting the following indicators must be adequate to monitor and explain how they change regionally. By regionally, we mean an area equivalent to the Division level of an Ecoregion classification system (e.g., Fenneman 1928; Bailey 1998; or Comer et al. 2003).

Interpreting trends in productive capacity requires long-term data sets that provide information about the stability or degradation of the land base. Terrestrial ecologists generally define physical rangeland degradation in terms of parameters related to vegetation and soil. Land degradation includes (Behnke and Scoones 1993; NRC 1994):

1. A change in plant species or life-form composition that is contrary to management goals associated with sustainable rangeland health.
2. A decrease in plant productivity, cover, density, or other plant parameters or measurement of attributes that adversely affect rangeland health.
3. A reduction in soil quality, for example, nutrient loss.
4. Accelerated soil erosion.
5. Changes in landscapes that adversely affect ecosystem function at the landscape/watershed level.

While U.S. rangeland health has been slowly but steadily improving since the 1930s (Mitchell 2000), there can be little doubt that its productive capacity is still less than desired. An assessment by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (USDA NRCS 1997) estimated that 60 percent of non-federal rangelands were in need of management or practices to remedy the effects of disturbances impacting productive capacity.

Thresholds

Relating productivity to sustainable management requires an understanding of thresholds. Thresholds, or discontinuities, are manifested in a number of ecological indicators of rangeland sustainability (Archer 1989; Lockwood and Lockwood 1993; Rietkerk et al. 1996; Peters et al. 2004 and 2006; Briske et al. 2005; Rietkerk et al. 2004; Washington-Allen et al. 2006 and 2009). The concept of thresholds declares that the state of an ecological system can change abruptly, and sometimes irreversibly, in response to a change in some driving variable (Lockwood and Lockwood 1993; Scheffer et al. 2001; Briske et al. 2010). Relating threshold values to sustainable management is difficult, at best, because of a number of uncertainties and limitations. Perhaps foremost, the delimitation of a threshold depends upon the spatial and temporal scale in which it is considered (Levin 1992; Gosz 1993; Briske et al. 2005; Briske et al. 2010).

Thresholds for rangeland community and ecosystem processes have been advanced by both theoreticians (Noy-Meir 1975; Hanley 1979; Lockwood and Lockwood 1993; Rietkerk et al. 1996; Scheffer et al. 2001; Beisner et al. 2003,) and empirical studies in rangelands (Archer 1989; Westoby et al. 1989; Tilman et al. 1996; Allen and Breshears 1998; Peters et al. 2004 and 2006; Washington-Allen et al. 2006, 2008, and 2009). For example, catastrophic shifts to lower biomass, physiognomic composition, vegetation pattern, and greater erosion state in response to repeated droughts and intensive domestic livestock grazing was observed over a 27-year period by Zimmermann et al. (2007) and Washington-Allen et al. (2004 and 2009). A meta-analysis of 171 studies showed both nonlinear and positive patterns between species richness and productivity to be more or less prevalent, depending upon scale (Mittelbach et al. 2001). However, no studies have verified an unmistakable discontinuity in ecosystem stability or function in relation to changing diversity, in part because the science of ecology is too complex to enable predictions of ecosystem-level outcomes of changing biodiversity. In addition, the idea of ecosystem resilience is imprecise at best, relating to two general concepts: the ability to recover to a pre-existing state following a disturbance and the ability to exist in the form of alternate ecosystem states (Grimm and Wissel 1997).

Nearly a decade ago, a Society for Range Management task group reported upon its work for evaluating rangeland sustainability at the management unit level (Task Group on Unity in Concepts and Terminology 1995). The group highlighted the importance of ground cover thresholds, below which unacceptable soil erosion rates will occur. O'Brien et al. (2003) proposed ground cover thresholds for aspen, alpine, mountain big sagebrush, and tall forb communities in the Intermountain United States. A correlation between ground cover and actual soil erosion has been shown at a regional scale (Hardy 2002).

Models evaluating the risk of crossing thresholds have demonstrated that ecological considerations are not the only factors to be considered; for example, profitability of livestock production and technology can also be primary factors to consider when assessing trends in desertification (Ibáñez et al. 2008).

Remote Sensing Applications

The first two, and perhaps the third, of the six Productive Capacity indicators lend themselves to be remotely monitored using sensors (Hunt et al. 2003; Running et al. 2004; Kulawardhana et al. 2009). Specific tools are described in their respective sections.

Aboveground Phytomass

Description and Importance of the Indicator

Phytomass is the mass of plants, including dead attached parts, per unit area at a given time. Phytomass is commonly measured in units of kilograms per hectare (or pounds per acre). It is a direct measure of biomass production, carbon storage, energy availability, and available forage for potential grazers and users of rangelands. It also serves as a fuel source for rangeland fire. Phytomass is not to be confused with the next indicator, primary productivity, which describes rates of biomass accumulation.

The measurement of aboveground phytomass, when separated into live and dead plant material, provides an acceptable estimate for NPP (above and belowground), particularly for ecosystems dominated by species having a single growing season. Most of the data available (Table 4.1) have been collected in terms of peak standing crop estimates of herbaceous and shrub vegetation. These data provide a valuable tie to past management actions, giving trends in biomass production through space and time (Scurlock et al. 1999).

Phytomass can be used to estimate residual forage supplies in regions where browsing and grazing by livestock or wildlife are not in equilibrium with NPP because of a lack of grazing or burning, such as on lands set aside for national parks and the Conservation Reserve Program (e.g., Stoms and Hargrove 2001). As a result, these lands often contain excessive standing dead material, often at levels that curtail primary productivity and cause decadence (Weaver and Rowland 1952).

Spatially explicit maps of biomass and standing dead material are becoming extremely useful for providing inputs into wildfire behavior models (Keane et al. 2001). Moreover, under the increased impacts of stressors like plant invasions and climate change, wildfires are collectively posing one of the largest challenges facing rangeland managers.

In a world with continuously increasing demands for energy, some scientists and policymakers see the possible use of biomass, including that from tallgrass species, as a substitute for fossil fuels (Ramsey 1985). Such an outcome is more likely in developing countries; however, research in the U.S. tallgrass prairie has shown that native grasslands have the potential as an energy source while not impacting cropland food production or biodiversity (Tilman et al. 2006). The actual indicator pertaining to biofuels is described below (Annual Removal of Native and Non-forage Biomass).

Geographic Variation

Rangeland vegetation types are highly variable in annual phytomass production because of variation in precipitation, temperature, soil quality, and other factors. For broad scale assessments, not only is the average amount of phytomass important, so is the spatial distribution within ecological or physiographic regions.

Scale in Time and Space

Phytomass information is generally collected at the management-unit level using plot data. Aggregating local data to a regional scale for the purpose of national reporting is problematic. Vegetation indices derived from historical remote sensing data archives from the early 1970s, particularly the Landsat (30-m to 80-m pixel resolution) and Advanced Very High Resolution Radiometer (AVHRR) archives, can be calibrated with properly scaled field calibration data and used as proxies for local to national biomass estimates and annual phenology tracking (Sellers 1985). Another approach for detecting significant regional changes in phytomass for national reporting might be to employ meta-analysis techniques (Glass 1976).

Data Collection and Availability

Because of the time and cost of obtaining phytomass estimates, data collection, analysis, and reporting occurs at local, regional, and national levels. Data collection methods are not standardized among or within scales (Scurlock et al. 1999). In addition, agencies can have intrinsic inconsistencies at a given scale (i.e., an organization may have protocols that are not followed or interpreted the same way throughout the organization). In recent years, federal agencies have become much more consistent in collecting data, so this problem is rapidly diminishing. For example, phytomass sampling is incorporated into two national plot-based monitoring systems: the NRCS's National Resources Inventory (NRI [Nusser and Goebel 1997]) program and the USDA Forest Service's Forest Inventory and Analysis (FIA [USDA Forest Service 1990]) program. It has become necessary for these two systems to jointly monitor federal rangelands more comprehensively, and this is the case in the Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), where vegetation plots from a number of federal agencies and NGOs were used to generate different vegetation parameter maps (Rollins and Frame 2006). For example, national forest biomass was predicted from FIA plots and satellite reflectance data by Blackard et al. (2008) and NRI data of more than 800,000 field plots in five years has shown the same potential (Herrick et al. 2010).

The Global Index of Vegetation-Plot Databases (GIVD) consists of 78 databases from around the world, representing more than 1,500,000 relevés that have uploaded their metadata. With an average of 20 species per plot, GIVD presently represents approximately 30 million species records, all with compositional data and most of them with precise location, with environmental and structural data (http://www.botanik.uni-greifswald.de/givd.html).

However, data collection of phytomass at the state and local levels can still be incomplete, but an effort has been made to collect and standardize historical U.S. and global NPP data sets for validation/calibration of satellite derived data sets, e.g., the data archive of the grasslands NPP data with the NASA Distributive Active Archive Center for biogeochemical cycling at Oak Ridge National Laboratory (Scurlock et al. 1999), and the National Phenology Network, which has a goal to archive plant and animal data related to phenology (Morisette et al. 2009). Further, a national network of eddy covariance flux towers, called AmeriFlux, has been established for estimation of the large-scale carbon cycle and calibration/validation of estimates derived from satellite imagery (Heinsch et al. 2006; Xiao et al. 2008).

Aboveground phytomass data are collected both directly and indirectly. Direct methods require destructive sampling of aboveground biomass through clipping and weighing plant material. Indirect methods involve weight-estimate procedures, where mass per unit area is estimated visually or in some other manner, such as correlating it with canopy cover (Mitchell et al. 1987; Scurlock et al. 1999). Double sampling techniques utilize both approaches in combination with regression techniques for developing correction factors (Scurlock et al. 1999). Indirect methods using satellite data for biomass estimates are discussed in the section, Annual Primary Productivity. Figure 4.1 estimates aboveground biomass in U.S. rangelands from 1982 to 2009 (Unpublished data, R.A. Washington-Allen, Texas A&M University). The 8-km pixel resolution map time series was derived from the annual summed normalized difference vegetation index (NDVI), Advanced Very High Resolution Radiometer (AVHRR), Global Inventory Modeling and Mapping Studies (GIMMS) data set from 1982-2006 (Nemani et al. 2003; Tucker et al. 2004 and 2005; Bai et al. 2008), and the 1-km pixel resolution Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 5 net primary productivity (NPP) data set from 2000-2009 (Zhao et al. 2005; Zhao and Running 2010). The annual sum of NDVI approximates NPP and is equal to it when combined with a production efficiency model (PEM) (Potter et al. 1993; Prince and Goward 1995; Running et al. 2004; Zhao et al. 2005; Zhao and Running 2010). A calibrated NPP time series from 1982 to 2009 is produced by conducting a time series regression between the temporal overlap of the Annual Sum NDVI AVHRR GIMMS and the 8-km resampled MODIS NPP for the period 2000-2006 of the rangeland portion of the conterminous U.S. Calibrated NPP is then converted to aboveground biomass (Kulawardhana et al. 2009) (Fig. 4.1).

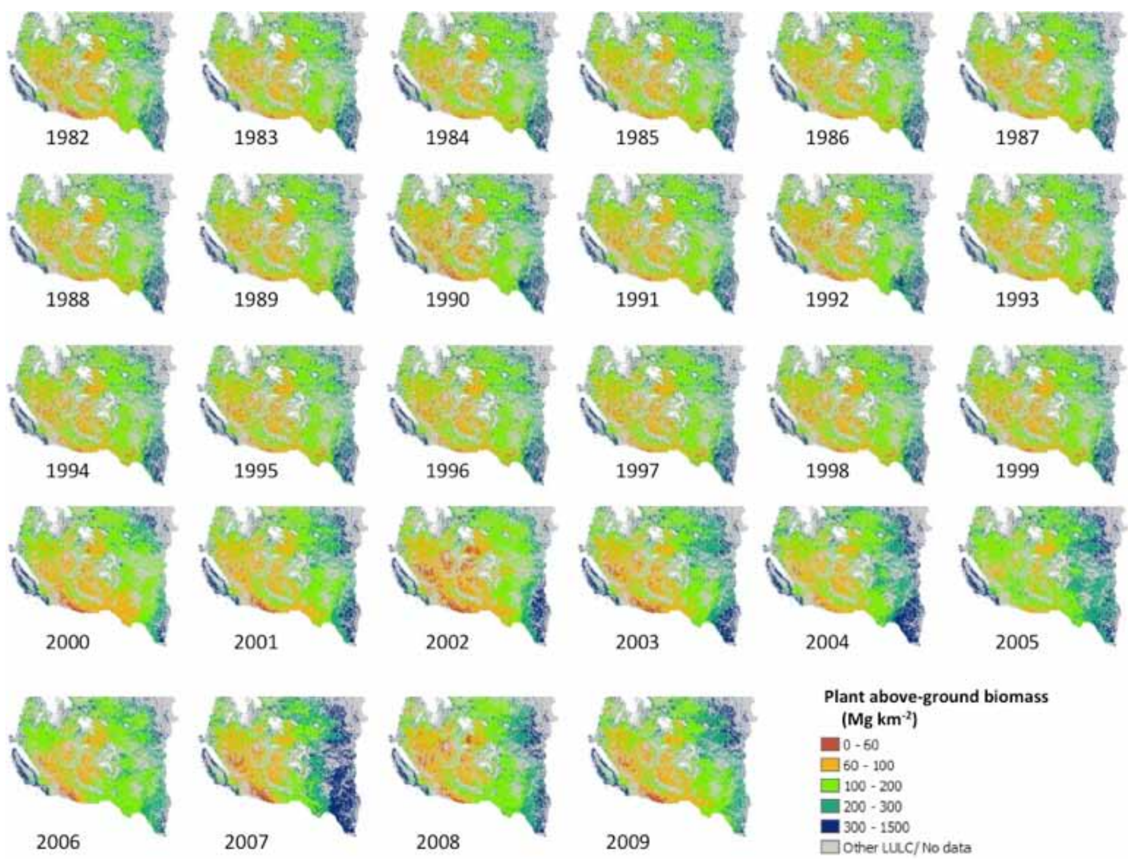

Figure 4.1. Aboveground biomass from 1982 to 2009 that was derived from calibrated NPP. Calibrated NPP was derived from the time series regression between MODIS NPP from 2000 to 2006 and annual sum NDVI AVHRR GIMMS for the same period.

Clarity to Stakeholders

This indicator can be understood by stakeholders, particularly the public, because amounts or states are more intuitive than rate processes like productivity. Thus, phytomass is important for understanding rangeland sustainability and maintenance of productive capacity on rangelands for two reasons: (1) its value as a measure of accumulated phytomass, and (2) its usefulness as a measure that most people can easily understand.

Annual Primary Productivity

Description and Importance of the Indicator

NPP is the rate (on an annual basis) at which CO_2 is converted to biomass (all plant life-forms) through photosynthesis. Thus, it is the first critical step in the carbon cycle on earth. Productivity is a flow or ecosystem process measured in terms of mass per unit area per time. NPP takes place in both above- and belowground biomass (i.e., plant shoots and roots). However, the reality is that, with the exception of a few local studies, little data exist on belowground productivity, even though the proportion and turnover of belowground biomass varies among ecosystems (Reeder et al. 2001). Annual aboveground net primary productivity (ANPP) is the ecosystem measure of the rate at which aboveground biomass is produced annually. Although ANPP and aboveground phytomass (Indicator 1) are two separate measures, represented by two different units, they are often used interchangeably to describe rangeland production (Sala 2001; Rambal 2001).

Primary productivity is the foundation for measuring the productive capacity of terrestrial ecosystems, both terrestrial and aquatic, and is key to understanding ecosystem sustainability. As an essential component of the carbon cycle, NPP will always be a critical indicator for monitoring and assessing interrelationships between the atmosphere, natural ecosystems, and human populations. Thus, changes in terrestrial primary productivity affect the kind, amount, and distribution of life on the planet (Roy et al. 2001).

Our focus is on rangeland ecosystems. Joyce (1989) estimated that forests and rangelands support approximately 70 million cattle, 8 million sheep, and 45,000 wild horses and burros. Wildlife populations found on rangelands have increased substantially over the past quarter of the 20th century to 500,000 elk, 630,000 pronghorn antelope, and 5.5 million wild turkeys (Flather et al. 2009), along with smaller numbers of goats, bison, wild sheep, and moose, plus unknown numbers of rodents, rabbits, insects, and other creatures. All life in rangeland ecosystems is sustained through primary productivity. Plant material derived from NPP is then available for consumption by herbivores (secondary productivity or primary consumption) and carnivores (secondary consumption). After plants and animals die, the activities of microflora and microfauna on rangelands are important in the mineralization of organic compounds within and upon the surface of the soil. Microorganisms allow nutrient cycles to function properly and keep phytomass from accumulating.

Geographic Variation

Annual rangeland NPP has high spatial variability, ranging from near zero to around 3,000 g m^{-2} (Running et al. 2004). Savannas, for example, can produce as much biomass annually as coniferous forests. This variability occurs for a variety of reasons in which one variable can seemingly "drive" the system or a combination of variables collectively control the environment. Below are some sample explanations.

The principal change drivers that affect primary productivity on rangelands include 1) land-use change (including changes that affect soil), 2) climate change (precipitation and temperature), 3) change in composition of the atmosphere (CO_2), and 4) changes in biodiversity. Early estimates of global NPP, made 30 years ago, were based primarily upon evapotranspiration data converted from air temperature data (Lieth and Whittaker 1975). Recent research using an ecosystem productivity model has shown that input temperature data must be within 2° to 3° C to accurately predict NPP (Matsushita et al. 2004).

In most cases, NPP declines with changes in land use (Burke et al. 1991; Alcamo 1994). In some cases, NPP may be increased with land-use changes that include high energy inputs such as irrigation and fertilizer. Similarly, as precipitation decreases and temperature increases, NPP generally declines (Sala 2001). This may or may not be the case with global warming, since climate change models indicate that changes may include increasing precipitation, as well as declining precipitation, in different global regions. With increasing CO_2 in the atmosphere, NPP often increases (Field et al. 1995a; Owensby et al. 1999). In some regions like the tallgrass prairie, researchers have found a positive correlation between biodiversity and NPP (Mooney et al. 1995; Tilman et al. 1996). Sufficient monitoring does not exist to determine if this will be true across all rangelands.

Rangelands in the mostly arid or semiarid western U.S. occur in ecosystems that can experience prolonged periods of water shortage. As a result, water tends to be a dominant factor affecting productivity. It is not surprising then that the major effects of climate change on such ecosystems are experienced primarily through changes in soil/plant water dynamics (Morgan 2005; Heisler-White et al. 2009). However, the degree to which climate change impacts these rangelands is likely to differ considerably due to their present ecology, how climate change will manifest in specific regions, and the resulting consequences for each regions' economic and social structures and conditions.

In U.S. Mediterranean shrublands and woodlands, timing and amount of precipitation and soil nutrients are the major environmental variables controlling plant productivity (Rambal 2001). A drying climate is a primary global climate change driver in the Mediterranean system, which, when coupled with fire and intermittent heavy rain events, fosters flushes of annual grass biomass, thus fueling more potential fires.

The main controls on primary productivity in desert ecosystems are precipitation and soil fertility (Ehleringer 2001) and to some extent soil texture. The ability of desert plants to convert precipitation to NPP varies by season, growth form (shrub/herb), and ability to utilize deep soil moisture (mainly shrubs) versus shallow soil moisture. Crypto-biotic crusts play a critical role in maintaining productivity in desert ecosystems through the regulation of input and loss of nitrogen (Dregne 1983), by limiting soil erosion, and by affecting soil water infiltration.

Scale in Time and Space

Rangeland productivity is highly variable, spatially and temporally. The indicators are meaningful when sample sizes are large enough to provide the necessary statistical power to detect change. Further interpretation can be enhanced through an understanding of climate and land-use changes. Different approaches for estimating NPP apply at different scales. This is discussed below.

Data Collection and Availability

Although NPP and annual aboveground biomass production are two different concepts, the most common way to estimate NPP is to equate peak aboveground biomass with annual productivity (Sala and Austin 2000). Data are available for all rangelands although quality and quantity vary widely, making assessments difficult (Rotenberg and Yakir 2010; Schimel 2010). Belowground biomass has only been broadly estimated across biomes, adding to the uncertainties in data sets describing rangeland productive capacity (Jackson et al. 1996 and 1997).

NPP is measured in three ways. The first method is field-based direct, destructive sampling of above and belowground biomass over time. For example, in temperate grasslands, the annual turnover of biomass approximates unity. Therefore, the most common way to estimate NPP in grasslands is by estimating aboveground biomass only, often by directly clipping and weighing the biomass, or using weight-estimate procedures (Bonham 1989). It should be noted that several methods are available for directly measuring or estimating productivity. The most effective methods to meet long-term monitoring goals have yet to be agreed upon.

A second approach to measuring, calibrating, and validating NPP is provided by the AmeriFlux network that involves a network of eddy covariance flux towers that measure the CO_2 flux in an ecosystem (Running et al. 1999).

The third method for monitoring NPP is through modeling its amount and spatial distribution. A number of modeling approaches have been developed, particularly remote sensing-based, physiological-based, or a combination of both. Remote sensing-based models interpret the light spectrum reflected by the land surface, converting known relationships developed from direct measurements, while physiological-based models simulate NPP from environmental variables.

The use of remote sensing-based models is becoming more widespread, advancing from pioneering global analyses involving the Advanced Very High Resolution Radiometer (AVHRR) by Tucker et al. (1985) and research by Potter et al. (1993). Advances since that period include:

- Prince and Goward's (1995) Global Production Efficiency Model (GLOPEM) data set (http://glcf.umiacs.umd.edu/data/glopem/) showing that time series of NPP can be generated.
- Fields et al.'s (1995b), and Nemani et al.'s (2003) use of the AVHRR Global Inventory Modeling and Mapping Studies (GIMMS) data set.
- Current research using data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on both the Terra and Aqua satellite platforms that produce a low-cost Global NPP product at 1-km resolution from 2000 to the present (Reeves et al. 2001; Running et al. 2004; Zhao et al. 2005; Zhao and Running 2010).

Clearly, the best potential for monitoring NPP at various temporal and spatial scales lies with remotely sensed data (Lutz et al. 2008). In fact, the AmeriFlux network coupled with NPP derived from MODIS has been used to estimate both NPP and Net Ecosystem Production across the entire continental U.S. (Xiao et al. 2008).

As indicated at the start of this section, critical review and comparison of various data methods are essential. This is critical for correlating remotely sensed data with ground validation. The two other types of NPP measurements – direct biomass measurement and CO_2 flux estimates – no single one can match the spatial and temporal extent and grain of current satellite data (Running et al. 2004).

Clarity to Stakeholders

NPP can be understood by those who understand basic ecosystem processes. It is probably the key indicator of the "Maintenance of Productive Capacity on Rangelands" criterion. Many of the indirect measurement and estimation techniques, on the other hand, involve complex data sets and sophisticated analysis procedures that are beyond the comprehension of average citizens. Fortunately, most rangeland stakeholders have learned to accept information coming from high technology monitoring, so the complexity of the data collection and analysis process should not be problematic.

Percent of Available Rangeland Grazed by Livestock

Description and Importance of the Indicator

This indicator is a measure of the availability of suitable rangeland that is grazed annually by domestic livestock, such as cattle, sheep, goats, and horses. This indicator does not intrinsically represent a biological capacity. Rather, it is an administrative and economic capacity, limited by the definition of rangelands, market forces, management decisions, laws, regulations, and planning documents. The land area involved will always be a subset of the indicator, Extent of Land Area in Rangeland, described in Chapter 3.

The area of rangeland grazed by livestock provides information on rangeland use patterns and is influenced by wildlife and other non-livestock commodity demands, as well as changing social and economic values. The indicator may be used separately or with other indicators reporting livestock numbers to quantify primary production consumed by livestock. It describes the net land area used to produce livestock forage in proportion to total rangeland. As long as livestock forage use is not limiting demand for red meat, and as long as land management agencies keep sustainable management as a strategic goal, the percentage of available rangeland grazed by livestock will remain primarily a socio-economic measure. However, where demand for meat exceeds supply or high value is placed on livestock grazing, this indicator could reflect changes in rangeland health.

Geographic Variation

This indicator provides consistent information across geographic regions because domestic livestock numbers are used in tax valuations, in estimates of current and future market needs, and for assessing range livestock needs in association with non-grazing rangeland needs. The area of rangeland grazed by livestock is obviously correlated with national and regional herd sizes.

Scale in Time and Space

The percentage of available rangeland grazed by livestock is meaningful at different scales and provides a measure that is aggregated from public and private land management records to multiple scales – states, by federal agency, by ecoregion or physiographic region (Bailey 1998), and for the nation as a whole.

Data Collection and Availability

Obtaining data on the percentage of available rangeland grazed by livestock is feasible using habitat suitability approaches (Wade et al. 1998). However, crucial data on livestock water availability are currently not available, and would be labor intensive to develop. This indicator requires two kinds of data by ecoregion or physiographic region: (1) area of rangeland available for livestock grazing, and (2) area of rangeland actually grazed. Kulawardhana et al. (2009) have estimated that the area grazed in the conterminous U.S. to be 236 million ha by using a climatic definition, the aridity index (mean annual precipitation [MAP] divided by the mean annual potential evapotranspiration [MAPET]) (UNEP 1992). Ungrazed suitable areas were estimated using a National Wilderness Preservation Areas mask acquired from the USGS National Atlas (http://www.nationalatlas.gov/). Urban areas and other non-rangeland classes were also masked out (Fig. 4.2).

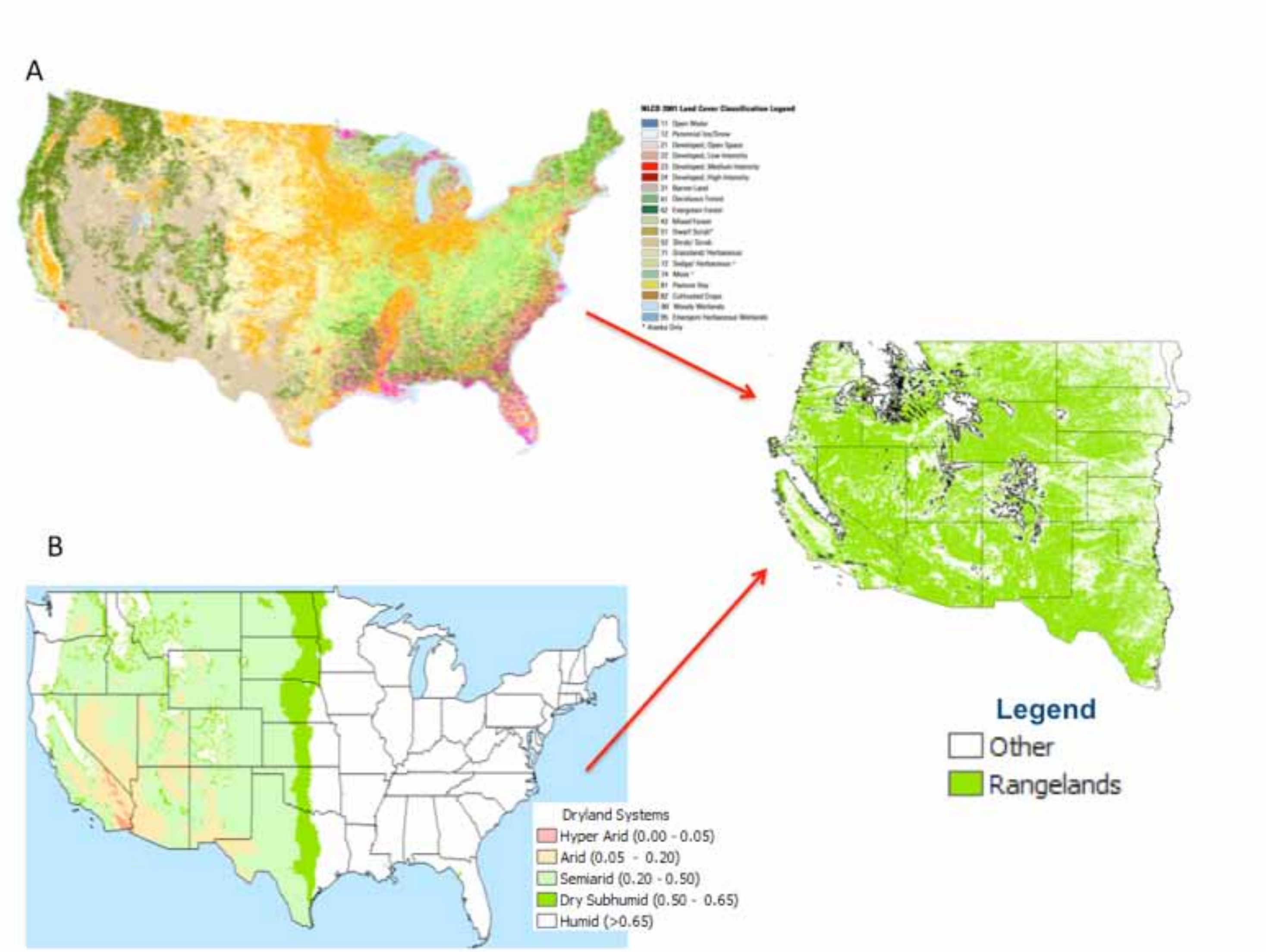

Figure 4.2. The National Land Cover Dataset (NLCD, A) is converted to a shrubland and grassland cover map and combined with the aridity index climatic map to delineate the land area grazed by livestock. This area was further defined by subtraction of the National Wilderness Preservation System areas.

Two factors can keep rangeland from being available for livestock grazing, one relatively simple and one difficult to discern. The first includes legal statutes, covenants, land-use restrictions, etc., that prohibit livestock grazing for policy and social reasons. Although keeping a current database of rangelands excluded from livestock grazing is conceptually feasible, the practical implementation of such monitoring protocols is anything but simple. Regardless, the more complicated factor, if included in the definition of available rangeland, is the employment of suitability criteria. Suitability criteria provide parameters that demarcate the extent of primary rangeland and secondary rangeland. Primary rangeland is the area that livestock normally use under proper management. When primary rangeland is overused, livestock tend to move onto secondary rangeland. Unsuitable rangeland often results from physiographic and soils features like steep slopes, highly erodible soils, and lack of water. At regional or national scales, it may be difficult to derive suitability criteria that match the grain and extent of the rangeland base. If this problem proves insurmountable, the available rangeland would be defined only on the basis of the first factor.

The area of privately owned rangeland actually grazed is a sensitive issue with many private landowners and will require proprietary protections for data to be collected. Federal and state lands leased for grazing in any given year will seldom be released in a formal published form that provides ratios of grazed to ungrazed lands. While the potential for such information is available, policies do not exist for these publications.

Clarity to Stakeholders

The indicator is understandable. However, it requires a clear and accepted definition of the term "available rangeland." Within the rangeland community, different perceptions by various stakeholder groups about the availability of rangeland on any given year will vary until such time as clear definitions are developed.

Number of Livestock on Rangeland

Description and Importance of the Indicator

This indicator measures the quantity of livestock (cattle, sheep, horses, and goats) that spend part or all of the year on rangeland. It is an index of secondary productive capacity by a major category of primary consumer. Livestock do not spend their entire life on rangeland, so an inventory at any one time will underestimate the total extent of rangeland use by livestock.

The indicator, linked with other indicators, represents rangeland grazing and browsing use by domestic animals. It accounts for short-term management strategies by individual graziers, as well as more long-term strategies followed by land management agencies. It also accounts for laws restricting livestock use on rangelands. Clearly, a positive relationship exists between the percentage of suitable rangeland grazed by livestock and this indicator.

Livestock numbers can be reported in several ways. Actual numbers, expressed as herd sizes at county, state, and national levels, are already reported by USDA National Agricultural Statistics Service (NASS) (Fig. 4.1). Livestock and other grazing herbivores can also be reported in terms of Animal Units (AU), an approach that normalizes different classes of grazing animals into a standardized AU, typically a 1,000-lb. cow (Holechek 1988). The Animal Unit Day, Month, or Year (e.g., AUM) expresses the amount of dry weight of forage consumed by an AU for that time period. Addition of the time dimension enables economic valuation of rangeland products. Grazing pressure or density is the AU per unit land area, most often hectares in the scientific literature. The rate of grazing or stocking rate is grazing pressure over time calculated for a year as AU ha^{-1} yr^{-1}.   Domestic livestock found upon rangelands include cattle, sheep, goats, horses, and mules, along with a number of minor grazing animals like donkeys, llamas, and alpacas.

In the United States, cattle numbers (including calves) rose steadily from when records were kept in the mid-19th century until 1975, when they peaked at 132 million head (Mitchell 2000). Over the next decade, the number of cattle declined to about 100 million head, where it has maintained a somewhat dynamic equilibrium. U.S. cattle numbers have undergone cycles lasting roughly 10 years since the 1880s, primarily because time constraints prevent producers from quickly responding to price changes (Fig. 4.4). The latest national cattle cycle troughed in 2004 and peaked only three years later at roughly 97 million head (Haley 2008). Cattle cycles are affected by droughts, feed costs, and import/export restrictions. Extended droughts can cause animal numbers to be cut dramatically. Trends toward larger-framed cattle are resulting in heavier slaughter weights, a factor that can offset the tendency of the national herd size to decrease from historical highs.

The number of sheep has slowly declined from nearly 50 million head to less than 8 million head over the past half-century (Mitchell 2000). NASS sets a herd size threshold for reporting goat and other livestock numbers; consequently, only Texas has goat herd sizes sufficient to report. Sheep and goats may be more important to society from a sustainability point of view than mere numbers on rangeland imply. This is because sheep, as well as goats, are often used as a tool for prescribed grazing to manage invasive weeds and to reduce fire hazard at the urban/rural interface.

Equine species (horses, mules, and donkeys) are now primarily used for various forms of recreation. Their numbers appear to be insensitive to agricultural and other land-use economic forces, resulting in a fairly constant national herd size over the last 50 years (Mitchell 2000).

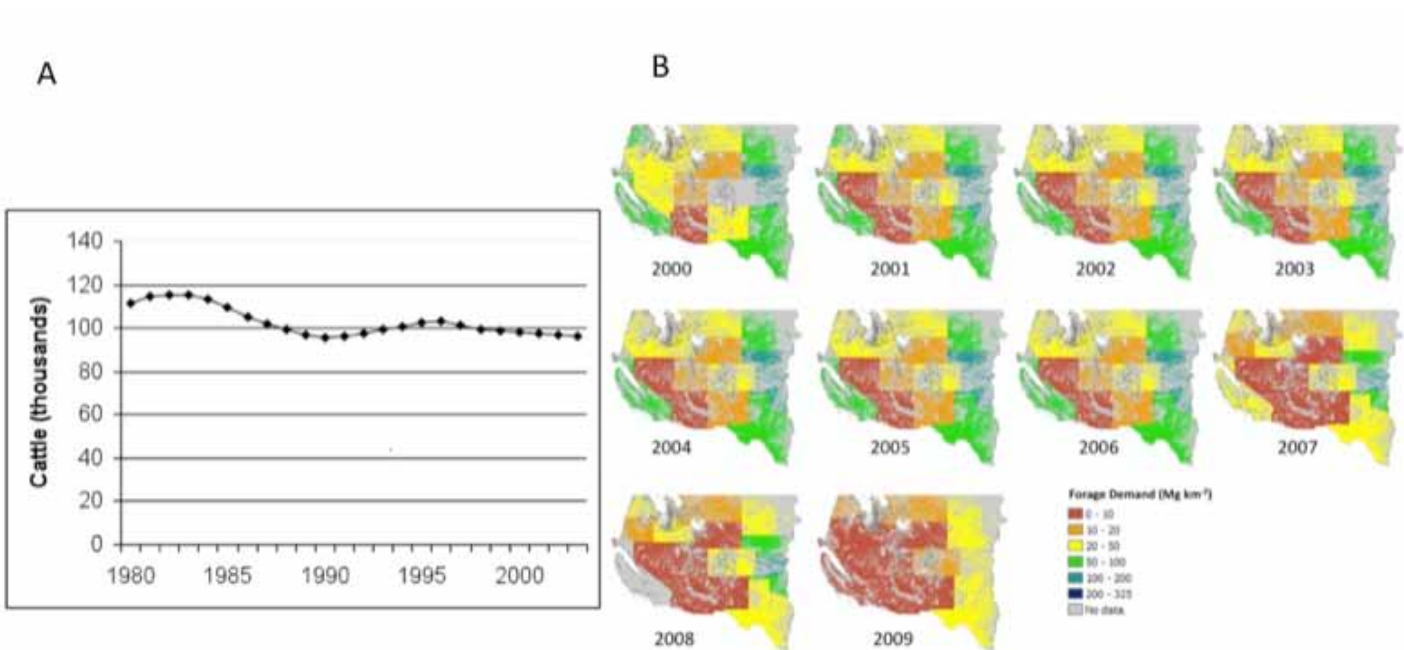

Figure 4.3. Total U.S. cattle numbers from 1980-2003 (A) and a preliminary map of the spatial distribution of livestock (cattle, sheep, and goats) forage demand (Mg km-2) for a 6-month period at the state level. Livestock data are from the National Agricultural Statistics Service, Washington, DC.

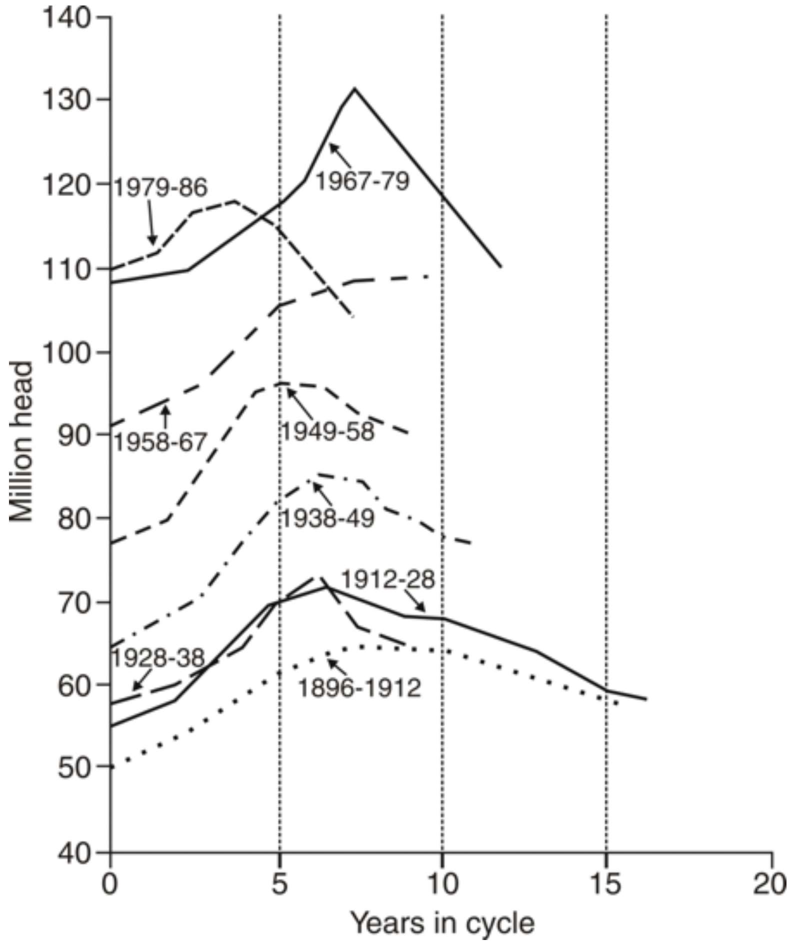

Figure 4.4. Cattle inventory cycles in the United States, 1896-1996. Adapted from Hughes (1997).

Measuring the number of livestock grazing on rangelands annually, as well as the cyclical variations in this number, provides a way to assess the extent to which natural vegetation is supplying the nation's forage needs (Fig. 4.1). Droughts, land-use changes, and reservation of public lands for biodiversity, wilderness, and watershed stabilization constitute mechanisms that negatively influence the availability and quality of our nation's rangeland forage supply, and thus livestock numbers. Above-normal precipitation, investments in rangeland improvement practices (restoration/rehabilitation), public policies that promote grazing, and other policies can increase the supply of forage.

Estimates of aboveground biomass (Fig. 4.1) can be viewed as the forage available (FA) to livestock, and livestock numbers can be converted to forage demand (FD, Fig. 4.3), consequently FA – FD is equal to the impact of livestock appropriation of biomass and can be used to detect hotspots where FD > FA and bright spots where FD < FA (Kulawardhana et al. 2009, Fig. 4.5). This study found that 0.01 percent to 2.7 percent (and a mean of 0.7 percent) of rangeland was impacted by domestic livestock at the state level from 2000 to 2009 (Washington-Allen et al., unpublished data).

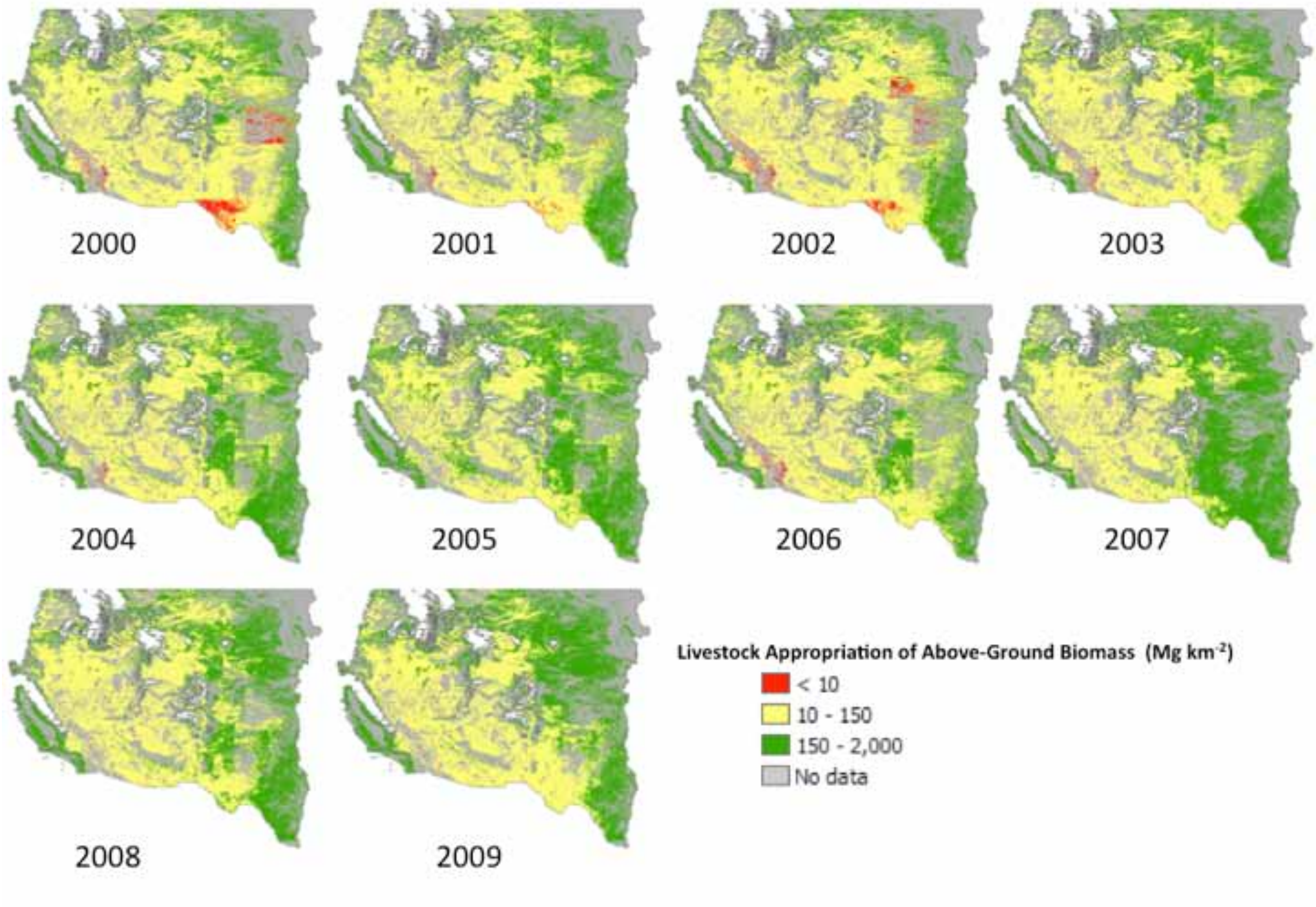

Figure 4.5. Livestock appropriation of biomass in the western U.S.: forage available (FA) minus the forage demand (FD) from 2000 to 2009 of livestock grazing on U.S. dryland productive capacity. Red areas are hotspots where FD > FA.

The Heinz Center report (Heinz 2008) included cattle numbers on "grassland and shrubland" as one of 14 ecological indicators (plus 13 additional core indicators) that characterize U.S. rangelands. The Heinz Center report recognizes that cattle production is one of the most important economic uses of rangelands, and it remains a vital element of the economic and social fabric of many parts of the United States, particularly west of the 100th Meridian.

Geographic Variation

The number of livestock grazing upon rangelands is equally meaningful in all geographic regions. Geographic variations exist due to the timing of grazing, with southern regions having much longer grazing seasons than northern or higher elevation regions.

Scale in Time and Space

Cattle, sheep, and goat numbers are meaningful at all scales. They can be aggregated across scales. The numbers of livestock on privately owned rangeland may be inadequate to provide statistically valid estimates of herd size at the county level and for some states. At the regional and national scales, herd sizes would be adequate to provide valid estimates if such data were collected.

Data Collection and Availability

The number of grazing livestock may be determined at a scale necessary for county, regional, state, and national assessments. We recommend that appropriate questions be incorporated into surveys used by the USDA NASS for developing these estimates. To date, the USDA NASS does not request information about where livestock are grazed (i.e., whether on rangeland, improved pasture, or grazed cropland) in developing agricultural statistics and reports of livestock surveys. Indirect estimates (total number of cattle less cattle on feed) require unacceptable assumptions concerning inadequate and incompatible datasets. Data on cattle numbers can be reviewed at http://www.nass.usda.gov.

This indicator will be most useful with both cattle and sheep numbers on rangeland. It will be necessary to work closely with USDA NASS to acquire the requisite data for both.

Clarity to Stakeholders

Cattle and sheep numbers on rangeland are clearly understood by nearly all people. Expressing these two classes of livestock in terms of animal units, particularly when describing the joint significance of cattle and sheep, will require some explanation. The additional data for goats, horses, mules, donkeys, llamas, alpacas, and others will also be clearly understood.

Presence and Density of Wildlife Functional Groups on Rangeland

Description and Importance of the Indicator

This indicator measures both presence and density of representative species within functional groups of wildlife and within ecoregions or physiographic regions. Examples of functional groups for purposes of measuring this indicator may be: large herbivores, small herbivores, large predators, small predators, avian foragers, avian predators, burrowing reptiles, surface reptiles, insect grazers, amphibians, fish, and pollinators. The concept of functional groups continues to evolve, primarily in discussion among wildlife biologists and wildlife policymakers.

Rangeland ecosystems provide all or a critical portion of many wildlife species annual habitat requirements. Habitat components include mating components, rearing young components, forage or food components, and resting components. Depending on the species, these may or may not be available or required in the same space. The components provide the critical factors to sustain population dynamics and species diversity. It is demonstrated that population densities of some wildlife species are affected by changes in rangeland habitat components (changes in the state of the ecological site and/or landscape) and/or changes in land uses (Winter and Faaborg 1999). A loss of one habitat component may result in the loss of that species' contribution to rangeland biodiversity for the entire area, whether an ecological site or the ecoregion.

Since the mid-19th century, the historic extent of rangelands has been dramatically reduced by other land uses. A study by Noss et al. (1995) found rangelands to be disproportionately represented among ecosystems they identified as critically endangered for wildlife, i.e., more than 98 percent of their area had been converted to other uses. Flather et al. (1999) identified 11 critical western rangeland ecosystems considered to be endangered according to this definition, more than half of which were found in the Pacific Coast states of Washington, Oregon, and California. They determined that a high proportion of the endangered rangeland ecosystems recognized by Noss et al. (1995) were located east of the 95th Meridian, where natural grasslands and shrublands have always been rare. In other words, the disproportionate representation of endangered grassland/shrubland ecosystems in the East was likely a consequence of their rarity (Flather et al. 1999). Nonetheless, there are precarious wildlife habitats in western rangelands in need of restoration through a multiplicity of management practices (Crawford et al. 2004).

The State of the Nation's Ecosystems (Heinz 2008) utilizes a similar indicator called At-Risk Native Grassland and Shrubland Species. This indicator uses a combination of factors, including the relative risk of extinction of native rangeland species, both plants and animals, and population trends of at-risk native rangeland species. The report concluded that 18 percent of native rangeland animals are at risk, although this number included lands in Hawaii, which has a much higher percentage of rangeland at-risk species than any other state. It also suggests that this indicator is not yet useful, and will not be so until population trend data become more widely available.

Geographic Variation

Some indicator wildlife species transcend ecoregion boundaries, while the home range of other species do not; for example, barren-ground caribou and ptarmigan only occur in the grass and brush tundra (Bailey 1998). It may be beneficial to include both kinds of wildlife species to represent dynamics of this indicator. These representative species can be identified through a collaborative selection process involving the various governmental agencies, particularly state wildlife management agencies and groups that collect wildlife population data within each ecoregion.

Scale in Time and Space

The indicator is meaningful at different spatial and temporal scales. However, as described above, representative species must be selected at the ecoregion level to be useful at the national level. This does not preclude data collected at local levels from being aggregated upward as long as there is consistent data collection protocol for the representative species that recognizes the effect of vegetation in sampling population size and extent. It is recognized that all species will never be adequately monitored at a national level.

Temporal scale trends are important when combined with other indicators to evaluate rangeland sustainability. This indicator should show both short-term and long-term trends in presence and density. This is particularly important because many wildlife species densities can be influenced by normal cyclical climate changes that can cause populations to fluctuate up and down, sometimes year to year. Therefore, longer-term trends will typically be representative of productive capacity changes. The evaluation of these changes becomes the role of policymakers.

Data Collection and Availability

Wildlife species numbers (spatial and temporal) can provide both species presence and species density at various scales. Surveys of animal numbers that collect count data are, intrinsically, only indices of population size, so interpretations of changes in population are subject to error (Link and Sauer 1998). Moreover, most wildlife species data are collected by state wildlife agencies, and both the species monitored and the collection methodologies followed lack consistency for regional/national assessments. Perhaps the most uniform national wildlife survey is the North American Breeding Bird Survey (BBS). The BBS has collected data for nearly 50 years, and it now monitors several hundred species of birds along more than 3,500 survey routes across the 48 conterminous states (Peterjohn 1994). The USDI Fish and Wildlife Service has responsibility for keeping track of threatened and endangered species.

At a broad landscape scale, Gap analysis species maps portray distributions of numerous vertebrates, including wildlife species found on rangelands, based upon field samples and species-habitat models (Jennings 2000). These maps, which are validated for accuracy, provide an alternative to monitoring actual wildlife numbers.

Clarity to Stakeholders

Rangeland stakeholders and, for the most part, the general public usually understand the indicator and indicator units with little explanation. However, rangelands provide habitat for such a variety of wildlife species that clarity might be promoted by selecting representative species by functional groups and ecoregion for monitoring.

Annual Removal of Native and Non-Forage Biomass

Description and Importance of the Indicator

This indicator measures the annual harvest from rangelands of 1) native hay and non-forage plant materials, including landscaping and decorative plant materials, 2) edible and medicinal plants, 3) wood products, and 4) biomass for biofuels.

Traditional non-forage biomass products have relatively high local value and may have exceedingly high international value (Lazaroff 2003). Under some conditions, the net effect of recurring harvests and/or removals of non-forage products could significantly impact ecosystem properties and processes at a broader scale than the activities themselves. During droughts, the value of native hay significantly increases, even in adjoining regions not suffering from drought. While annual production may or may not be altered due to these commodity removals, excessive removal may deplete biodiversity and alter habitats, thus reducing sustainable productive capacity of rangelands.

Biofuels

Interest in biofuels as a form of renewable energy rapidly increased during the late 20th century, both domestically and internationally (Ramsey 1985). Presently, most of the energy produced from biomass comes from corn starch (for ethanol added to gasoline), along with wood and wood products for heating commercial and residential buildings. If biofuels are to substantially replace liquid fossil fuels, the resulting expansion will require breakthroughs that allow the commercial production of cellulosic crops for bioenergy (Walsh et al. 2003). Some scientists are calling for a national strategy of burning biomass for electricity generation, instead of converting it to liquid fuels, as matter of efficiency (Ohlrogge et al. 2009). Regardless, if rangeland grasses and woody material are produced for biofuels, monitoring mechanisms should be expected to be put in place by agencies such as NASS and/or the National Renewable Energy Laboratory.

Oak Ridge National Laboratory, in conjunction with the departments of Agriculture and Energy, produced a landmark report on biofuels availability that became commonly known as the "Billion Ton" study (Perlack et al. 2005). The report lumps perennial grass biomass from rangeland with pastureland and agricultural lands in its projection that agricultural lands can produce 377 million dry tons of perennial crop biomass from 55 million acres by 2030. Switchgrass (*Panicum virgatum L.*) in particular has attracted considerable attention for biofuels production due to its considerable energy production potential with lower fertilizer and fossil fuel inputs on marginal croplands than corn (Walsh et al. 2003). However, there are concerns over conversion of large swaths of native rangelands to biofuels monocultures (Fargione et al. 2008). These include increased agri-chemical pollution, loss of diverse forage resources, and loss of landscape and associated biological diversity (Groom et al. 2008).

Geographic Variation

This indicator is important and meaningful to completely characterize the productive capacity of rangelands. The ecosystems that have evolved and produce these important economic products are as variable as the plant species that are produced in those ecosystems. Ecoregion sampling designs will be required to reflect the unique cultural and biological differences and temporal product demand shifts in several of these commodities. Preliminary searches at the state level indicate that data on native hay harvests are not now available, but agricultural statistic agencies may collect such data if additional funds become available. There are currently no statistics concerning the plants discussed below.

Desert rangelands produce some of the highest valued commodities in the form of cacti and yucca (Lazaroff 2003), which are physically removed for transplanting, often illegally, to urban areas throughout the country. Many of these landscape-valued plants have highly evolved adaptability to desert ecosystems, including unique photosynthesis pathways, slow growth, and survival in the most severe conditions. Medicinal and ceremonial plants valued by American indigenous cultures also have high market value throughout North America. This has led to significant over-harvesting and the loss of large areas where production previously occurred.

Temperate tall and midgrass prairies and subirrigated native meadows have historically been harvested for hay. Since the late 19th century, these meadows have assured livestock producers of hay availability during winters and dry seasons. During settlement times prior to 1890, the lack of harvested hay could lead to rangeland overgrazing (Mitchell and Hart 1987). The recent development of "grass banks" by some grazing associations in cooperation with federal agencies represents a non-harvested form of forage available during droughts and other times when rangeland forage is not available for livestock grazing. However, rangeland set aside for grass banks is not considered in this indicator.

Southern savannas and pinyon-juniper woodlands contain species that are highly valued for essential oils distilled from root masses, as well as aboveground trunks for fence posts and firewood, particularly the juniper species (Conner et al. 1990). Pinyon pine communities provide a highly valued pine nut used for cooking and consumption. Pinyon nuts are now used in gourmet food recipes throughout the world. Properly managed, this resource provides a significant income to some American Indian tribes.

Pinyon and juniper species are distributed throughout North America with different juniper species unique to various ecosystems. When kept in balance by periodic fires and properly managed grazing, the junipers provide habitat for many species of birds and small mammals. It is commonly perceived, however, that pinyon-juniper woodlands have widely expanded into adjoining ecosystems over the past 150 years, primarily because of overgrazing in the late 19th and early 20th centuries, and the resulting decrease in fires following the loss of fine fuels (Springfield 1976). However, evidence of extensive invasions of pinyon-juniper into grassland ecosystems is not necessarily conclusive. Some scientists believe these ecosystems have primarily increased in abundance by changing from savanna types to dense woodlands and have re-established on sites previously occupied (Samuels and Betancourt 1982). It is likely that the answer lies somewhere between these extremes, and pinyon-juniper woodlands have fluctuated within recent geologic time. However, recent expansions are primarily the result of decreasing fire intervals and understory fine fuels (Miller and Wigand 1994; Van Auken 2000).

In addition to the previously listed plants, several herbs that grow in natural prairies in the eastern United States along with the more arid rangeland regions also provide the modern herbalist with materials for homeopathic remedies.

Scale in Time and Space

The distribution of native and non-native harvested biomass is highly variable, geographically. Spatially, most data will be most relevant at the ecoregion or physiographic region level. In some instances, the species have very long (multi-century) growth and reproduction cycles and, due to the distribution characteristics, have very long time frames.

Data Collection and Availability

Data describing non-forage biomass and related products are conceptually feasible, but no regional-national methods, procedures, or datasets currently exist. Most existing data are local in scale and associated with site-specific biodiversity issues, such as removal and depletion of landscaping yucca and cacti (Lazaroff 2003), high-value juniper (cedar), golden cheeked warbler (*Juniperus ashei*) habitat, and medicinal herbs. Public lands seed collection permit numbers is one source of data that has yet to be developed.

Native hay production data can conceivably be obtained at the state level if adequate funding is found. Statistics could then be aggregated to regional and national levels for recurring assessments.

Clarity to Stakeholders

This indicator is understandable to broad audiences at relevant scales. While the information appears to be isolated in some instances to specific regions, (such as the north central prairie or southwestern desert states), the concepts involved in the use of and the loss of these unique components of rangeland are understandable by a very broad audience, as witnessed by the recent reports on loss of cacti for ornamental uses (Lazaroff 2003).

Summary

Productive capacity is a trait of ecological systems that science has identified as an important measure of sustainable management. Declines in ecosystem productivity often go together with reductions in ecosystem goods and services important to society (Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments 2000). While this concept is reasonably understood by the general public, there appears to be little connection between understanding the relationship between delivery of goods and services and the capacity to produce these goods and services through sustainable management. Recent surveys of objectives and beliefs of people living in the United States show a strong agreement with statements that natural resources and biodiversity should be preserved by restricting timber harvest, grazing, and mining (Shields et al. 2002). Yet there is an apparent lack of public understanding regarding the linkage between productivity on one hand and ecosystem health and biodiversity on the other (Tilman et al. 1996).

In earlier decades, when more people lived closer to agriculture, we suspect public attitudes were more accepting of productivity indicators as central for monitoring sustainable management. For example, forest visitors coming from rural communities tend to be somewhat more agreeable to livestock grazing than visitors from more urban environments (Mitchell et al. 1996). Thus, outreach activities may be needed to show the place of productive capacity as an essential criterion of rangeland sustainable management.

Indicator development for the productive capacity criterion focuses on quantifying primary (photosynthesis) production and secondary (consumption by herbivores) production levels of energy flow in an ecosystem. The first emphasis is on primary productivity, both total biomass (production) as well as rates of production (productivity). The secondary production focus is on long-term trends in utilization by domestic and wild grazers and the associated communities, both human and wildlife, that are dependent upon these ecosystems. A final focus examines other biodiversity effects from utilization of non-forge rangeland products. Collectively, the indicators measure and characterize energy flow through the ecosystem from photosynthesis through grazing animals.

Rangelands comprise a wide spectrum of ecological communities, from deserts and prairies, to coastal grasslands and savannas, to cold desert shrub-steppes. The need to assess total productive capacity, therefore, must include both remotely sensed imagery and direct estimates of biomass utilizing a variety of measurement techniques suited to the type of ecosystem being monitored.

Many of the data sets required to assess productive capacity are available in disparate forms, which reside within different public, state, and local entities and non-government organizations. One continuing objective of the SRR is to promote the collection of data that can be aggregated across political and agency boundaries, as well as over time. Monitoring productive capacity, like working toward a goal of sustainable rangeland management, is itself a journey – a long-term endeavor that will hopefully benefit from collaboration among data collectors and advances in monitoring technology.

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Part II

Socio-economic Criteria and Indicators

CHAPTER 5
Criterion IV: Social and Economic Indicators of Rangeland Sustainability

Daniel W. McCollum,[1] Louis E. Swanson,[2] John A. Tanaka,[3] Mark W. Brunson,[4] Aaron J. Harp,[5] L. Allen Torell,[6] and H. Theodore Heintz, Jr.[7]

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Abstract: Social and economic systems provide the context and rationale for rangeland management. Sustaining rangeland ecosystems requires attention to the social and economic conditions that accompany the functioning of those systems. We present and discuss economic and social indicators for rangeland sustainability. A brief conceptual basis for each indicator is offered, describing its potential relationship to rangelands.

Authors are [1]Economist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 80526, USA; [2]Vice Provost for Outreach and Strategic Partnerships, Colorado State University, Fort Collins, CO, USA, 80523; [3]Professor and Head, Dept of Renewable Resources, University of Wyoming, Laramie, WY, 82071, USA; [4]Professor, Dept of Environment and Society, Utah State University, Logan, UT, 84322, USA; [5]Sociologist, Ypsilanti, MI, 48197, USA; [6] Professor, Dept of Agricultural Economics and Agricultural Business, New Mexico State University, Las Cruces, NM, 88003, USA; [7]Economist (retired), U.S. Department of the Interior and Council on Environmental Quality, Washington, DC, 20503, USA.

The listed authors comprise the core of the Social and Economic Working Group of the Sustainable Rangelands Roundtable. Other participants engaged in discussion from time to time, including Charles Curtin, Ralph Crawford, Marty Beutler, James Cash, Neil Rimbey, and Tom Bartlett. Their contributions to the discussion and process resulting in these indicators are gratefully acknowledged. Keith Owens and Neil Rimbey, the Editor and Associate Editor of Rangeland Ecology & Management, along with two anonymous reviewers provided helpful comments and suggestions that improved the clarity and relevance of this chapter. Finally, Olivia Salmon provided editorial suggestions that improved the clarity and readability of this chapter.

Correspondence: Daniel W. McCollum, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 80526, USA; email: dmccollum@fs.fed.us

Introduction

Healthy rangeland ecosystems depend on supportive social and economic infrastructures. Social and economic infrastructures provide the framework or context in which rangeland use occurs and rangeland health improves or deteriorates. To look at rangeland sustainability exclusive of that social and economic infrastructure is to see an incomplete picture.

The economic and social literature on conservation values and behavior consistently indicates that farmers may have strong stewardship values, but those values are not always reflected in actual conservation behavior. This "disconnect" between beliefs and values on the one hand and actual behavior on the other is often evident when markets mediate management decisions (Coughenour and Swanson 1994). This association has a long history in the socioeconomic conservation literature. Heady and Allen (1951) determined that Iowa farmers who practiced conservation appeared to act irrationally when their behavior was evaluated strictly relative to market demands. Indeed, conservation policy since the New Deal has sought to narrow the gap between what farmers would like to do and what they can put into practice given market realities and incentives (Coughenour and Swanson 1994).

While this literature has focused on farming, the basic principles are relevant for ranchers and rangeland management. Implementing sustainable practices in the context of competitive markets can be difficult. Like farmers, ranchers are expected to internalize the costs of conservation. And, like farmers, ranchers have often chosen economic viability over their desire for more sustainable systems. Sustainable rangeland management, whether on public or private lands, will be influenced by the values of key stakeholders and by the political economy and market structures in which management decisions are made. It is important that such factors be measured and applied to empirical assessments of rangeland sustainability.

The relevance of social and economic factors to sustainable ecosystems was pointedly illustrated by Vosti (1993) when describing survival in the Brazilian Amazon:

> Jose (Carvalho) doesn't have a perverse desire to denude the world of rain forests, nor does he love the toil, danger, or high cost associated with felling massive trees with fairly rudimentary tools. Jose wants to guarantee food on the table and a livelihood for his family of six living in one of the least hospitable places in the world. It is not an easy task. Jose has been dealt a bad hand in the social reshuffling of natural resources. But by hook or by crook, he gained access to trees (lots of them), poor soils, seasonally torrential rains, malaria (lots of it), and isolation—all of which combine all too frequently to generate hunger.
>
> Jose is not completely ignorant about the valuable hardwoods or rich biodiversity contained in the remaining forested portion of his lot that persuades him to pick up his saw. No, he has heard that his private forest contains strange and potentially useful trees and plants. But he is a newcomer to the area, and there is no one to tell him which plants are possibly valuable, and virtually no scope for turning these trees or special plants into cash or food, which is what his patch of forest must generate in order to sustain his family.
>
> Jose is not shortsighted either. He does look to the future. He knows his annual cropping patterns will deplete soil nutrients. But his view of the future is through the window of the present – action taken today may bring doom tomorrow, but failure to undertake today's action will almost certainly bring today's doom.

> Jose knows that some agricultural strategies require much less forest conversion than others. He knows that horticultural pursuits require the least amount of cleared land, and cattle require about one hectare of cleared forest per head. But poor market links, virtually nonexistent banking systems, and ever-increasing shortages of agricultural labor (including on-farm labor as Jose's family grows older and off-farm wage labor as urbanization trends accelerate in these hinterland areas) force his hand. He must diversify his production activities in ways that reduce risk and can be done with available labor – the trend towards increased cattle production is clear and rational. (Vosti, p. 24)

The story is from Brazil, but the dilemma is repeated in many parts of the developing world. The principles underlying Jose's situation are relevant here.

"Given his ecosystem, his aspirations, and the constraints he faces, Jose has no choice but to deforest small plots of his land. It is legal to do so on up to 50 percent of his land. Once the land is exhausted—often after a few years—he needs to deforest more. His choices are limited; his future is bleak. He begins to saw the next tree." (Vosti 1993, p. 25).

The Roundtable on Sustainable Forests acknowledged the necessity of social and economic indicators (USDA Forest Service 2004), but the group focused primarily on ways in which the natural resource base benefits the economy and society. We attempt to take that a step further and give equal weight to the reciprocal relationship: the potential positive and negative impacts of the economy and society on the sustainability of natural resources, and rangelands in particular (Azar et al. 1996). Not only do natural resources contribute to economic and social well-being, but economic and social infrastructure and conditions contribute to (or detract from) ecosystem condition and sustainability.

It is difficult to define economic and social indicators that directly relate rangelands and rangeland conditions to social and economic dynamics. Social and economic structure is bigger than rangelands. Rangelands (and other natural resources) play different roles in different places. In some areas, rangeland and its uses are major components of local society and economies. In other areas, rangeland plays virtually no role at all. Because of those different levels of involvement in local social and economic systems, the indicators we consider relate to communities rather than specifically to rangelands. Depending on the locality, rangelands and rangeland use are just one of multiple natural resource-based land uses. Rangelands are not unique in their dependence or their influence on social and economic infrastructure. Timber and mining, for example, have similar interplay with communities. This points out one of the differences between the social and economic indicators and the more ecological-oriented indicators that are detailed in other chapters of this monograph. The ecological-oriented indicators focus directly on the land and on rather specific plots or groups of plots. The social and economic indicators focus directly on communities and people that affect and are affected by the land and only indirectly focus on the land itself. That is not to say that one set of indicators is more important than the other, just that they are different and the two sets complement one another.

Underlying this discussion of social and economic indicators of rangeland sustainability is the notion that there is a reciprocal relationship between social, economic, and ecological well-being. That is a fairly standard interpretation of sustainability. But, how does this relationship work? And how do actions or conditions or disturbances in one realm (i.e., social, economic, or ecological) affect conditions in other realms? The key question is: What linkages exist between (and within) social, economic, and ecological components of the big picture of rangeland ecosystems and how do they affect sustainability? The Sustainable Rangelands Roundtable (SRR) has proposed a conceptual framework in which to think about such linkages and effects (Fox et al.

2009), and some illustrative applications of the framework can be found in Maczko and Hidinger (2008). That framework suggests pathways along which to look for linkages among the social, economic, and ecological realms of rangeland ecosystems, and explore potential interactions. The example of Jose Carvalho and the Brazilian rainforest cited earlier fits within this framework. That example suggests the ecological well-being is a function of economic and social well-being. A hypothesis then would be that we expect to see an increase in sustainable rangeland management practices as ranchers' social and economic well-being improves. There is also likely to be a relationship in the other direction, i.e., positive and negative effects of the resource base on the economy and on society. As rangeland condition or health improves or deteriorates, we expect to see human and community well-being also improve or deteriorate. Further, we expect to see individual components of social, economic, and ecological well-being react as they are influenced by changes in other components.

Directly measuring economic and social indicators at the national or even regional levels of analyses presents an array of conceptual and methodological challenges when the objective is to provide unambiguous empirical associations with other indicators and conditions of rangeland health. These challenges include 1) establishing the relationship of economic and social factors to rangeland sustainability, 2) determining causal relationships among socioeconomic and ecological indicators, 3) addressing issues associated with the unit of analysis (scale), and 4) finding and obtaining data for the indicators.

Several of the socioeconomic indicators described here are indirect measures that include economic and social structures generally associated with individual and community well-being. For example, measures of demographic structure provide indirect indicators of population stability, distribution of populations by age, gender, ethnicity, social stratification, and rates of change that can be assumed to indirectly measure components of actual well-being of individuals and their communities. The conceptual and methodological challenge is to tease out the degree of association among these indicators that can reasonably be attributed to the relationship between rangeland health and human activity.

Even in sub-regions of the United States that are predominantly characterized by rangeland ecosystems, the economic and social activities occurring within landscapes may have limited direct impacts on rangeland ecology. A rural community may gain population due to natural amenities that attract retirees while the number of people in direct production activity on rangeland declines. Or, as rural communities diversify their economic base, they may provide off-ranch employment opportunities that make it easier for otherwise economically marginal ranching operations to stay in business. We address this lack of direct measures by providing a minimum number of indicators that cover basic conceptual issues associated with economic and social activity. This provides a basic dataset useful for examining the associations between socioeconomic activity and rangeland sustainability.

The Problem of Scale

The issue of scale presents a persistent challenge when defining and using social and economic indicators. Economic and social conditions within any county, state, or region are potentially very diverse. This is especially true as the scale of analysis moves from the local or specific area to a regional or national level. Changes in local areas can be masked by conditions across a larger area.

It is our contention that social and economic indicators are most meaningful at a local scale. Ideally, we would like to have the ability to measure indicators at a community level. Higher levels of aggregation can mask effects and impacts that are important to communities. In cases where an aggregated perspective is desired, communities can be combined to provide such higher levels of aggregation. Pragmatically, however, counties seem to be the closest approximation possible to communities with a reasonable degree of consistency of available data. Social and economic data are generally reported at the county level. In most cases, the actual sampling is at a finer level, such as the individual, family, or household. In some cases, opportunities exist for spatial and temporal analyses below the county level, but such data are spotty at best and often incomplete in terms of the number of years for which data have been collected. Sample sizes in a county-wide sample are often not large enough to permit rigorous analyses of sub-county areas.

Generally, data related to rangeland uses and user behaviors are sparse and often not collected in a way that allows one to distinguish across vegetative types. Recreational use of rangelands is one example. Data are available for some specific areas but not others and for some specific activities but not others. Even when data are collected on the same activities, the definition of variables may not be consistent enough to be combined across geographic areas and over time. Even grazing data are incomplete and inconsistent. Data are collected on the number of animal unit months (AUMs[1]) available in particular grazing allotments but often not on the number of animals actually grazing the allotment.

While only a very imperfect representation of a community, the county level is the spatial scale most likely to provide consistent data across multiple areas. In an ideal world, we would be able to aggregate indicator data up to regional and national scales. As noted by Haynes (2003, p.2), however, little guidance is available for how to scale community information upward to broader spatial scales. Interpretation of community-oriented indicators becomes more difficult, and probably less meaningful, as scale broadens to regional or national levels.

Social and Economic Indicators of Sustainability

We have chosen three groups of indicators in our attempt to capture the interplay between social and economic structures and processes and rangeland sustainability. "National Economic Benefits" considers the types of products coming from rangelands that are valued by society. This is one aspect of the ways in which rangelands affect people and vice-versa. "Community Well-Being and Capacity" seeks to describe how communities are faring in rangeland-dominated areas.

The indicator set, "Community-Level Explanatory Indicators that might be Relevant to Sustainability," seeks to understand how communities affect rangelands. Each indicator is discussed within its grouping. "Data sufficiency" for each indicator is classified as A, B, C, and/or D depending on whether methods and procedures for data collection and reporting are sufficient and whether datasets of a useable quality exist at an appropriate scale. The data sufficiency categories are shown in Appendix 1-E.

National Economic Benefits

Indicators titled "National Economic Benefits" relate to the products and benefits derived directly from rangelands and rangeland use. The indicator numbers refer to the overall list of rangeland indicators developed by the Sustainable Rangelands Roundtable (SRR). The complete list of criteria and indicators can be found in Appendix 1-C.

1 An animal unit month (AUM) is defined as the amount of forage required by one animal unit (defined as a 1,000 pound cow, or the equivalent) for one month or the tenure of one AU for a one-month period.

Indicator 27. The value of forage harvested from rangeland by livestock.

Livestock grazing is the historical economic use of rangelands and continues to be an important use on both public and private lands. Changes in the value of forage used by grazing animals can indicate change in rangeland sustainability because they suggest increased (or decreased) pressure to harvest vegetation as forage to the exclusion or detriment of other uses or values. Forage values can also indicate quality of the forage in a particular area.

Indicator 28. Value of non-livestock products from rangeland.

This indicator relates to the economic value of products from rangeland that are not related to livestock production, including recreation, wildlife and wildlife habitat, scenic views, nature experiences, open space, etc. Rangelands produce more than just livestock. The value of these other outputs is important for recognizing the full range of contributions made by rangeland and the land-use pressures that might affect sustainability.

Indicator 29. Number of visitor days by activity and recreational land class.

This is a measure of the quantity of recreation use on rangelands and where it occurs. It has relevance to sustainability as a measure of benefits derived from recreation on rangelands and intensity of use. Different types of recreation affect land differently in relation to rangeland health and sustainability. Classifying recreational land as primitive areas, roadless areas, open public lands, private lands, or other types provides a basis to compare the intensities of recreation use across rangelands and how use changes through time.

Indicator 30. Reported threats to quality of recreation experiences.

This indicator is envisioned as a way to address a problem inherent in simple measures of recreation use: rangeland sustainability is influenced by the ecological and social impacts of recreation use, and these impacts are not necessarily correlated with user density.

Biophysical impacts of recreation typically follow a curvilinear pattern where marginal changes in impacts (e.g., soil compaction, change in plant species composition) become smaller as use levels increase. As a result, changes in visitor numbers may or may not indicate loss of additional value at the site level, depending on whether use is already low, moderate, or high. Social impacts of recreation – crowding, conflict between user groups, and depreciative behaviors (vandalism, littering, rule violation, etc.) – are more dependent on characteristics of the use and users than on simple numbers of users.

Accordingly, a useful indicator of recreation value, and the relationship of recreation activity to sustainability, should account for quality as well as quantity. One way to do this might be to create a composite index based on manager reports from a scientific sample of rangeland recreation settings, stratified by the number of discrete units and the spatial extent of land ownerships. Questions used in this index could include

1. "How would you characterize the level of crowding complaints by recreationists in your jurisdiction during the past year: significantly decreased, slightly decreased, same, slightly increased, or significantly increased?"
2. "How would you characterize the level of conflicts between recreation uses or user groups in your jurisdiction during the past year: significantly decreased, slightly decreased, same, slightly increased, or significantly increased?"

3. "How would you characterize the level of depreciative behaviors (vandalism, littering, rule violations, etc.) in your jurisdiction during the past year: significantly decreased, slightly decreased, same, slightly increased, or significantly increased?"

Along with this (qualitative) index, quantitative data related to physical features such as road density, trails, home density, and so on, would need to be collected and linked to the index.

Indicator 31. Value of investment in rangeland, rangeland improvements, and recreation/tourism infrastructure.

This indicator relates to expenditures on new structures and similar inputs for a variety of uses. It is the amount agencies and individuals are willing to spend on infrastructure for any given use of rangelands. It would be useful if data could be found that differentiate between public investment, private investment, and cost-sharing (joint investment). In terms of sustainability, it should indicate how much the current generation is willing to invest to maintain and improve the resource base for a variety of uses. Investment explicitly implies that funds are expended to obtain (or enhance) future returns from productive rangeland uses by expanding or enhancing natural capital (the natural resource base).

Indicator 32. Rate of return on investment for range livestock enterprises.

This indicates whether ranch families are earning a competitive rate of return from producing livestock on rangelands. If the rate of return on rangeland-based livestock operations is not competitive, it might indicate that other on-ranch forms of economic returns and/or lifestyle values are important (Torell et al. 2001), other off-ranch sources of income are important, or that the ranch is likely to be converted to other uses. The latter may pose threats to biological diversity of ecosystem processes (e.g., oil/gas development, rural subdivision).

Indicator 33. Area of rangelands under conservation ownership or control by conservation organizations.

This indicator measures the number of conservation easements and number of acres protected under conservation easement. It shows the presence and trend of open space or other undeveloped or minimally developed land areas. It is an amenity availability measure and speaks to the desirability, adaptability, and resilience of communities, and to the community perception of the importance and value of that land use or asset. (Wiebe 1995; Wiebe et al. 1999)

Indicator 34. Expenditures (monetary and in-kind) for restoration activities.

The amounts of funds and in-kind contributions, like time volunteered, that organizations and individuals contribute to rangeland restoration activities indicate the strength of importance that people place on restoring and maintaining rangelands. These expenditures are made to maintain, enhance, or restore the rangeland ecosystem without explicit future monetary returns necessarily expected from the investment.

Indicator 35. The threat or pressure on the integrity of cultural and spiritual resource values.

This indicator relates to the intensity of concern over, and pressures for management of, cultural and spiritual resources, which are assets valued by particular groups of people (Eisenhauer et al. 2000). It is assumed that when spiritual or cultural values are threatened by activities on rangelands, citizens will suffer loss of value from those rangeland uses and may act to protect those values in ways that might decrease the value of other resources (e.g., by restricting livestock grazing or recreation access—either by legislation or regulation).

This indicator could be a two-part, subjective measure of increase/decrease in concern over potential threats or pressures placed on spiritual and cultural resources. The best way to do this might be via two direct questions on an annual survey (census or random sample) of field-level managers of public rangelands. While it is likely important on private lands, those data are not likely to be known, available, or acknowledged. Question items might include

1. "How would you characterize the level of public concern expressed during the past year over the status of spiritual resources (e.g., religiously important sites, citizens' ability to obtain desired contemplative benefits from rangelands) in your jurisdiction: significantly decreased, slightly decreased, same, slightly increased, or significantly increased?"
2. "What is your perception of the occurrence of incidents during the past year that compromised the integrity of historic or archaeological sites within your jurisdiction: significantly decreased, slightly decreased, same, slightly increased, or significantly increased?"

Community Well-Being and Capacity

Indicators of "Community Well-Being and Capacity" are intended to portray local social and economic structure and capacity. According to rural sociological theory, the theoretically appropriate unit is a community, or at least a relatively local unit of social organization (Wilkinson 1991). While there is a wealth of social and economic data that can inform inquiries about well-being, most of the relevant data are only available at the county level. Only infrequently, and in limited areas, are such data collected at the smaller community scale. As stated above in the section on "Scale," we are left to assume that the county is a "reasonable" or "best available" approximation to the community unit.

Which characteristics describe the "community" as a whole and the interactions and relationships between individuals within the community? That has been, and continues to be, an active topic of research. Our hypothesis is that consideration of certain key characteristics and tracking them over time is indicative of the resilience of a social system and its capacity to weather and adapt to changing resource conditions. These characteristics and their interpretation may be only indirectly tied to rangeland, but the health and resilience of the local social and economic structure is very likely to play a role in the sustainability of rangeland and rangeland use.

Indicator 36. Poverty rate – general.

The U.S. Department of Agriculture (USDA), in cooperation with other federal agencies, sets the poverty rate at the level where one-third or more of the household budget is spent on food. It is assumed that any household spending one-third of its budget on food is unlikely to be maintained at a minimal quality of life. This general poverty rate is a gross measure of social stratification that indicates the extent of poverty within a county or local area (U.S. Census Bureau 2000). The greater the concentration of poverty (e.g., a higher percentage of a given population in poverty) the less likely it is that the population has the resources necessary to adapt to ecological and socioeconomic changes (Newman 2002: Chapter 10). Such increased social stratification, then, is related to a reduced ability to sustain counties. A lower capacity to adapt to changes implies a lower level of sustainability. This indicator is needed to interpret interaction effects with other indicators.

Indicator 37. Poverty rate – children.

This indicator adds to the previous one by measuring the proportion of children (age 17 or younger) who live in households determined to be at or below the poverty threshold. Children in poverty can be a more specific indicator of community resilience because it may portend future capacity. Communities with high rates of poverty appear to have a legacy of poverty over time (O'Hare and Johnson 2004). A higher rate is associated with lower integration into the community and a higher likelihood of undesirable outcomes like reduced health status, human capital, and social capital. This indicator is needed to interpret interaction effects with other indicators.

Indicator 38. Income inequality.

This indicator addresses economic distribution and speaks to social equity. It indicates the general welfare of the community by looking at the distribution of people across a range of incomes and measuring the income disparity in the community. It is a direct measure of economic and social stratification that complements poverty statistics. Lower levels of income inequality are associated with higher cohesion or integration of the community, leading to a more stable and resilient community. This indicator permits more sensitive measurement of social and economic inequality when a Gini coefficient is applied. A Gini coefficient is a widely used rough measure of the amount of inequality in the income distribution (Eckert and Garner 2003). Gini coefficients measure the divergence between the income distribution actually occurring in a given geographic area (as portrayed by the Lorenz curve) and a totally equal distribution of income.

Indicator 39. Index of social structure quality.

As noted above, at the county level there are extensive data on social and economic conditions. Social science literature often addresses the multidimensionality of concepts being measured using indexes, i.e., the adding together of multiple indicators to create a single broad-based measure complying with standard statistical rules of internal reliability and validity of measurement. Since it is not possible to predict which particular variable(s) might provide the best measure of quality of local social structure for any given inquiry on sustainability, we suggest that combining several relevant variables into indexes provides a better, and more generally useable, indicator. The quality of social structure might include such things as access to and quality of medical care (e.g., per-capita hospital beds, numbers of physicians and nurses), the presence and extent of cultural and community services, the extent and availability of public recreational facilities (expenditures per capita on parks, etc.), and crime rates, among other things (Marans and Mohai 1991; Fureseth and Walcott 1990). Indexes of this type are frequently constructed to rate quality of life or desirability of living in different places, e.g., *Money* magazine's "Best Places to Retire" (www.money.cnn.com/best/bpretire/ , and periodically featured in the magazine). However, there is little basis in social theory for most such indexes. Given that decisions about specific variables to include, units of measure, and weighting can strongly influence the values and sensitivity of such an index, we suggest use of this indicator should come only after considerable research and model testing. We remain convinced of its relevance but recognize its need for research and development.

An alternative to the Index of Social Structure Quality discussed above might be a measure of community resilience. Such a measure has been proposed and developed by the Roundtable on Sustainable Forestry (see the various links related to "Indicator 38: Resilience of Forest-Dependent Communities" (from September 6, 2007 meeting) found on http://www.sustainableforests.net/summary20062007.php , and Magis 2010). While developed in the context of forest-dependent communities this indicator is equally relevant to rangeland-dependent communities. The indicator is intended to measure the ability of communities to adapt to changing conditions. The premise behind the indicator is that all communities have access to numerous kinds of resources, otherwise known as capitals. These include: natural, human, cultural, financial, built, social, and political capitals. A resilient community actively develops and utilizes all of its capitals, includes all segments of the community in community endeavors, engages groups to work together, works strategically toward development of the community, and works to ensure equity across community members. As the community invests in and develops its various capitals, it develops capacity to respond effectively to change, i.e., it develops Community Resilience (USDA Forest Service 2010, p. 2-96). The same capitals that allow a community to react and adapt to changing conditions allow the community to behave proactively to avoid or mitigate potentially disruptive changes. Both the capacities to adapt to change and to behave proactively before change occurs are characteristics of a sustainable community. Sustainable communities have implications for the sustainability of rangelands. The extent to which these various capitals are present in a given community can be assessed using qualitative research methods like interviews and/or surveys, and expressed in terms of an index or a set of scores based on the individual capitals. Such a measure could then be assessed and monitored over time. Research is needed to develop a measurable expression of community resilience from this conceptual construct.

Indicator 40. Community satisfaction.

This indicator describes the level of satisfaction a community or county has with socioeconomic infrastructures, employment opportunities, and social support networks (Goudy 1990; Brown 1993; Marans and Mohai 1991; Wilkinson 1991; Bender 1978). Places with low satisfaction risk significant out-migration and having low capacity for adapting to opportunities and threats. The indicator measures how the local community feels about sustaining local resources and the potential of that community to take action toward sustainability. In a rangeland context, this indicator can measure the contribution of local natural resources to individual satisfaction with multiple dimensions of community life. Conversely, community satisfaction level could be related to the likelihood of maintaining a viable mix of rangeland uses. The latter, once again, calls for additional research on links between social infrastructure and resource sustainability.

Indicator 41. Federal transfers by categories (individual, infrastructure, agriculture, etc.).

Federal transfer payments (e.g., food stamps, social security, Medicare/Medicaid, support for Women, Infants, and Children–WIC) are a relatively stable source of income to individuals and to local, especially county, governments during most economic conditions. This indicator is another aspect of economic resilience and the capacity to endure changes in economic conditions. The presence of such transfers could help counteract some of the adverse effects of poverty and income inequality.

Indicator 42. Presence and tenure of natural resource non-governmental organizations at the local level.

The presence of private sector non-governmental organizations (NGOs) is considered to be an indicator of professional administrative capacity for conceiving, implementing, and managing community projects relating to rangeland sustainability or restoration that otherwise would be unsupported by government agencies. It is also an indicator of how strongly such groups feel about the importance of natural resources in an area.

Indicator 43. Sources of income and level of dependence on livestock production for household income.

This indicator measures the degree of dependence of ranch families on livestock production for household income. Surveys have shown few ranchers rely totally on the ranch for household income (Gentner and Tanaka 2002; Coppock and Birkenfeld 1999). Higher dependence on the ranch for income may relate to the level of grazing during drought and the ability (or inclination) to follow sustainable grazing practices that might affect ecological sustainability, analogous to the Brazilian example described by Vosti (1993). A testable hypothesis might be: As income dependence on the ranch increases, ecological sustainability may be negatively affected. Alternatively, as non-farm income increases, ranch and rangeland sustainability might be positively affected. Data on sources of income for agricultural households are discussed by Brooks and Reimund (1989), Oliveira (1990), Hoppe et al. (1997, 2001), and USDA Economic Research Service (not dated).

Indicator 44. Employment diversity.

An economic diversity index can be developed to describe the industries and sectors present in an economy. If economic diversity is defined as "a large number of different types of industries being present in an area" or "the extent to which the economic activity of a region is distributed among a number of industrial sectors," a summary statistic can be used to describe the diversity of an area and compare it to other areas. Measures such as location quotients compare local areas' proportional employment in industries to those of a larger region. The Shannon-Weaver Diversity Index measures diversity of employment, considering both numbers of industries present and the distribution of employment across them, against a uniform distribution where employment is equi-proportional across all industries (Shannon and Weaver 1949; Attaran 1986). We hypothesize that economic diversity is related to economic resilience and the ability of an economy to respond and adapt to changes in conditions. Actual measures need to be calculated to provide full and consistent coverage, but necessary data are available at the county level. Data sources include the U.S. Economic Census (U.S. Census Bureau 1997, and other years) and the Bureau of Economic Analysis in the Department of Commerce.

Indicator 45. Agriculture (ranch/farm) structure.

This is a multi-component measure of direct production in agriculture. A farm or ranch is defined as having $1,000 or more in gross agricultural sales. Other components of production include type of commodity produced, acres in production, dollar or volume levels of farm sales (a measure of scale), and the type of business organization (family, corporate, etc.). Farm structure is an indirect indicator of production capacity for food and fiber. It has become a data point to assess whether or not production can be sustained. There is not broad agreement on how the data might be interpreted, but there is agreement that these data are one basis for assessment (USDA National Agricultural Statistics Service 1992, 1997; USDA Economic Research Service, not dated).

Indicator 46. Years of education.

This indicator measures the years of formal education of the population of rangeland-dependent communities. It is an important measure of the human (and to a lesser extent social) capital available for sustaining a social group. Moreover, communities whose populations have higher levels of education may tend to have increased ability to recognize and respond to problems on local rangelands. Finally, communities with more highly educated populations might be associated with an increased likelihood of developing and maintaining community characteristics, such as cultural and arts infrastructures, which enhance a community's ability to attract and maintain a diverse and sustainable population and economy. Data are collected both by census enumeration and through the Current Population Survey. A person is asked to indicate the number of years of education completed ranging from no formal education to years in graduate education.

Community Level Explanatory Indicators That Might Be Relevant to Sustainability

The following indicators describe local human conditions in ways that are hypothesized to be linked to rangeland use and sustainability. They also attempt to capture some of the underlying beliefs and attitudes in local areas that guide the ways in which people relate to and interact with natural resources in general, and rangeland in particular. Like most indicators, their primary utility may come from monitoring trends, rather than from values measured at any one time. Establishing some of the specific links between the indicators and rangeland sustainability is a subject for continued research.

Indicator 47. Value produced by agriculture and recreation industries as percents of total economic output.

Agriculture- and recreation-based industries appear to be two of the primary sector groups of the economy related to rangelands and rangeland sustainability. While neither occurs exclusively on rangelands, tracking what happens to them in rangeland-dominated counties should indicate the pressures being placed on rangelands. As population grows and economies change, we expect there to be a differential effect on rangelands. Of course, the values that comprise this indicator will only reflect production that flows through the economy. Nonmarket values that accrue to people from such things as recreation (beyond that captured in markets) and ecosystem services provided by rangelands will be missed by this indicator. Such values should not be ignored, however. They might become the bases for additional indicators or components of indicators over time.

Indicator 48. Employment, unemployment, underemployed, and discouraged workers by industrial sector.

Data on these variables provide information on the vitality of the local economy. High numbers in the unemployed, underemployed, and discouraged worker categories could indicate an economy in trouble and a community under stress. Such high numbers occurring in rangeland-related industries (e.g., livestock production, recreation, tourism) would provide an indication of pressures on rangeland-dependent livelihoods and lifestyles.

Indicator 49. Land tenure, land use, and ownership patterns by land size classes.

This indicator measures changes in ownership, ownership stability, and how the land is being used (e.g., ranging from public to private ownership, production agriculture to residential lots). It will measure how quickly rangelands are turning over (i.e., converting from one owner to another or from one use to another). It is important to sustainability because conversion of open rangeland to housing developments, for example, have an effect on many aspects of rangelands (e.g., loss of open space, habitat fragmentation, noxious weeds) as well as diminishing future options for the land. It is also important to know what the land use is changing to as turnover occurs.

Indicator 50. Population pyramids and population change.

Population pyramids are commonly used to describe a population's basic structure. They require data on gender and age. Data are organized into 5-year age cohorts; male and female. Each population pyramid provides a snapshot of the distribution of age groups and gender. For example, the baby boom cohorts born between 1945 and 1960 bulge out as they move through an otherwise relatively rectangular population structure.

This measure provides evidence of community sustainability by indicating key characteristics of social organization as they relate to providing social and economic services within a community. A population pyramid that varies little from the youngest to the oldest cohorts is considered to be sustainable. Widely different proportions of population in general age classes indicate differing needs over time with respect to social and economic infrastructures that may be more or less likely to be derived from rangeland activities. Bulges in the population pyramid indicate changing relative needs over time as the bulge moves through age classes. For example, a population with a structural bulge in older age groups has a different relative need for "senior centers" versus elementary schools than does a population with a bulge in very young age groups. Expanding and contracting needs for social services puts more stress on community infrastructure than does a situation in which there are fairly constant relative demands for social services over time. Actual measures must be calculated to produce population pyramids that provide full and consistent coverage.

Indicator 51. Income differentials from migration.

This indicator measures the differential between household income of existing residents in an area and that of in-migrants to the area. It addresses whether the people moving in are wealthier (or less wealthy) than those already there. Retirees or the wealthy may not rely on local natural resources for livelihoods in the same fashion as long-time residents or lower income in-migrants. Moreover, disparities in income are one indication of a lack of community cohesion that can be a barrier to local action on behalf of rangeland protection or sustainable management. This indicator could be expanded to compare out-migrants, remaining residents, and in-migrants. The same dataset could provide numbers of in- and out-migrants to an area, contributing to an assessment of trends in population increase or decrease.

Indicator 52. Length of residence.

This indicator measures individuals' longevity of residence in a particular community and relates to social cohesion and integration, as well as a willingness to interact with others for a common good. It is also a measure of community stability. A large proportion of new residents could point toward social dysfunction or low community cohesion that might have implications for rangeland sustainability.

Data on this variable have not been consistent over time in the U.S. Census of Population and Housing. The most recent censuses have focused on where people lived five years previous (same location as current residence, different location in the same county, different county in the same state, different state) as opposed to asking people how long they have lived in their current community, county, state. That might or might not decrease the usefulness of those data.

Indicator 53. Income by work location versus residence.

This indicator is an indirect measure of income generated within workers' areas of residence versus that from outside the area of residence. It indicates whether the residence community provides both economic and social benefits to the income earner. For rangeland communities, it indicates the extent to which rangelands provide the desirable rural setting where people want to live, but without the employment opportunities they require.

Indicator 54. Public beliefs, attitudes, and behavioral intentions toward natural resources.

Public perceptions, intentions, and behaviors influence cultural, legal, and public policy decisions toward the management, consumption, and preservation of natural resources (Brunson and Steel 1994, 1996; Shields et al. 2002). In order for rangeland management decisions to be socially sustainable (especially on public lands), they must achieve and retain some minimum threshold of acceptability with citizens. Moreover, information about people's preferences and behavioral intentions can help in defining appropriate benchmarks for other indicators. This indicator would provide for regular measurement of preferences, attitudes, and intentions with respect to rangelands (and potentially other natural resource-based lands such as forests). Social science research indicates that a person's behaviors in political and planning arenas are influenced by his/her beliefs, attitudes, and behavioral intentions (Brunson and Steel 1996). Other indicators provide for measurement of behaviors (e.g., recreation uses, property sales, participation in restoration activities), but there are none that focus on the perceptual factors that underlie and guide those behaviors. Because there are no consistently available inventories of public preferences or values concerning natural resources and natural resource uses, data on public perceptions are often not diffused to the larger public or to the full spectrum of natural resource managers. These data would be applicable to all natural resources.

Conclusion

The development of indicators for the "Social and Economic Indicators of Rangeland Sustainability" criterion focused on three component areas. First, our focus was on products derived directly from rangeland ecosystems that are used by people and communities. Second, we focused on the communities themselves and how they react to what is happening in the larger ecosystem. Third, we tried to consider whether what is happening in the community is having an impact on the rangeland ecosystem. This latter effort is particularly troublesome because the links between social and economic indicators and rangeland sustainability are unknown in any rigorous sense. Data can be collected that describe whether local populations are growing and otherwise changing, as well as whether social and economic infrastructures are changing. Whether and how these factors of social and economic sustainability affect the ecological sustainability of rangelands remains unknown. Research is needed to rigorously identify and document such links.

Each set of indicators centers on one of these three ways of viewing the interactions among ecological, social, and economic systems. For this approach to be specifically useful for rangeland sustainability (as opposed to more broadly defined natural resource sustainability), we believe that the data must be sorted and analyzed by "rangeland counties," or those with some base level of dependence on rangeland and rangeland activities. While this definition needs to be developed, refined, and tested, we believe it is the only way to look at social and economic data in a useful way for rangeland sustainability specifically.

Much of the basic data needed to assess this criterion are currently available (Appendix 5-A). In many cases, those basic data will need to be organized and combined to calculate specific indicator variables. The weakest data are for the first grouping, "National Economic Benefits." Only two of the 10 indicators have good, existing data while two others have partial data. This is in contrast to the "Community Well-Being" and "County-Level Explanatory Indicators" groupings where only two indicators in each group do not have methods and existing data. Taken as a whole, the set of indicators should provide information that can be used to assess the social and economic benefits derived from the nation's rangelands. The issue still remains whether data can be disaggregated to a level that is relevant to the management of rangeland and to rangeland-dependent community sustainability.

Admittedly, these social and economic indicators are rather like a laundry list. Social and economic indicators of resource and resource use sustainability, in general, are at an earlier stage of development than ecological indicators just because people have not given them as much thought. With additional research and hypothesis testing, in the context of the conceptual framework laid out by Fox et al. (2009) and further developed by ongoing research, this list can be reduced to a more manageable list of indicators for which relevance to rangeland sustainability can be empirically demonstrated.

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Appendix 5-A. Data availability for Sustainable Rangelands Roundtable criteria and indicators.

No.	Indicator Category/Title	Geographic variation	Scale	Data Status (See Appendix 1-E)
27	The value of forage harvested from rangeland by livestock	Private lease rates, grazing costs (fee and non-fee costs), etc., are highly variable by geographic areas.	Mostly state-level; varies through time and space	A
28	Value of non-livestock products from rangeland	Currently unknown; specific products of interest vary geographically due to supply and demand.	Should vary through time and space	Will vary by product – must be clearly defined
29	Number of visitor days by activity and recreational land class	Generally unknown; specific locations near population centers see higher demand	Relevant at more local scales; will vary through time and space	C
30	Reported threats to quality of recreation experiences	No variation in reports; specific locations near population centers see higher incidence	Various; will vary through time and space if measures are consistent	B
31	Value of investment in rangeland, rangeland improvements, and recreation/tourism infrastructure	Demand differs by region	If tracked correctly, could be aggregated to any scale	D
32	Rate of return on investment for range livestock enterprises	Likely to be sensitive to regional variation	Useful at ranch, county, regional levels over time	D
33	Number and value of conservation easements purchased	Likely to be sensitive to regional variation	Parcel; could be aggregated to any level, most likely county	B
34	Expenditures (monetary and in-kind) for restoration activities	Likely to be sensitive to regional variation	Local; could be aggregated to any level, most likely county	C or D
35	The threat or pressure on the integrity of cultural and spiritual resource values	Meaningful at levels of individual jurisdictions, regions, nation	Can be aggregated to any level across time if measured consistently	D
36	Poverty rate – general	Regional variation, often related to minority populations	Easily aggregated over time and space	A
37	Poverty rate – children	Regional variation, often related to minority populations	Easily aggregated over time and space	A
38	Income inequality	Regional variation	Distribution is sensitive to scale	A
39	Index of social structure quality	Regional variation	Sensitive to temporal and spatial scales	B
40	Community satisfaction	Survey design can be used to capture variation	Relevant to temporal and spatial scales if gathered consistently	A

No.	Indicator Category/Title	Geographic variation	Scale	Data Status (See Appendix 1-E)
41	Federal transfers by categories (individual, infrastructure, agriculture, etc.)	Can vary by region	Local, county; can be aggregated	A
42	Presence and tenure of natural resource non-governmental organizations at the local level	Unknown	Unknown	C
43	Sources of income and level of dependence on livestock production for household income	Likely to vary based on data used	Unknown; likely to be meaningful based on measures used	Depends. Either B or D
44	Employment diversity	Should vary by region	More useful at local scales; can be used at county level	A
45	Agriculture (ranch/farm) structure	Should vary by region and locality	Sensitive over space and time; subject to changes in definition and needs to be adjusted for inflation	A
46	Years of education	Varies little by region; related to urbanization	Sensitive over space and time; easily aggregated	A
47	Value produced by agriculture and recreation industries as percents of total economic output	Should vary by region	Sensitive over space and time	A
48	Employment, unemployment, underemployed, and discouraged workers by industrial sector	Should vary by region	Local and county; sensitive over space and time; can be aggregated	A
49	Land tenure, land use, and ownership patterns by land size classes	Local, regional, national	Sensitive over space and time	D
50	Population pyramids and population change	Sensitive to location	Sensitive over space and time	A
51	Income differentials from migration	Sensitive to regions	Sensitive over space and time	A
52	Length of residence (native, immigrant more than 5 yrs, less than 5 yrs)	Sensitive to regions	Sensitive over space and time	A
53	Income by work location versus residence	Sensitive to regions	Sensitive over space and time; localized	A
54	Public beliefs, attitudes, and behavioral intentions toward natural resources	Sampling issue; expensive locally	Sensitive over space and time based on sampling frame	C or D

CHAPTER 6
Criterion V: Legal, Institutional, and Economic Framework for Rangeland Conservation and Sustainable Management

John E. Mitchell,[1] Stan Hamilton,[2] Thomas Lustig,[3] Kenneth Nelson,[4] Tom Roberts,[5] and Brian Czech[6]

Abstract: Laws, institutions, and economic policies play a large role in determining the sustainability of rangelands. They provide the basic framework from which many lasting decisions about rangeland management are made. The SRR has identified 10 primary indicators to assess how this framework influences the long-term health and productivity of rangeland in this country. The indicators within this criterion are broadly defined and examine the legal, institutional, and economic framework of rangeland conservation on a large scale. They can, therefore, be measured in multiple ways.

Authors are [1]Rangeland Scientist Emeritus, USDA Forest Service, Fort Collins, CO, 80526-8121, USA; [2]Director (retired), Idaho Dept of Lands, Boise, ID, 83709-3949, USA; [3]Staff Attorney (deceased), National Wildlife Federation, Boulder, CO, 80302, USA; [4]Economist, USDA Economic Research Service, Washington, DC, 20036-5831, USA; [5]Rangeland Conservationist (retired), USDI Bureau of Land Management, Washington, DC, 20004-1701, USA; and [6]Conservation Biologist, USDI Fish and Wildlife Service, Arlington, VA, 22203-1610, USA.

Correspondence: John Mitchell, Rangeland Scientist Emeritus, USDA Forest Service, Fort Collins, CO, 80526-8121; Phone: 970-295-5957; email: john.mitchell@colostate.edu.

Introduction

The legal, institutional, and economic framework for rangeland conservation and sustainable management in the United States can be assessed in many different ways. Indicators associated with this criterion can be numerous and detailed, such as were developed by the Montreal Process, or broadly defined and fewer in number, as is done in this report. The Montreal Process criterion entitled "Legal, Institutional, and Economic Framework for Forest Conservation and Sustainable Management" contains 20 of the 67 indicators of sustainable forest management, or 30 percent of the total (USDA Forest Service 2004).

The Sustainable Rangelands Roundtable (SRR) has divided the Legal, Institutional, and Economic Framework for Rangeland Conservation and Sustainable Management criterion into 10 broad indicators that constitute 16 percent of the 64 indicators of sustainable rangeland management, each of which is described in terms of primary data categories (Appendix 6-A). These indicators deal with land law and property rights, public participation in public land-use planning, involvement of institutions and organizations in rangeland sustainable management, economic policies, education and technical assistance, the nature of land management programs, land planning and assessments, protection of special values, monitoring rangelands and rangeland communities, and research and development.

None of the 10 legal-institutional-economic framework indicators are expressed in terms that routinely lend themselves well to specific measures that can be monitored. Normally, indicators use qualitative or quantitative methods to measure anthropogenic impacts over time on the environment, economy, and human well-being. Broadly defined indicators tend to be measurable in multiple ways, so employing them in a monitoring program first requires defining measures that provide specific details about the precise variable being inventoried (Wright et al. 2002). An alternative approach is to conduct research studies on the status and trends one or more of the components of an indicator, and use publications resulting from such studies to assess how they are or are not contributing to rangeland sustainability. A number of studies have reviewed how U.S. property rights have affected sustainable management, for example Anderson and Hill (1975) and Eaton et al. (2007).

Indicator 55. Land law and property rights.

This indicator describes the extent to which laws, regulations, and guidelines clarify property rights and land tenure arrangements on rangelands. It also evaluates how these laws recognize customary and traditional rights of indigenous people on rangelands, and whether these laws provide means of resolving property disputes by due process.

Underlying the elements of this indicator is a set of assumptions:

1. Stable property rights are essential for sustainable rangeland management.
2. Property rights reflect a society's values.
3. Property rights are evolutionary.
4. Property rights are determined by means of due process.

When the United States became a nation, the significance of protecting private property was prominent in the Founding Fathers' understanding of the rights of citizens versus the powers of government. The resulting principles that bolster the U.S. legal system rest largely on the value of individual liberties, limits on government power, and the right of people to property. The Fifth Amendment to the U.S. Constitution reinforces the balance between private and public property rights by providing that no person shall be deprived of life, liberty, or property without due process of law; nor shall private property be taken for public use without just compensation. Recently, the concept of "public use" has been extended by the courts to a broader definition than was commonly used during the 300 years after the Fifth Amendment was ratified in 1791 (Lewis 2004).

The "police power" of the government to regulate private property is exercised in a manner consistent with the Constitution and applicable laws. Environmental and zoning regulations are two examples of police powers that limit the rights of landowners. Property owners also are not able to utilize property in a manner that endangers or damages the lives or property of others. As society's values and norms slowly change over time, the balance of government power and private property rights is repeatedly subject to changing legal interpretation.

The variety of forms of property ownership, such as corporate ownership, property as collateral, intellectual property, liens, and easements, complicate the notion of property rights. Water is a special form of property on western U.S. rangelands. Western states follow the doctrine of appropriation in which water is appropriated for "beneficial" uses (Schorr 2005). During drought, when water is scarce, those who had earliest appropriated water from a particular source have superior rights over more recent (junior) right-holders. Although water cannot be "owned," water rights can be bought and sold by separate deed, through stock transfers, or with the sale of land.

Property rights of American Indians are considered a critical component of this indicator. The United Nations Permanent Forum on Indigenous Issues has affirmed that indigenous peoples have the same rights as every other person in the world, and that respect for indigenous peoples' knowledge and traditional practices contributes to the sustainable management of all countries (United Nations Economic and Social Council 2002).

Tribal sovereignty is more than an abstract legal concept; it is closely tied to the military, social, and economic development of the United States. Under the Constitution, Congress has power to regulate commerce with American Indian tribes, and it has used this means to recognize and limit tribal sovereignty. Presidential authority over tribal sovereignty rested in the ability of the United States to enter into treaties – at least until 1871, when Congress passed a law that prohibited the United States from entering any additional treaties with tribes. Until that time, 367 treaties between the federal government and American Indian tribes were ratified by the U.S. Senate. Since then, the primary mechanism for defining tribal sovereignty has been through the U.S. Supreme Court's role of interpreting the actions of the Legislative and Executive branches of government to strike a balance between the rights of tribes and the decrees of the federal government. Earlier, in 1832, the John Marshall Court had established the principle that states cannot regulate or tax American Indian nations.

In the 19th century, the Supreme Court defined several principles related to American Indian sovereignty: 1) tribal nations possessed a limited form of sovereignty that did not allow them to interact with other nations outside the United States, 2) thus tribes were characterized as having a "trust relationship" with the United States, and 3) tribal sovereignty was subject to diminution by the United States. This trust relationship was used into the 20th century to justify federal involvement in the internal affairs of American Indian communities. For example, federal policy, as upheld by the courts, restricted the ability of tribes to control the development and use of natural resources located on tribal lands until latter parts of the 20th century.

Over the past 25 years, changes in federal legislation and case law have upheld the principle of tribal sovereignty and allowed tribes to exercise greater control over their natural resources (Cornell and Kalt 1987). The Indian Self-Determination and Education Assistance Act of 1975 gradually altered the role of the federal government, changing it from one of being a "guardian" to that of a "mentor." As a result, primary decision-making authority over investment, marketing, pricing, and production has been taken from the Bureau of Indian Affairs and been given to individual tribes. There are approximately 300 American Indian reservations in the U.S., with lands comprising 225,000 km^2. A large proportion of these lands are located west of the 90^{th} Meridian where public domain was available to provide to tribes (Sutton 1975). Thus, tribal governments collectively manage a substantial area of rangelands throughout the West, and the influence that they can have on rangeland sustainable management at local and regional scales is considerable (Appendix 6-B).

The property rights relevant to the sustainability of rangelands and other natural resources include the ability to exclude or control access to the land, and the rights to dispose, alienate, transfer, manage or manipulate, use, withdraw, consume, transform, and enjoy it.

While roughly the same concepts apply to land law and property rights governing federal, state and private lands, there are some important differences among them. First, the federal code of land and property rights law is far more complex and detailed than state codes, and state codes are usually far more complex than local codes. Second, legal mechanisms are less rigid in governing activities on state and private lands. Federal laws often speak directly to regulating grazing, oil and gas leasing, off-road vehicle use, mining, wildlife protection, or other similar activities on federal lands.

State laws governing the management of state lands are beginning to recognize the importance of sustainable management. Although Western states manage state endowment rangelands to maximize income for use by schools and other institutions, they now recognize that federal and state environmental laws apply to these lands, and thus can constrain the objective of income generation. Colorado and Arizona have changed their philosophy concerning the use of state lands so that maximizing income is no longer the only consideration. In 1996, Colorado voters amended the state constitution allowing a stewardship trust on $1/10^{th}$ of the 3 million acres of state trust lands to protect "long-term productivity and sound stewardship" (Colorado Division of Wildlife 2005). The same year, Arizona established a preservation initiative whereby state lands can be reclassified for conservation and subsequently leased or sold at auction for that purpose. Municipalities can apply for state matching grants to make conservation purchases at the local level easier.

Decisions by agencies managing federal lands are strictly regulated, reviewed, and periodically revisited. On state and private lands, the laws governing rangelands tend to be less constrained and reviewed. Federal land managers cannot make a decision on how rangeland is to be managed without doing an environmental analysis under the National Environmental Policy Act (NEPA). That decision can usually be appealed to the federal courts. Federal grazing land permittees are subject to whatever management constraints are imposed by the responsible public land manager. State land manager decisions may be subject to requirements of "little NEPA" laws in some states but not in others. In general, state land managers have fewer constraints on management actions than federal land managers. The owners of private land have even fewer constraints on the management of deeded lands; these constraints usually come from federal and state water quality laws.

Until the mid-20^{th} century, landowners historically allowed access to deeded rangelands for the local community good and for the benefit of friends and neighbors, e.g., for hunting and other recreational activities. Increasing populations, exurban development, and the changing nature of landowners have transformed the customs employed by ranchers, however, to one that generally prohibits free rights of entry to private rangelands. This, in turn, has impacted efforts to implement cross-boundary conservation (Yung and Belsky 2007).

Is the "Land Law and Property Rights" indicator meaningful? Like most developed countries, the United States has highly developed property rights systems at federal, state, and local levels. Although the number of policies and regulations that affect the actions of property holders concerning their lands and natural resources have rapidly multiplied in recent years – leading to uncertainty about land-use restrictions, increased transaction costs, risk of civil and criminal penalties, and overlapping governmental jurisdictions – it is infeasible to consider any measure of land law and property rights as a significant indicator of sustainable rangeland management.

Legalities of land tenure and land use have historically reflected changing societal values. One might expect an indicator that monitors trends in land law and property rights to be more worthy of consideration in less developed countries. In particular, the ability to initiate land stewardship practices through conservation and land trust initiatives relies heavily upon a strong legal system of private property rights in balance with public land policy. An indicator that synthesizes laws that give landowners, including indigenous peoples, the right to use their lands for their long-term good and gives recognition to the value of ecosystem services resulting from such uses would be a valuable indicator in countries not having a strong land tenure system. It is argued that the structure of property rights governs the distribution of resources, and the distribution of resources is more important than the quantity of resources when it comes to promoting sustainable development (Sened 1997). A key element in the structure of property rights is individual property rights to land and land titling by government (Heltberg 2002).

What is the availability of datasets for the "Land Law and Property Rights" indicator? Methods and procedures and dataset(s) of useable quality exist at the regional-national level. Most of the data are found in government documents, found in legal casebooks and databases, and from private sources. Although considerable data are available in raw form, analysis and synthesis of this information is infrequent.

Indicator 56. Public information and public participation.

This indicator measures the extent to which laws, regulations, guidelines, institutions, and organizations provide opportunities for public access to information and public participation in policy and decision-making processes relating to rangelands.

Public participation ensures that policy and programs are vetted by a cross section of the people who are affected. Public participation can foster political support for sustainable management. All steps in the management decision process – problem identification, data collection, analysis, alternative formulation, and choice – must be open to public participation. Public involvement is thus a complex, dynamic, interactive process of bargaining, negotiating, and mediation among and between constituents and managers. Engaging the public does not ensure sustainability in itself. It does, however, inform participants about the issues involved, conflicting laws, resource limitations, and what other people and groups want.

The challenge of promoting sustainable rangeland management in a way that harmonizes economics with social and environmental needs can only be met through active public participation in public issues. Goals of citizen participation include 1) furthering democratic values by recognizing the diversity of majority interests while also considering the needs of other groups, 2) educating the non-participating public by reaching out to them, 3) allowing for social change by providing for broad access to various ecosystem services emanating from rangelands, 4) obtaining citizen ownership and trust in agency goals and plans, and 5) obtaining better conditions that reflect the objectives of sustainable rangelands.

Principle 10 of the Rio Declaration on Environment and Development states that environmental issues are best handled with the participation of all concerned citizens. “States shall facilitate and encourage public awareness and participation by making environmental information widely available” (United Nations 2000). To participate effectively, people must have access to decision-making, access to public information, and a legal standing providing access to justice. In democracies, all three components of public participation are provided through the legal system.

On private lands, the capacity for public participation is typically motivated by private self-interest because of the property rights issues discussed above. On federal lands, the legal framework for public participation is largely a result of congressional acts and rulemaking over the past 60 years. The Administrative Procedure Act of 1946 resulted from the rapid growth of federal agencies and programs during the New Deal, which had led to the increasing use of regulations. The act created a “Notice of Proposed Rulemaking” in the Federal Register and required agencies to give the public an opportunity to submit written comments about them. By the mid-1960s, seven federal legal mandates for public participation existed. By 1972, there were 81 mandates (Cortner 1995). Today, more than 20 chapters of the U.S. Code of Federal Regulations list public participation requirements for federal actions involving natural resource management (US GPO 2008). Among the acts are the Freedom of Information Act (FOIA) of 1966, NEPA (1969), the Federal Advisory Committee Act (FACA) of 1972, Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, Federal Land Policy and Management Act (FLPMA) of 1976, National Forest Management Act (NFMA) of 1976, and the Soil and Water Resources Conservation Act (RCA) of 1977.

The FOIA limits the ability of federal agencies to withhold information from the public. FOIA only applies to the executive branch, not to the judicial or legislative branches or to state and local governments. Interest in FOIA increased dramatically during the 1970s when public trust of governmental entities, such as the FBI, CIA, and the White House, declined following the Watergate scandal (Olmsted 1996). Subsequent amendments to FOIA have broadened access to federal files and, concomitantly, interest by a more extensive cross-section of American society. As a result, every federal department and agency, including all land management agencies, now has its own office and protocol for processing FOIA requests.

Virtually all states now have freedom of information acts equivalent to the federal legislation. However, each has its own requirements for requesting information, and each has its own rules and guidelines to follow. Each state legislature has also established its own categories of information that agencies may legally keep from the public. Local governmental agencies may or may not have freedom of information acts of their own; however, they are commonly subject to the same laws that apply to state agencies. Private owners of rangelands, individual or corporate, have limited obligations to provide any information about their operations on private land.

NEPA, the Forest and Rangeland Renewable Resources Planning Act, the Federal Land Policy and Management Act, and the National Forest Management Act are the principal laws mandating public participation in rangeland management. The Endangered Species Act (ESA) is also occasionally relevant. For example, when local and state jurisdictions write habitat conservation plans under ESA because landowners want to develop property, such activities provide for public participation and involvement.

The Federal Advisory Committee Act (FACA) provides another mechanism for rangeland stakeholders to make comments and recommendations about ongoing and proposed actions to federal agencies. The purpose of FACA is to ensure that expert advice rendered to executive branch agencies by various advisory committees, task forces, boards, and commissions formed by Congress and the President be both objective and accessible to the public. FACA defines how federal advisory committees operate by addressing subjects such as open meetings, public involvement, and reporting upon their work. Resource Advisory Committees (RAC) are one form of advisory committee implemented under FACA. They exist to provide advice and recommendations to U.S. Department of the Interior (USDI) Bureau of Land Management (BLM) state offices on a wide variety of public land management issues, including grazing and energy and mineral development. Membership on RACs is meant to be balanced among commodity, environmental, tribal, local governmental, and academic interests. Members are generally appointed through an annual public nomination process and typically serve for three years. Other rangeland-related advisory committees and boards make recommendations about wild horse and burro management, land restoration and preservation, and invasive species issues, etc.

In general, legal interpretations and changing policy in recent years have pushed back limits to public access to federal information. A related factor is the interpretation of federally generated information and the public's ability to control it.

In 2000, Congress enacted the Data Quality Act (DQA) as an obscure two-paragraph provision in an appropriations bill, primarily in response to increasing agency use of the Internet to disseminate information. Under the DQA, federal agencies must specify quality standards for information in any medium or form, including textual, numerical, graphic, cartographic, narrative, or audiovisual. Standards in the act are not supposed to override privacy and intellectual property rights protections. However, the White House Office of Management and Budget guidelines allow presumptions of objectivity to be challenged (OMB 2000). Although the ramifications of the DQA have yet to be played out, the possibility exists for public participation in the public's information could actually change the nature of the information itself. One concern is that opponents of agency regulations will attack their data as a way to stop or change policy (Pielke 2002).

Is the "Public Information and Public Participation" indicator meaningful? Similar to the previous indicator on land law and property rights, the United States has achieved a broad and effective framework of laws and regulations ensuring public access to information and agency planning. Public participation is now a routine and integral part of land management and other agency activities. Increasingly, rangeland managers must understand the importance of public involvement in rangeland sustainability.

Numerous approaches exist to monitor trends in this indicator – some broad and inclusive and some more narrowly defined. Perhaps a measure of the number and kinds of legal actions taken by public organizations would show a trend in how successful agencies are in accommodating the public within the legal framework afforded them. Another approach, more difficult to measure objectively, might address the cumulative effects that public participation has under a given law or suite of laws.

What is the availability of datasets for the "Public Information and Public Participation" indicator? The availability of data will depend upon what measure(s) are selected to represent this indicator. Volumes of data exist describing the kinds and extent of public participation in federal activities. For example, the U.S. General Services Administration maintains a Federal Advisory Committee Act database of approximately 1,000 advisory committees government-wide. The database, used by federal agencies, Congress, and the public, contains a number of elements that could be monitored to show trends in this aspect of public involvement in agency planning and management (http://www.facadatabase.gov/. Accessed 17 February 2011).

Indicator 57. Institutions and organizations.

This indicator describes governmental agencies, educational institutions, and other for-profit and not-for-profit organizations that exist to promote the conservation and sustainable management of rangelands.

This indicator is extremely broad in scope. In the United States, the list of institutions and organizations with an interest in rangelands and rangeland stewardship is exceedingly long. Included in this list are federal, state, and local governmental agencies (broadly defined), as well as educational institutions and non-governmental organizations (NGOs). The cumulative number of such entities associated with the SRR comes to more than 100 (Appendix 6-C), and that list barely scratches the surface, particularly when it comes to the expanding number of environmental, commodity, and science-based NGOs with missions pertaining to rangelands and rangeland use. Even states, counties, and municipalities are starting to recognize the importance of sustaining rangelands for their citizens. The organizations, universities, and agencies that participated in SRR's criteria and indicator development are shown in Appendix 1-A.

Federal agencies have a rich history of rangeland conservation, both in terms of management and research. The U.S. Department of Agriculture, Forest Service was formed in 1905 to manage the recently created Forest Reserves in order "to improve and protect the forest, secure favorable conditions of water flow, and to furnish a continuous supply of timber." During the 100 years of its existence, USDA Forest Service (USFS) policy and management have reflected the shifting values American society holds toward stewardship and use of the nation's natural resources. As we enter the 21st century, the USDA Forest Service continues to evolve and develop new paradigms of management (Mitchell et al. 2005).

The BLM was created in 1946 when the Grazing Service and General Land Office were merged. Grazing was managed under the Taylor Grazing Act of 1934 (Carpenter 1981). In the year of the United States' bicentennial, Congress passed the BLM's Federal Land Policy and Management Act (FLPMA) of 1976, also known as BLM's Organic Act. This act recognized the value of the remaining public domain by stating that "public lands be retained in public ownership." FLPMA thus provided a framework whereby the public lands "could be managed in perpetuity for the benefit of present and future generations" (http://www.blm.gov/ flpma/. Accessed 15 November 2008). This has not been an easy task, given the increasing demands for minerals and energy on public lands – programs administered by the BLM.

The USDA Natural Resources Conservation Service (NRCS) – originally called the Soil Conservation Service – has provided technical assistance and leadership to private landowners since 1935, helping them to conserve soil, water, and other natural resources on their property. NRCS rangeland conservationists were among the first to recognize the importance of monitoring range condition (Dyksterhuis 1949). In recent years, the NRCS has promoted the incorporation of more sophisticated state and transition models of plant succession into rangeland classification and management (Briske et al. 2005). In addition to providing technical assistance to individual farmers and ranchers, the NRCS has a science and technology branch that conducts broad-scale monitoring of U.S. non-federal lands, allowing the agency to assess resource conditions and trends (Nusser and Goebel 1997).

The Agricultural Research Service (ARS) is the research arm of USDA. Although historically focused on forage and livestock production, ARS scientists are increasingly involved in advancing our knowledge about protecting rangeland ecosystems being managed for livestock and other commodities (Child and Frasier 1992). In 2003, as the agency celebrated its 50th anniversary, ARS leadership recognized the primary importance of research objectives that enhance rangeland economic and environmental sustainability (ARS Information Staff 2004). An example of such work is the ARS rangeland carbon dioxide flux project, a cooperative research project to assess the role of rangelands in the global carbon cycle (Svejcar et al. 1997).

The land grant colleges also have considerable longevity, dating back to the mid-1800s (Appendix 6-D). Land grant colleges literally created the professional land management curriculums that are so important today. Similarly, the extension and technical assistance programs of the USDA and many state agriculture departments provide much needed assistance to the many ranchers and others who use rangelands. These institutions are addressed more directly in Indicator 59, "Professional Education and Technical Assistance."

Other government agencies, education institutions, American Indian tribes, professional societies, and private organizations also play key roles in the development of expertise needed to manage rangelands, as well as their actual administration. Local government programs can slow the loss of rangelands, and thus promote sustainability, if they are successful in working together with both urban and ranching interests (Resnik et al. 2006).

Is the "Institutions and Organizations" indicator meaningful? The utility of this indicator greatly depends upon the precise measure selected to represent it. This indicator, as described, is so general that many different measures can be used to support it. Two factors make an actual measure of this indicator a complicated task. First, the idea of sustainability is broad and multifaceted, and various rangeland interests have different ideas about what constitutes sustainable management. As a result, activities to promote sustainability by federal, state, and local agencies will be perceived and valued differently by different stakeholders. Universities are sometimes considered to be more responsive than governmental agencies and NGOs because they are not tied to long-term goals or organizational mandates; however, universities can also become embroiled in differing perceptions concerning sustainability (Stokstad 2006).

Second, this indicator deals in part with federal agencies whose regulations are primarily dictated by Congress. Because Congress influences the policies of federal agencies nation-wide, there will likely be some overlap between this indicator and other indicators within this criterion that measure the actions of federal agencies.

If the conservation and sustainability of rangelands are to be guiding management principles in the future, institutions and organizations must commit to the concept of sustainability. Leadership at all levels of organizations must agree to instill sustainability concepts into the culture of the organization and vigorously seek out resources to implement programs that promote sustainability. This indicator should help in assessing the extent to which institutions and organizations are achieving this objective.

What is the availability of datasets for the "Institutions and Organizations" indicator? Like the previous indicator, availability of data will depend upon which measure(s) are selected to represent it. Possible data categories include 1) measures of programs and activities of governmental agencies, 2) majors, faculty, and curricula of university natural resource management schools, and 3) programs and activities of for-profit and not-for-profit organizations.

Indicator 58. Economic policies and practices.

This indicator describes the extent to which economic policies and practices affect the conservation and sustainable management of rangelands. The indicator explores the relationship between micro-economic and macro-economic processes and long-term sustainable management on rangelands.

This indicator can be measured in a myriad of ways.

Recent years have seen a transition from policies that primarily promote increased productive capacity on rangelands to a trend of encouraging ecosystem health and restoration. One example is the Conservation Reserve Program (CRP), which has been included in multiple farm bills over the past 20 years. The original Food Security Act, passed in 1985, created the CRP to help resolve two separate issues – decreasing net income to farmers and high levels of wind erosion caused by "plowouts" for small grain farming during the previous decade (Chapman 1988; Crosson 1991). Five years later, the Food, Agriculture, Conservation, and Trade Act of 1990 extended the CRP and broadened its objective to include improving water quality and other environmental goals. In 1996, the Federal Agriculture Improvement and Reform Act confirmed the new emphasis on environmental goals and provided more focus on water erosion (Mitchell 2000). One net result was to cause the distribution of enrolled lands to shift east toward the Midwest.

Historically, most efforts to monitor the economic effects of changing rangeland-use policies assumed that ranchers will employ production strategies that maximize ranch profit. However, extensive research has shown that important outputs of ranches are often not incorporated into conventional economic analyses (Torell et al. 2001). These outputs include things like family, tradition, and a rural way of life (Gentner and Tanaka 2002).

In addition to their management-unit level effects, economic policies influence rural communities and regions. NEPA contains a provision requiring economic analysis to assess how policy alternatives can affect local economies. As with outcomes of economic policies at the ranch level, analyses of regional economies can depend upon the model employed (Robison 1997).

Is the "Economic Policies and Practices" indicator meaningful? An economic policies and practices indicator contains no inherent measures. A myriad of ways to describe economic policies and practices exist, and the value of this indicator will greatly depend upon what precise measure is used to track the indicator at a broad scale over time.

An example of how an economic policy indicator might be useful in assessing sustainable management is embodied in the 2002 Farm Bill (Farm Security and Rural Investment Act). Prior to this act, conservation policy emphasized programs that retired erodible and marginal farmland from crop production, most notably the CRP. The 2002 act changed the focus to the conservation of working landscapes, including rangelands. Several programs, including the Environmental Quality Incentives Program (EQIP), the Wildlife Habitat Incentives Program, and the Conservation of Private Grazing Land Program, now provide technical and financial assistance to ranchers to conserve soil and water, improve wildlife habitat, and meet society's increasing demands for recreation and open vistas (Claassen 2003). If a protocol was implemented that consistently monitored federal expenditures for conservation programs on private and tribal rangelands, it could have utility as an indicator of rangeland sustainability.

What is the availability of datasets for the "Economic Policies and Practices" indicator? There is a lot of information concerning economic policies and practices that pertain to rangeland. However, identifying quantitative datasets is problematic for several reasons. First, it is difficult to separate rangeland-related data from larger datasets addressing agriculture in general. Second, policies are embodied at both micro- and macro-economic scales, making a true synthesis indicator difficult. In the same manner, the many major federal and state laws, court cases, regulations, and guidelines relating to economic processes affecting rangeland resources are not easy to describe.

Indicator 59. Professional education and technical assistance.

This indicator describes the extent to which institutions and organizations provide for professional education and technical information related to the conservation and sustainable management of rangelands.

This indicator cannot be considered independently from the "Institutions and Organizations" indicator, described above, because institutions and organizations are required to carry out teaching and extension activities. However, they can be separated in principle because the former focuses on structure while the latter concentrates upon process.

Professional education and training encompasses a broad range of categories, including formal academic degree programs, distance learning, accreditation of rangeland professionals, in-service training for agency employees, technical assistance by state and federal agencies and NGOs, and environmental education programs aimed at different parts of society.

Academic education. Rangeland education is in the midst of a transition, trying to respond to the changing values of society and students, as well as the changing missions of land management agencies (Nielsen and Decker, 1995). The interests of faculty, students, and agencies are shifting toward integrated subjects like conservation biology, restoration ecology, and ecosystem management. This transition is leaving some university administrators behind as they seek ways to keep up.

Indicators of academic education have historically focused upon the number of students enrolled at various institutions offering rangeland management or science degrees. In recent years, such an indicator has assumed increased importance because federal natural resources' agencies will be losing a significant proportion of their workforces to retirement (Gropp 2004). At the same time, the number of students in natural resources' programs, including rangeland science, has been dramatically shrinking. In fact, most observers do not believe an adequate number of students exist to fulfill future agency needs (Renewable Natural Resources Foundation 2004).

Distance learning. Independent learning courses are primarily correspondence and telecourse distance credit courses offered through individual delivery methods or a combination of two media. Using study guides, textbooks, and additional reference materials, students have the opportunity to learn at their own pace without classroom attendance. Online learning allows students to access courses from anywhere in the world using computer-based instruction.

Online programs that grant undergraduate and graduate range management or science degrees are beginning to increase. In 2008, Colorado State University had a graduate curriculum with approximately 35 M.S. students enrolled (http://www.learn.colostate.edu/distance/dd.asp). The National Learning Center for Private Forest and Range Landowners, administered by a consortium of 24 universities, offers online courses in livestock management, wildlife-livestock interactions, mitigating wildfire effects, riparian area management, and rangeland monitoring (National Learning Center for Private Forest and Range Landowners 2008). However, it does not offer academic degrees. Nonetheless, as U.S. rural areas join urban communities in acquiring high-speed Internet access, prospects for online education are expected to increase dramatically (Gary R. Evans, Director (retired), Natural Resource Distance Learning Consortium, Northern Virginia Campus, Virginia Tech, Alexandria, VA, personal communication). If academic distance learning is to reach its full potential, however, faculty members will have to be given the flexibility, training, and reward structures needed for them to move into this field (He 2004).

Accreditation of rangeland professionals. State accreditation of professional foresters is an established practice for identifying those who meet defined standards for practicing forest management (Block 2000). The roots of accrediting rangeland management professionals date back to the 1972 California Professional Foresters Licensing Act, which was legally interpreted to include all wildlands and thus required a "licensed professional forester" to supervise wildland management. After a series of compromises, the 1994 California Code of Regulations was amended to state licensing of Certified Rangeland Managers under the certification auspices of a professional society. The California Section of the Society for Range Management (SRM) began certifying professional rangeland managers in 1995.

In 2000, SRM initiated a national-level Certified Professional in Rangeland Management program, opened to all who meet specified education, experience, and ethical conduct standards (Jolley and Burwell 2004). The SRM program is designed to certify individuals who possess the professional credentials required to plan and implement sound rangeland management practices. Certification must be renewed through participation in approved continuing education opportunities.

In-service agency training. In-service technical training of federal employees includes both introductory instruction for new employees and continuing education for experienced employees. An example of the former is the "boot camp" carried out by NRCS (http://www.nedc.nrcs.usda.gov/ catalog/bootcamp.html. Accessed 15 November 2008). Initial training has become increasingly important as agency hire employees from diverse, urban backgrounds who lack basic skills in map reading, construction, handling livestock, etc. Continuing education rises and falls with agency budgets, but advances in online learning has the potential for creating new opportunities in this area. Within the USDA, an online program called AgLearn has integrated administrative, technical, and career development training (http://www.aglearn.usda.gov/. Accessed 15 November 2008). The BLM provides similar kinds of in-service training through its National Training Center (USDI BLM 2008a).

One advantage of online training from a sustainability indicator perspective is that excellent records are kept about numbers and characteristics of students enrolled in various programs.

Technical assistance. If farmers and ranchers are to sustain healthy and productive lands that not only provide food and fiber for the nation, but also protect soils, watersheds, and ecosystems, mechanisms must be in place to educate them about evolving tools and resources available to them. Management and monitoring tools for private landowners are effective when they can be easily understood, appreciated, and shown to be cost-effective. Skills for providing technical assistance, on the other hand, are often complex, often not appreciated, and sometimes costly.

At the federal level, the NRCS has the primary mission for providing conservation assistance to private rangeland owners and managers. Over the years, NRCS has been very successful in accomplishing this goal. For example, in recent years NRCS has developed or applied conservation systems that improve the health and productivity of approximately a half million acres of grazing land per year (USDA NRCS 2006).

State and local extension activities have taken place under Cooperative Extension Services of state land grant universities since they were authorized in the Smith-Lever Act of 1914. Historically, extension activities dealing with rangeland management concentrated on livestock production practices. More recently, an emphasis has been placed on teaching people about sustainable practices. However, these programs have included subjects equally applicable to urban and rural households (e.g., composting and recycling). Another recent innovation has been collaboration between state Extension and federal agencies to produce a range management school for ranchers that covers multiple subjects from plant identification to land management planning (Kennedy and Brunson 2007). Research has shown that most ranchers who utilize extension services make positive changes in their operations such as implementing new management practices or adjusting business tactics to increase ranching profits (Richards and George 1996).

In recent years, NGOs and professional societies have become more involved in on-the-ground education. The famous King Ranch in Texas formed the King Ranch Institute for Ranch Management at Texas A&M University-Kingsville, which, among other things, holds an annual symposium for ranchers and rangeland managers on subjects such as integrated resource management and the balanced scorecard (Shadbolt 2007).

Environmental education programs. Nearly every Western state has a "range camp," open to youths, primarily of high school age, who want to learn about rangelands and natural resource management. These camps are co-sponsored by sections of the SRM, NRCS, state conservation districts, NGOs, and others. Participants learn plant identification and study interactions between soils, water, vegetation, wildlife, and livestock.

A number of general environmental programs sponsored by non-profit organizations exist for the benefit of students and K-12 teachers. Among the most notable of these programs are Project Learning Tree, Project WILD, and Project WET. All three programs are designed to be concept-oriented and balanced with regard to value-sensitive issues. Unfortunately, the reach of these programs extends to less than 3 percent of the United States teacher population. Funding is the major constraint for most programs.

Is the "Professional Education and Technical Assistance" indicator meaningful? As with all the Legal-Institutional indicators, the professional education and technical assistance indicator, as written, is overly broad and requires a specific measure. Some observers believe the most logical measure would be the number of students enrolled in rangeland management and science degree programs. Recording the number of students enrolled in rangeland-related disciplines is not easy, however. Over the past decade, academic departments have consolidated as student enrollments declined, and opportunities for students to enroll in generalized majors like natural resources management and environmental studies have increased. Consequently, a common definition of what constitutes a rangeland management or science degree program would be necessary. One approach would be to only count students enrolled in academic programs accredited by SRM. As of 2010, nine universities have accredited rangeland management education programs.

This indicator might also monitor the number of faculty positions dedicated to teaching courses concentrating on rangeland management or science. As is the case with student numbers, however, defining a consistent protocol for identifying relevant disciplines can be problematic.

A coarser measure of academic education might be the number of departments teaching rangeland science in the United States. In addition to these nine universities with accredited rangeland management education programs, 13 more U.S. colleges and universities offered degrees in rangeland ecology, science, or range management. Another 17 colleges and universities have been identified as offering rangeland science and management courses as part of various agriculture or natural resource degree programs (http:// www.rangelands.org/links_universities.shtml . Accessed 15 November 2008).

What is the availability of datasets for the "Education and Technical Assistance" indicator? No systematic procedures are in place for monitoring the number of students enrolled in various rangeland management disciplines or the number of faculty members employed to teach them. Most such data are kept by various universities, often in incompatible formats, instead of a central data repository. Data on extension services provided by federal, state, and NGOs are also difficult to obtain. Detailed NRCS records are protected by the Privacy Act and by agreement with individual landowners, and they have only been summarized in national reports. However, state and regional data summaries may be useful for monitoring trends at regional and national levels.

Indicator 60. Land management.

This indicator describes the extent to which land management programs and practices support the conservation and sustainable management of rangelands. Like other indicators pertaining to this criterion, a land management indicator can reflect legal, institutional, and economic factors.

Federal land management programs. Federal agencies within the departments of Interior, Agriculture, Defense, and Energy manage more than 275 million acres of rangeland in the United States. Federal statutes require management for a wide range of environmental, cultural, social, and/or scientific values on rangelands. Some of the important pieces of federal legislation for managing rangeland resources are:

1. Taylor Grazing Act of 1938
2. Multiple-Use Sustained-Yield Act of 1960
3. National Environmental Policy Act of 1969 (NEPA)
4. Federal Advisory Committee Act of 1972 (FACA)
5. Endangered Species Act of 1973. P.L. 93-205. 87 Stat. 884.
6. Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)
7. National Forest Management Act of 1976 (NFMA)
8. Federal Land Policy and Management Act of 1976 (Organic Act)
9. Archaeological Resources Protection Act of 1979. P.L. 96-95. 93 Stat. 721
10. Federal Land Policy and Management Act of 1994. P.L. 94-579.

With notable exceptions (Clean Water Act, Endangered Species Act), the Federal government does not directly regulate activities on state and private land. However, federal agencies often participate in resource management decisions at all levels and, in some cases, provide incentives through technical and financial assistance to encourage and facilitate better management practices.

Federal law enforcement. Federal laws that regulate natural resource management generally belong to one of the following categories: 1) environmental protection (air quality, water quality, species preservation, and soil conservation), 2) public property protection, and 3) special features protection (i.e., protection of sensitive or fragile areas containing unique environmental attributes or resources). Limitations on natural resource management activities can also come in the form of guidelines and regulations. All federal laws, regulations, and guidelines have varied applicability and are enforced within a complex jurisdictional structure. (Jurisdiction describes the enforceable reach of a law and who has the responsibility of enforcing that law.)

State land management programs. State land management agencies, particularly in the Western states, collectively manage more than 100 million acres of rangeland – primarily for livestock grazing. Until recently, state agencies spent little time or money evaluating the impacts of grazing on the land. Most of the law relating to the management of state-owned rangelands was directed toward the procedures for issuing leases for grazing and other uses. There was little concern about the manner in which grazing lands were used or the intensity of grazing practices.

However, legal changes are gradually taking place. Federal statutes now allow states to implement regulations equal to or even stricter than those adopted by the U.S. Environmental

Protection Agency (EPA). At least 41 states now have some requirement for federal agencies to evaluate the environmental impacts of proposed management actions (e.g., issuing or renewing leases). Fourteen of these states have "little NEPA" laws modeled on federal NEPA laws (Sive and Chertok 2005). The other 27 states have informal or scattered requirements for environmental impact assessments.

Increasingly, state land management agencies are requiring their lessees to manage state-owned lands in accordance with written management plans. The development of these plans requires the land management agencies to undertake assessments of the condition of the lands to be leased.

NGOs are active in promoting a broad range of environmental regulations at federal, state, and local levels. Nationally, the Natural Resources Defense Council, Environmental Defense Fund, and Earthjustice (formerly Sierra Club Legal Defense Fund) have interests in actions affecting ecosystem management, including environmental impact statements.

State law enforcement. The role of state and local governments include regulating property rights for privately owned lands and administering federal laws that affect private property rights. State laws that govern land management practices on private lands in various manners include "little NEPA acts," coastal zone management acts, clean air acts, hazardous waste removal laws, pesticide and insecticide laws, worker safety laws, and endangered species laws. These laws may apply directly or indirectly to state, federal, or other government lands.

Private land management programs. Ownership of the nation's privately owned rangelands is distributed among several hundred thousand individuals. The most effective results in managing these lands have been achieved through voluntary programs where private landowners are encouraged, advised, and assisted in developing stewardship programs. These technical and financial assistance programs are typically managed by federal and state agencies, as well as various for-profit and not-for-profit associations.

Voluntary and/or required land management practices. Specific recommended management practices for agriculture, including rangelands, have been developed in almost every state in the United States. Some of these management practices for rangeland management activities (notably practices that affect non-point source water quality) are required under various local, state, or federal laws. Other management practices are implemented through various voluntary or quasi-voluntary programs. Other methods of encouraging specific management practices include 1) cost-share payments under a variety of state and federal programs, 2) preferential property or income tax treatment, 3) technical assistance and extension education programs, 4) environmental education programs, and 5) conservation easements.

Is the "Land Management" indicator meaningful? The Land Management indicator provides another approach for assessing how well our nation's rangelands are being managed for long-term biodiversity, productive capacity, social value, and other goals. Indicators in other criteria measure the direct response of rangeland ecosystems and social systems to human activities. This indictor, alternatively, monitors the manner in which federal, state, and local governments, as well as NGOs, provide legal and institutional direction to land management practices on the ground.

On private lands, the "Economic Policies and Practices" indicator may provide an adequate measure of trends in rangeland management by monitoring incentive programs like EQIP. On public lands, however, an indicator that tracks federal, state, and local laws and regulations promoting sustainable rangeland management may be more useful. However, this indicator will only have meaning when a specific variable is selected that can be measured consistently over time.

What is the availability of datasets for the "Land Management" indicator? Presently, no regional or national datasets exist to support a land management indicator. In fact, no common measure for the indicator has yet been accepted. Data supporting a land management indicator are not now required to be collected by federal or state agencies or NGOs. The lack of protocols for how and when to monitor changes in a land management indicator will make it difficult to implement, regardless of its perceived importance.

Indicator 61. Land planning, assessment, and policy review.

This indicator describes the nature and extent of periodic rangeland-related planning, assessment, and policy review activities, including planning and coordination between institutions and organizations.

All federal land management agencies have proceeded according to some general strategy since their earliest beginnings. Now, however, federal law mandates and governs federal land-use planning at multiple scales. Formal planning is now more comprehensive, both procedurally and substantively. Managers have less discretion in deciding whether and how to plan. Planning is a central component of all land management. Each statute and administrative strategy governing land management incorporates planning. Planning guides individual discretionary decisions through explicit plan goals.

Land management policies, as well as planning and assessments, are governed in part by statutes and case law. As the regulatory situation changes over time, planning and assessment activities undertaken by agencies have to be flexible enough to keep up.

Federal planning, assessment, and policy review. Periodic planning, assessment, and policy review are a major component of the work federal land management agencies perform. The main drivers of federal planning, assessment and policy review are the Taylor Grazing Act, Federal Land Policy and Management Act (FLPMA), Forest and Rangeland Renewable Resources Planning Act (RPA), National Forest Management Act (NFMA), Soil and Water Resources Conservation Act (RCA), and a variety of legislation dealing with mining and mineral leasing of federal lands. Assessments and planning documents are to be issued at specified intervals, although there is often a delay in complying with these schedules and sometimes the schedules have no legal obligation.

The Government Performance and Results Act of 1993 (GPRA) provided for the establishment of strategic planning and performance measurements by all federal agencies. Section 3 of the act requires agencies to prepare strategic plans every three years (with a five-year window) that include comprehensive mission statements, general goals and objectives, and plans to meet the goals and objectives. Section 4 mandates annual performance assessments and reports that show how well each agency is attaining its general goals in a measurable and verifiable manner.

Even though all land management agencies must adhere to the requirements of GPRA, they also must follow individual statutes. Planning direction for the BLM is contained in FLPMA, described earlier. The USFS follows the mandates in RPA and NFMA. Congress ordered that management decisions must be "consistent" or "in accordance" with formal plans for both agencies. However, the USFS is required to comply with a relatively specific set of procedures in its planning while the BLM has only very general provisions guiding its work.

Moreover, the planning documents of federal agencies operate on several different scales. There may be nation-wide guidance (such as the BLM's riparian policy), regional assessments and plans (such as BLM resource area management plans), and local plans (such as allotment management plans). Under federal law, when assessments, plans, and policies are issued or revised, extensive coordination opportunities are required, including "consultation and coordination" with state and local governments, tribes, and the public. All of these parties have the right to review drafts of policies, plans, rulemakings, and assessments.

At the management unit level, the USDI National Park Service (NPS) has a partial statutory planning requirement, and the U.S. Fish and Wildlife Service (FWS) has none. Both agencies do prepare land-use plans for a variety of uses. These plans are similar to discretionary regulations, in that they guide officials but rarely dictate the specified result. They do, however, provide reviewing courts with standards against which to judge subsequent management actions for arbitrariness or capriciousness. The Department of Defense also has a statutory requirement to prepare integrated natural resources management plans for military lands. This is spelled out in the Sikes Act (16 USC 670).

Federal land management agencies must make assessments of how well they are achieving strategic management goals as part of the GPRA. In addition, the agencies are required by the acts listed above (e.g., RPA, NFMA, GPRA, RCA) to make assessments of lands and resources (USDA NRCS 1996). Since 1975, the USFS has presented a decadal assessment that includes an analysis of present and anticipated uses, as well as the demand for and supply of renewable resources on all U.S. forest, range, and other associated lands (USDA Forest Service 2001).

Because agencies cannot develop comprehensive assessments of lands under their jurisdiction without considering the status and dynamics of surrounding lands, both public and private, they are beginning to recognize the need for collaboration and sharing of data in the assessment process.

Regional planning, assessment, and policy review. Recently, comprehensive assessments have been undertaken in California (Fire and Resource Assessment Program 2003), the interior Columbia River Basin (Everett et al. 1994), and other areas. There are many different and often conflicting reasons for undertaking such regional assessments, but they do evaluate the current condition of all lands, including rangelands. One approach has been to compare current condition to an earlier condition as obtained from historical records. The current condition is then compared to some "desired future condition," and a management plan is developed to move to the desired future condition.

Problems in accomplishing large-scale regional plans include the difficulty in eliciting adequate public participation and vague requirements for different institutions to collaborate. However, the Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management (Federal Register, Vol. 65, No. 202, p.62566-62572) does direct the departments of Interior, Agriculture, Commerce, and Defense, the EPA, and the Tennessee Valley Authority to collaborate.

Local planning, assessment, and policy review. In recent years, some Western states have begun to develop and implement management plans for state-owned trust rangelands under their jurisdictions. These rangeland resource plans are intended to be a principal guiding document, providing long-range direction, operation objectives or targets, and a budget framework that will assure coordinated and balanced implementation of state-owned rangelands.

Since the early 1970s, nine states have adopted programs to assert state control over land development policies to provide consistency and direction among counties (or other local jurisdictions) where zoning decisions traditionally lie (Zinn 2004). These programs attempt to reconcile the goal of environmental protection with that of economic development.

Virtually all planning and assessment programs for private lands are voluntary. Even the states that have land development policies tend to tread lightly with limitations on the use and development of private rangelands.

Is the "Land Planning, Assessment, and Policy Review" indicator meaningful? An indicator addressing planning, assessment, and policy review has meaning within both a legal and an institutional framework. At the federal level, laws on land management planning at local and national scales are firmly established, as described above. However, the legal and institutional basis for planning at state and regional levels is more of a patchwork. A measure that monitored the spatial degree and extent of planning and/or monitoring could be useful.

This indicator examines how a society plans for the use of rangeland resources and is based on the specific value assigned to particular uses. Without planning and assessment, sustainable management is less feasible.

What is the availability of datasets for the "Land Planning, Assessment, and Policy Review" indicator? The history of national rangeland assessments and concomitant availability of data was reviewed in the 2000 RPA rangeland assessment document (Mitchell 2000). In contrast to U.S. forests, comprehensive national plot-based biophysical data are not available to support national rangeland assessments. The sampling land base of the two national monitoring systems, the National Resources Inventory (NRI), administered by NRCS, and Forest Inventory and Analysis (FIA), administered by the USFS, are individually or collectively exhaustive when it comes to rangelands (Frayer and Furnival 1999). NRI sample points can be found on all U.S. lands. However, actual data are only collected from non-federal lands. FIA sample points are presently located on forested lands of all ownerships, so no data are collected from non-forested lands, including rangelands.

Datasets supporting land management planning have greatly improved in recent years. Executive Order 12906 of 11 April 1994 (The White House 1994) required geospatial data used by federal agencies to be accompanied by metadata in the format set by the Federal Geographic Data Committee. This data was also required to be accessible to all interested parties. Agency guidance on data used in land-use planning requires that corporate data be able to withstand scientific and legal scrutiny and be readily available to both agency personnel and interested publics (http://www.blm.gov/nhp/efoia/wo/fy03/im2003-238.htm). Advances in Geographic Information System (GIS) technology now allow agencies to store and display digital geospatial data in map layers in ways that facilitate the requirements in Executive Order 12906.

The availability and quality of data supporting planning and assessments can be used as a measure of a planning, assessment, and policy review indicator because when accurate and reliable data are available, they are always used in these processes.

Indicator 62. Protection of special values.

This indicator assesses the extent to which laws, regulations, institutions, and organizations conserve rangeland for special environmental, cultural, historic, social, and/or scientific values.

Federal, state, and local governments have the authority to conserve special areas for these values. In addition, there are a number of NGOs that do the same thing through purchasing land or conservation easements. The variety of governmental and organizational efforts to preserve special values makes monitoring or defining this indicator difficult. In addition, the levels of protection assigned to lands for different values is often controversial, causing decision makers to try and balance the differing ideals of various rangeland stakeholders. A good example of this is the Grand Staircase-Escalante National Monument, which was set aside primarily for scenic and wilderness values but is valued for grazing and motorized recreation uses as well (USDI BLM 2008b).

More than 250 federal laws protect special values pertaining to forests and rangelands. In the same manner, numerous records exist for identifying and cataloging these laws (Coggins et al. 2002). Some are spatially explicit; others focus on the kinds of values to be protected; yet others deal with specific resources, like water or wildlife. Beyond the laws themselves, management of special values is affected by agency regulations. A 1995 General Accounting Office (renamed to Government Accountability Office in 2004) study estimated that 43 percent of the land area administered by the USFS, BLM, FWS, and NPS are regulated by laws limiting land use or management (GAO 1995).

Relatively few state government programs exist to conserve special rangeland values. As described in the “Land Law and Property Rights” indicator section above, Colorado and Arizona now call for conservation goals on some state trust lands to protect productivity and sound stewardship. Other states have laws on wetlands conservation, surface mining restoration, and farm and rangeland preservation. For example, state governments can designate rangeland of “statewide importance” so it may come under the Farmland Protection Policy Act (FPPA) of 1981. The FPPA requires collaboration between federal programs and state and local efforts to prevent the conversion of private farm and rangeland to nonagricultural uses. The FPPA does not authorize the federal government to regulate the use of private or non-federal land and does not in any way affect the property rights of landowners. The FPPA categorizes farmland as prime farmland, unique farmland, and land of statewide or local importance.

Conservation of special values on private lands relies upon voluntary legal options, such as conservation easements, land retirement programs, mutual covenants, deed restrictions, and leases for conservation use. Unfortunately, no inclusive analyses of private land initiatives for conserving special values on rangeland have been attempted.

A number of national NGOs work toward conserving lands for special values. The Conservation Fund has helped protect nearly 5 million acres in the Western states since it was founded in 1985 (http://www.conservationfund.org/. Accessed 15 November 2008). The Nature Conservancy, the Land Trust Alliance, and the Trust for Public Land are other major players in promoting special values on public and private rangelands. In 2007, New Mexico expanded its state tax credit for land conservation, in part because of support by environmental organizations.

Is the “Protection of Special Values” indicator meaningful? An indicator pertaining to special values will integrate well with other indicators within this criterion, some of which are more narrowly focused. These indicators include 1) “Threat or Pressure on the Integrity of Cultural and Spiritual Resource Values,” 2) “Area of Rangelands Under Conservation Ownership or Control by Conservation Organizations,” and 3) “Public Beliefs, Attitudes, and Behavioral Intentions Towards Natural Resources.” The indicator also provides a more legal perspective of the way the United States sets aside and otherwise protects environmental, cultural, historic, social, educational, and scientific values on rangelands.

What is the availability of datasets for the “Protection of Special Values” indicator? Given the extensive and complex nature of laws and rules restricting rangeland use and management to promote special values, numerous measures are possible to monitor this indicator. Information dealing with areas set-aside by major laws, such as the National Park System and the National Wilderness Preservation System, is widely available, but data describing the status of more obscure actions, such as heritage areas and restoration acts, are not yet available.

Indicator 63. Measuring and monitoring.

This indicator measures the extent to which agencies, institutions, and organizations devote human and financial resources to measuring and monitoring various rangeland conditions.

Monitoring of rangeland ecosystems and rangeland-dependent social systems have become critical elements of rangeland management and planning on public and private lands in the United States. Detecting and documenting changes in rangeland conditions provide reliable information for evaluating various management activities and programs. These evaluations are necessary precursors for conducting assessments. Assessments, in turn, allow managers and policymakers to make decisions using the best information available.

The Government Performance and Results Act (GPRA), discussed earlier under the "Land Planning, Assessment, and Policy Review" indicator – directs agencies to provide up-to-date reports of strategic planning and performance. The GPRA has significantly increased the amount of coordination within agencies. According to the U.S. House Appropriations Committee Report for the Department of Interior and Related Agencies Appropriations Bill for FY 2002, "Prior to the passage of the Government Performance and Results Act, it is likely that any consistency of information disseminated by U.S. government agencies was coincidental."

Historically, rangeland monitoring systems have concentrated upon describing ecological sites using plot-derived data. As described above in the discussion on the availability of datasets for the "Land Planning, Assessment, and Policy Review" indicator, the only national monitoring framework that samples rangelands, the NRI, does not include the roughly 275 million acres of federal rangelands in its sampling population. As a result, attempts to monitor and measure U.S. rangelands are increasingly relying upon remote sensing technology (Washington-Allen et al. 2006).

The data within this criterion can be found and monitored in the periodic work done by the USFS in its RPA Assessments, the BLM's Public Land Statistics, and the NRCS's NRI and RCA appraisal work. This capability is diminished at the state and local levels and dependent upon the level of detail and scope of questioning. There is not an equivalent GPRA for state governments or one that could be consistent across the country. Information relating to private rangelands is addressed by the NRCS and is only available to the Major Land Resource Areas level, in many cases a fairly large amount of acreage.

Strategic planning undertaken by state boards and agencies varies greatly from state to state. Nonetheless, information on whether planning occurs, and something about its extent, should be available from the Internet and other public information sources.

Another recent law, which may have an impact on federal agencies, is the Data Quality Act (DQA). The impact of the DQA has yet to be determined. However, it has the potential to have a significant impact on how the federal government collects, handles, and disseminates data, including that from monitoring efforts.

Is the "Measuring and Monitoring" indicator meaningful? This indicator measures the extent to which government agencies and NGOs expend resources to monitor indicators of sustainable management on rangelands. The United States has a large, but mostly fragmented, capacity to monitor changes in rangeland systems, both biophysical and socio-economic. About one-third of the nation's rangelands fall under the stewardship of the federal government and are managed by various agencies, primarily within the departments of Agriculture and Interior. These agencies have the ability to monitor land under their jurisdictions but currently do not measure the same variables, nor do they use consistent protocols to ensure consistent, reproducible results. States, tribes, and private landowners holding the majority of U.S. rangelands do little formal monitoring. The very problems that preclude monitoring systems from providing information at regional and national scales for all U.S. rangelands provide the evidence showing how meaningful an indicator that tracks measuring and monitoring would be, however.

What is the availability of datasets for the "Measuring and Monitoring" indicator? Data addressing a measuring and monitoring indicator do not actually measure biophysical or socio-economic attributes. Rather, datasets supporting this indicator would address the spatial and temporal extent, grain, accuracy, precision, and repeatability of monitoring protocols, considered collectively. SRR scientists utilized a data matrix for evaluating individual indicators during the development of criteria and indicators (Appendix 1-D). Thus, some groundwork has been accomplished for a measuring and monitoring indicator, but, like most indicators in the legal/institutional criterion, work still needs to be done in order to realize a quantitative measure of the indicator.

Indicator 64. Research and development.

This indicator measures the nature and extent of research and development (R&D) programs that promote the conservation and sustainable management of rangelands. Essentially, this indicator looks at the extent to which government agencies, universities, and NGOs spend human and financial capital to find new and innovative uses of rangeland and associated resources.

The relevance of R&D to innovation and success is well documented for businesses and private industry (Mansfield et al. 1977). However, a similar rationale for government R&D is not so widely understood. The mid-20th century Soil Bank, authorized in the Agricultural Act of 1956, provides an example of what happens when a large rangeland conservation program is not supported by a research and monitoring program. The Soil Bank program paid $2.6 billion (nearly $10 billion in today's dollars) to subsidize farmers for converting cropland to permanent grass or tree cover. In part, because of a lack of concomitant R&D, mistakes were repeated 30 years later when the CRP was initiated for generally the same purposes (Mitchell and Evans 1988).

Regardless of any shortcomings, the United States has made significant investments in the development of scientific understanding of rangeland ecosystem characteristics and functions. Research on rangeland ecosystem characteristics, functions, and processes has been carried out in universities and federal agencies for years, although some have argued that the scope of rangeland research has probably never been commensurate with their biological complexity and geographic extent (Olberding et al. 2005). Research addressing rangeland communities, natural and human capital, rangeland-linked cultures, and other social sciences lag far behind R&D in the biophysical sciences (Vavra 1995). Even further back is research that links rangeland ecosystem management with human well-being (Gunderson and Holling 2002).

New technologies. Technology in agriculture has historically been associated with increasing productive capacity. The "green revolution" of the mid-20th century saw the introduction of high-yield cultivars, a process that maximized crop yields and overlooked system stability (Daily et al. 1998). On rangelands, science for developing new technology emphasized rehabilitation equipment and strategies, which at the time was also related to increasing production (Rangeland

Technology & Equipment Council et al. 2007). In more recent years, technological advances have also focused upon sustainability issues, in particular the restoration of degraded ecosystems (Lodge et al. 2006). Natural ecological restoration is a slow process, often measured in centuries, so artificial interventions resulting from technology provide an important management alternative (Dobson et al. 1997).

Predicting impacts of human disturbances. There is research underway to predict impacts of human disturbances on rangelands. Some of these are discussed above in the "Measuring and Monitoring" indicator section. At a global scale, one of the most significant forms of human disturbance, the introduction of greenhouse gases into the atmosphere, is the subject of intense scientific research (Botkin et al. 2007). In 2001, the President launched a National Climate Change Technology Initiative that directed the Secretaries of Energy and Commerce to lead a multi-agency review of federal R&D efforts regarding climate change. From that Initiative, a multi-agency coordination activity, the U.S. Climate Change Technology Program, was organized (http:// www.climatetechnology.gov . Accessed 15 November 2008).

Is the "Research and Development" indicator meaningful? An R&D indicator can measure the different capacities of governments, universities, and NGOs to undertake research and disseminate its results. The number of full-time equivalent scientists working on the three legs of the sustainability "stool" (Newport et al. 2003) is one possible measure. Other measures of R&D on rangelands could be tied to federal agency research budgets, grant dollars received for research addressing hypotheses dealing with rangeland sustainable management, or the number of scientific papers published on this subject. Any of these measures would be meaningful to all rangeland interest groups, including Congress and other policymakers.

What is the availability of datasets for the "Research and Development" indicator? Numerous kinds and amounts of data exist that support different measures of an R&D indicator. For example, the National Institute of Food and Agriculture (formerly called the Cooperative State Research, Education, and Extension Service) maintains current and archived records of various R&D activities, including rangeland research, on its website (http://www.nifa.usda.gov/fo/rangelandresearchprogram.cfm. Accessed 10 June 2011).

One problem with these data, also common to other indicators within the "Legal, Institutional, and Economic Framework…" criterion, is the lack of consistency across datasets and the need for common repositories of data. For example, the Range Science Education Council, an informal organization of some 27 colleges and universities that offer courses and degrees in rangeland ecology and management, occasionally publishes information about numbers of graduate faculty, funding for research assistantships, etc. (Engle and Waller 1993). However, consistent monitoring and reporting of these variables does not take place.

Summary and Conclusions

We recommend placing increased emphasis on using scientific studies to evaluate the status and trends in the Legal, Institutional, and Economic Framework for Rangeland Conservation and Sustainable Management criterion. Many of the indicators are responsive to changing laws, regulations, and policies, none of which lend themselves to rigid monitoring systems, arranged a priori. For example, multiple reviewers evaluated the status of various forms of property rights in relation to legal institutions and other factors (Yandle and Morriss 2001). During the 20th century, recurring national assessments of U.S. rangelands took place that did not rely upon long-term data for specified indicators (U.S. Secretary of Agriculture 1936; Public Land Law Review Commission 1970; Committee on Rangeland Classification 1994).

Regardless of which mechanism is employed to monitor how well our country's legal, institutional, and economic structures support the sustainable management of U.S. rangelands, we are obligated to maintain the momentum to monitor and report upon a joint suite of environmental and social conditions, including those described above, in an integrated manner (Kates et al. 2001). The path toward understanding sustainable management, and how rangelands fit into the larger picture of sustainability, depends upon how well we can capture the dynamic interactions between nature and society.

On the surface, the legal, institutional, and economic framework for promoting sustainable rangeland management is well-developed in the United States. Land laws and property rights in rangeland states have arisen from an agricultural foundation (Ingersent and Rayner 1999). Numerous, organizations and institutions exist that promote sustainable management of rangelands from various perspectives, including commodity use, preservation, restoration, conservation, recreation, etc. Although fewer university departments are dedicated to rangeland science, alone, and larger universities are facing declining enrollments (Thurow et al. 2007), opportunities for students to study rangeland ecology and management still exist. The key element in rangeland education will be to use this diversity to create dynamics that can provide for changes in the discipline as concepts in sustainable management evolve (Scarnecchia 2003).

As a rule, rangeland economic practices are driven by broader environmental and agricultural policies, such as are found in farm bills. The mechanism for economic practices is often through support for technical assistance (Gordon 2008).

Opportunities for professional education and technical assistance are changing and becoming more diverse in the United States. At the same time that state Extension budgets are decreasing (Anderson and Feder 2007), other opportunities have become available (Tanaka et al. 2009).

Land management planning on public lands is driven by a suite of laws, many of which were enacted during the 1970s (Table 1.1). During the intervening quarter century, these and other laws have been tempered and made more specific by court cases and agency regulations, resulting in shifting public values that promote ecosystem health and amenity uses (Brunson 2003). This includes protection of special values (Kochan 2003).

Advances continue to be made in rangeland monitoring, a factor engrained in the SRR vision statement, "Criteria and indicators for monitoring and assessing the economic, social, and ecological sustainability of rangelands are widely accepted and used." Monitoring and assessing the benefits and costs of providing ecosystem services is attracting increased scientific and public interest (Meyerson et al. 2005). The geospatial aspects of rangeland monitoring continue to rapidly advance (Weber 2006).

Thus, laws, institutions, and economic policies are playing a large, and increasing, role in determining the long-term sustainability of our rangelands. As social scientists, economists, and ecologists continue to study the 10 broad indicators described above, and reporting about them begins to take place, rangeland stakeholders will be able to include this added dimension into assessments of rangeland sustainability, both in the United States and throughout the world.

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Appendix 6-A. Summary table of legal, institutional, and economic framework for rangeland conservation and sustainable management data categories.

1. Land Law and Property Rights Extent to which laws, regulations, and guidelines clarify property rights and land tenure arrangements, recognize customary and traditional rights of indigenous people, and provide means of resolving property disputes by due process.	Data Category 1: Major federal and state legislation relating to land law, property rights, and land tenure arrangements associated with rangelands. Data Category 2: Major governmental and state agency regulations and policies relating to land law, property rights, and land tenure arrangements associated with rangelands. Data Category 3: Major federal and state court cases relating to land law, property rights, and land tenure arrangements associated with rangelands. Data Category 4: Sales and transfers of rangeland titles and the right to take forage. • Private, state, and federal rangeland acres sold annually, by type of transfer, e.g., private treaty, auction, inheritance, or other device. • Private, state, and federal AUMs (or equivalent) sold or transferred annually, by type of transfer, e.g., private treaty, auction, inheritance, or other device.
2. Institutions and Organizations Extent to which governmental agencies, educational institutions, and other for-profit and not-for-profit organizations affect the conservation and sustainable management of rangelands.	Data Category 1: Programs and activities of governmental agencies that affect the conservation and sustainable management of rangelands. Data Category 2: Programs and activities of colleges and universities that affect the conservation and sustainable management of rangelands. Data Category 3: Programs and activities of for-profit and not-for-profit organizations that affect the conservation and sustainable management of rangelands.
3. Economic Policies and Practices Extent to which economic policies and practices affect the conservation and sustainable management of rangelands.	Data Category 1: Macro-economic policies and practices that affect rangeland sustainability including economic growth, interest rates, and international trade practices. Data Category 2: Federal and state legislation, regulations, and guidelines and court cases that affect economic processes related to rangeland resources. Data Category 3: University, public agency, and NGO studies on incidence and impacts of investment, trade, and taxation.
4. Public Information and Public Participation Extent to which laws, regulations, guidelines, institutions, and organizations provide opportunities for public access to information, and public participation in the public policy and decision-making process.	Data Category 1: Federal, state, and local laws, regulations and guidelines that affect public access to information that affect public access to information relating to rangelands. Data Category 2: Federal, state, and local laws, regulations, and guidelines that affect public participation and involvement in decision-making processes relating to rangelands.

5. Professional Education and Technical Assistance Extent to which laws, regulations, guidelines, institutions, and organizations provide for professional education and the distribution of technical information and financial assistance related to the conservation and sustainable management of rangelands.	Data Category 1: Federal and state agency and NGO public information, technical assistance, and other outreach programs that affect rangeland sustainability. Data Category 2: College and university education and training programs that affect rangeland sustainability. Data Category 3: Federal, state, and NGO agency internal training programs that affect rangeland sustainability.
6. Land Management Extent to which land management programs and practices support the conservation and sustainable management of rangelands.	Data Category 1: Legislation relating to management, use, and protection of rangelands, e.g., Federal Land Policy and Management Act, National Forest Management Act, Government Performance and Results Act. Data Category 2: Governmental agency regulations and policies relating to management, use, and protection of rangelands. Data Category 3: Court cases relating to management, use, and protection of rangelands. Data Category 4: Resources spent to enforce laws that affect rangelands. Data Category 5: Resources spent to develop and maintain infrastructure on rangelands, including facilities and improvements such as roads, fences, structures, and water systems.
7. Land Planning, Assessment, and Policy Review Nature and extent of periodic range-related planning, assessment, and policy review activities, including planning and coordination between institutions and organizations.	Data Category 1: FLPMA, Forest and Rangeland Renewable Resources Planning Act (RPA), Soil and Water Resources Conservation Act (RCA), and other plans and reports for public lands, and National Resources Inventory (NRI) reports for non-federal lands. Data Category 2: USDA Forest Service RPA assessments, NRCS appraisals made under RCA, BLM, USF&WS assessments, NRCS reports resulting from NRI, USDA Economic Research Service, and World Outlook Board projections and forecasts. Data Category 3: Monies spent on land and natural resource assessments (Interior Appropriations Act, etc.). Data Category 4: Programs and expenditures for financial assistance to owners and users of rangelands.

8. Protection of Special Values Extent to which laws, regulations, guidelines, institutions, and organizations conserve special environmental, cultural, social, and/or scientific values.	Data Category 1: Federal legislative and executive actions that set aside national parks and monuments that include rangelands, and identify the extent to which such acts affect conservation and sustainable management of rangelands. Data Category 2: Presidential executive orders that set aside rangelands for conservation of special resources, and identify the extent to which such acts affect conservation and sustainable management of rangelands. Data Category 3: Programs and activities of for-profit and not-for-profit organizations designed to protect tracts of rangelands for special values, and identify the extent to which such acts affect conservation and sustainable management of rangelands. Data Category 4: GIS tabular and visual displays of size, location, and special values protected, and nature of rangeland uses within the set-aside areas.
9. Measuring and Monitoring Extent to which agencies, institutions, and organizations devote human and financial resources to measuring and monitoring changes in the extent and condition of rangelands.	Data Category 1: Scope and reliability of rangeland-related information in existing databases. Data Category 2: Resources used to monitor and measure rangeland-related datasets by federal and state agencies and NGOs. Data Category 3: Extent to which the various agency databases may be combined and used effectively. Data Category 4: Additional resources needed to monitor and measure information deemed necessary but not being monitored.
10. Research and Development Nature and extent of research and development programs that affect the conservation and sustainable management of rangelands.	Category 1: Resources allocated to agency, university, and NGO research programs related to rangeland ecosystem state and function. Data Category 2: Resources allocated to agency, university, and NGO research programs related to integrating environmental and social costs and benefits into markets and public policies. Data Category 3: Resources allocated to agency, university, and NGO research programs related to new technologies and the capacity to assess the socioeconomic consequences associated with new technologies. Data Category 4: Resources allocated to agency, university, and NGO research programs related to predicting impacts of human intervention on rangelands, including restoration. Data Category 5: Resources allocated to agency, university, and NGO research programs related to the impacts of climate change on rangeland ecology and associated rangeland activities and uses.

Appendix 6-B. Partial List of American Indian reservations containing considerable rangeland.

Reservation Name (Tribe, if not in name) – State	Land Area (km^2)
Blackfeet – MT	7,800
Cheyenne River (Cheyenne River Sioux) – SD	11,051
Colville – WA	5,483
Crow – MT	9,341
Duck Valley (Shoshoni, Paiute) – ID, NV	1,167
Flathead – MT	5,020
Fort Apache (White Mountain Apache) – AZ	6,805
Fort Belnap (Atsina, Assiniboine) – MT	2,626
Fort Berthold (Mandan) – ND	4,000
Fort Hall (Shoshoni, Bannock) – ID	2,111
Fort Peck (Assiniboine, Sioux) – MT	8,520
Hopi (AZ)	6,557
Mescalero (Apache) – NM	1,862
Navajo Nation – AZ	67,000
Nez Perce – ID	3,095
Northern Cheyenne – MT	1,831
Osage – OK	5,900
Pine Ridge (Oglala Sioux) – SD	8,984
Rosebud (Lakota) – SD	5,103
San Carlos (Apache) – AZ	7,539
Southern Ute – CO	2,742
Standing Rock (Dakota, Lakota) – ND, SD	9,251
Tohono O'odham – AZ	11,534
Uintah and Ouray (Northern Ute) – UT	17,532
Warm Springs (Wasco, Paiute) – OR	2,640
Wind River (Shoshoni, Northern Arapaho) – WY	9,148
Yakima – WA	5,662

Appendix 6-C. Partial list of non-governmental, non-profit organizations involved in the conservation and sustainable management of rangelands.

- Allan Savory Center for Holistic Management
- Arizona Common Ground Roundtable
- Audubon Society
- CABI
- Center for Biological Diversity
- Collaborative Planning Organizations on the Colorado Plateau
- Diablo Trust
- EcoResults
- Idaho Conservation League
- King Ranch Institute of Ranch Management
- Malpai Borderlands Group
- National Wildlife Federation
- Natural Resources Defense Council
- Overseas Development Institute
- Public Lands Information Center
- Rocky Mountain Elk Foundation
- Sierra Club
- Sonoita Valley Planning Partnership
- Southern Arizona Grasslands Trust, Inc.
- The Nature Conservancy
- The Quivira Coalition
- U.S. Institute for Environmental Conflict Resolution
- Udall Center for Studies in Public Policy
- Western Gamebird Alliance
- Western Watersheds Project
- World Conservation Monitoring Centre

Appendix 6-D. Partial List of Colleges and universities with programs or courses in rangeland sciences.

- Angelo State University, San Angelo, TX
- Arizona State University, Tempe, AZ
- Brigham Young University, Provo, UT
- California Polytechnic State University (Cal Poly), San Luis Obispo, CA
- Colorado State University, Fort Collins, CO
- Fort Hays State University, Hays, KS
- Humboldt State University, Arcata, CA
- Iowa State University, Ames, IA
- Kansas State University, Manhattan, KS
- Montana State University, Bozeman, MT
- New Mexico State University, Las Cruces, NM
- North Dakota State University, Fargo, ND
- Oklahoma State University, Stillwater, OK
- Oregon State University, Corvallis, OR
- Sheridan College, Sheridan, WY
- South Dakota State University, Brookings, SD
- Sul Ross State University, Alpine, TX
- Tarleton State University, Stephenville, TX
- Texas A&M University, College Station, TX
- Texas Christian University, Fort Worth, TX
- Texas Tech University, Lubbock, TX
- University of Alberta, Edmonton, Alberta, CANADA
- University of Arizona, Tucson, AZ
- University of California, Berkeley, Berkeley, CA
- University of California, Davis, Davis, CA
- University of Florida, Gainesville, FL
- University of Idaho, Moscow, ID
- University of Montana, Missoula, MT
- University of Nebraska-Lincoln, Lincoln, NE
- University of Nevada, Reno, Reno, NV
- University of Wyoming, Laramie, WY
- Utah State University, Logan, UT
- Washington State University, Pullman, WA