Indicators for Soil and Water Conservation on Rangelands

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Abstract

Rangelands and associated civilizations rely on conservation and maintenance of soil and water resources to maintain themselves over time. The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion under which indicators can be identified and by which sustainability can be assessed. To this point, 14 indicators - seven soil-based, six water-based, and one soil and water-based - have been identified by the Soil and Water Resources Criterion Group. Soil erosion from water and wind, soil organic matter, soil compaction, soil aggregate stability, bare ground, and soil food web structure are the current focus of soil-based indicators. Biodiversity of aquatic organisms, water quality, stream channel geometry, wetland geographic extent, and duration of flow in rangeland intermittent streams are the current focus of water-based indicators. Regarding several of these indicators, several challenging questions remain to be answered. For example, can an indicator detected over a small geographic portion of rangelands be a credible indicator for rangeland sustainability at the national level? The Soil and Water Resources Criterion Group has used the Collaborative Delphi to solicit interdisciplinary feedback from SRR members to these challenging questions. The identification and eventual quantification of rangeland indicators related to soil and water might provide an approximation of status of rangeland sustainability for our Nation.

Introduction

Soils influence hydrologic processes by providing the medium for the capture, storage, and release of water (Whisenant 1999). Flow of soil and water through rangeland ecosystems is related, because flow of water can cause soil erosion. Soil erosion is regarded as a major contributor to declines in human civilizations over the past 7,000 years (Lowdermilk 1953). Rangelands and associated civilizations rely on conservation and maintenance of soil and water resources to maintain themselves over time.

The Sustainable Rangelands Roundtable (SRR) has explicitly included conservation and maintenance of soil and water resources as a criterion—a category of conditions or processes that is an explicit goal of sustainable management by which sustainability can be assessed. 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 that can be monitored over time. Fourteen indicators have thus far been identified. To settle on this criterion, we began by considering issues related to rangeland sustainability that would focus our indicator identification. Sustaining fundamental ecosystem processes and components, including biodiversity, were issues that stimulated inclusion of soil and water resources. A soils criterion group was originally formed, members of which deemed soils to be the single most important issue affecting rangeland sustainability. We identified four initial soil categories to focus our identification of indicators: (1) soil amount or loss, (2) soil constituents, (3) soil physical properties, and (4) soil food web structure. The SRR then used the Collaborative Delphi to introspectively analyze the originally formed criterion groups, looking for missing critical issues. The water resource was identified as a missing critical issue. Water resources were then added to the soils criterion group, forming the conservation and maintenance of soil and water resources criterion group (hereafter referred to as the Soil and Water Resources Criterion Group).

Indicators

Indicators are quantitative or qualitative variables that can be assessed in relation to a criterion. An indicator describes attributes of the criterion in an objectively verifiable and unambiguous manner, and is capable of being estimated periodically in order to detect trends.

Our 14 indicators are nearly evenly divided with seven being soil-based, six being water-based, and one being soil and water-based (Table 1). These 14 indicators are the outcome of a screening of the conservation and maintenance of soil and water resources indicators identified in the Roundtable on Sustainable Forests (RSF), plus identification of new indicators that we believe pertain to rangeland sustainability. The Soil and Water Resources Criterion Group screened the eight RSF soil and water indicators for their relevance to rangelands. The outcome of this screening was the retention of seven of the RSF soil and water indicators (Table 1).

The Soil and Water Resources Criterion Group has applied a framework of questions to each of the 14 indicators to varying degrees of completion. These framework questions focus on: (1) what the indicator is, (2) what the indicator measures, (3) why the indicator is important to rangeland sustainability, (4) the degree of meaning of the indicator at various geographic and climatic scales, (5) the relation of the indicator to its ability to be monitored over time including issues of data availability, (6) the sensitivity of the indicator to changes over time, and (7) the degree of understanding the public has for the indicator. The most important information we have currently on answers to these framework questions is in "Current Status of Indicators" below.

Current Status of Indicators

Soil-Based Indicators

Area and Percent of Rangeland with Significant Current Soil Erosion:

We are currently pursuing the applicability of the Water Erosion Prediction Project (WEPP), a physically-based erosion model, for national and regional-level prediction of soil erosion from water.

Erosion and the risk of erosion are difficult to measure directly. Other soil properties that affect erosion and can change with management, including soil surface stability, aggregate stability, infiltration, compaction, and content of organic matter, can be measured (USDA, Natural Resources Conservation Service, 2001a and b). We are considering whether changes in aggregate stability, content of organic matter, and compaction, three indicators we have already identified, can be surrogates for potential water erosion. Similarly, for wind erosion, we are considering whether changes in aggregate stability and organic matter content can be surrogates for potential wind erosion.

Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter:

Soil organic matter enhances rangeland sustainability because it: (1) binds soil particles together into stable aggregates, thus improving porosity, infiltration, and root penetration and reducing runoff and erosion; (2) enhances soil fertility and plant productivity by improving the ability of the soil to store and supply nutrients, water, and air; (3) provides habitat and food for soil organisms; (4) sequesters carbon from the atmosphere; (5) reduces mineral crust formation and runoff; and (6) reduces the negative water quality and environmental effects of pesticides, heavy metals, and other pollutants by actively trapping or transforming them (USDA, Natural Resources Conservation Service, 2001c). We are investigating the methodology and sampling issues associated with soil organic matter measurement. There is a possibility we will seek surrogates for soil organic matter that will facilitate the estimation of this indicator.

Area and Percent of Rangeland with Significant Soil Compaction:

Soil compaction is detected when soil particles are physically compressed, eliminating the air spaces, or pores between the soil particles. Soil compaction is problematic because the increased soil density and decreased pore space limits water infiltration, percolation, and storage, limits plant growth, and limits nutrient cycling (USDA, Natural Resources Conservation Service, 2001d).

We have concerns with this indicator relative to its applicability over broad geographic areas. An underlying basis for this concern is speculation that soil compaction can change drastically over very small distances; therefore, great spatial variability exists at a site level. In addition, speculation is that soil compaction is substantial only over very small portions of rangelands and therefore is not a widespread problem on rangelands. We are investigating these questions: (1) Can great spatial variability at a site level not compromise a broad geographic area characterization of soil compaction?, (2) Can an indicator detected over a small geographic portion of rangelands be a credible indicator for rangeland sustainability at a national level?

Table 1. The 14 soil and water resources indicators identified by the Soil and Water Group of the Sustainable Rangelands Roundtable (SRR).

Indicators	Originated with Roundtable on Sustainable Forests and Retained in SRR?	What the Indicator Describes
Soil-based		
Area and Percent of Rangeland with Significant Current Soil Erosion	Yes	Erosion and the risk of erosion from water and wind.
Area and Percent of Rangeland with Significantly Diminished Soil Organic Matter	Yes	Soil productivity, energy flow, nutrient cycling, and infiltration.
Area and Percent of Rangeland with Significant Soil Compaction	Yes	The physical properties of soils, including bulk density, infiltration. Measures effects on soil productivity and soil/water relations.
Area and Percent of Rangeland Experiencing Changes in Toxic Substances	Yes	Soil productivity; potential for groundwater contamination.
Area and Extent of Rangelands with Changes in Soil Aggregate Stability	No, a new indicator identified by SRR	Changes in soil erosion resistance to water and wind.
Area and Percent of Rangeland with Significant Variance in Diversity of Soil Organisms	No, a new indicator identified by SRR	Health of the soil food web structure, as a surrogate for soil productivity.
Change in Extent of Bare Ground	No, a new indicator identified by SRR	Erosion potential from water and wind.
Water-based		
Percent of Water Bodies in Rangeland Areas (e.g. stream kilometers, lake hectares) with Significant Variance of Biological Diversity from the Natural Range of Variability	Yes	Water quality and aquatic habitat conditions.
Percent of Water Bodies in Rangeland Areas (e.g. stream kilometers, lake hectares) with Significant Variation from the Historic Range of Variability in pH, Dissolved Oxygen, Levels of Chemicals (Electrical Conductivity), Sedimentation or Temperature Change	Yes	Water quality.
Quantifying Aquifer Change	No, a new indicator identified by SRR	Change in geographic extent of riparian and wetland ecosystems.
Area and Extent of Rangelands Occupied by Wetlands	No, a new indicator identified by SRR	Change in geographic extent of functional lotic or lentic wetlands.
Percent Stream Miles in Rangeland Catchments in which Stream Channel Geometry (W/D Ratio, Flood Plain Access, Substrate Composition, Sinuosity, etc.) Significantly Deviates from the Natural Channel Geometry	No, a new indicator identified by SRR	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.
Change in Number and Duration of Dry Periods in Rangeland Intermittent Streams	No, an indicator identified by The H. John Heinz III Center for Science, Economics and the Environment	Aquatic and terrestrial biodiversity, watershed functioning.
Soil and Water-based		
Area and Percent of Rangeland Managed Primarily for Protective Functions	Yes	Conservation of soil and water.

Area and Percent of Rangeland Experiencing Changes in Toxic Substances:

We believe toxic substances might be an important indicator for rangeland sustainability, although we have yet to investigate this indicator in detail. Similar to the soil compaction indicator, we have concerns with this indicator relative to its applicability over broad geographic areas. An underlying basis for this concern is speculation that rangeland soils with substantial toxic substances exist only over very small portions of rangelands and therefore are not a widespread problem on rangelands. We are investigating the answer to the question: Can an indicator detected over a small geographic portion of rangelands be a credible indicator for rangeland sustainability at a national level?

Area and Extent of Rangelands with Changes in Soil Aggregate Stability:

Stable soil aggregates are critical to erosion resistance, water availability, and root growth. Soils with stable aggregates at the surface are more resistant to water and wind erosion than other soils. Aggregated soils hold more water than other soils and provide pores for root growth (USDA, Natural Resources Conservation Service, 2001e). A field soil aggregate stability kit (Herrick et al. 2001) is a method for measuring soil aggregate stability in the field without having to transport soil samples to the laboratory. Plans are to measure soil aggregate stability in the field with the stability kit method in the Rangeland National Resources Inventory (NRI) beginning in 2002 and periodically thereafter (J. Herrick, pers. comm. 2002). Therefore, the indicator will apparently be measured over broad geographic areas with a statistically valid sampling scheme.

Area and Percent of Rangeland with Significant Variance in Diversity of Soil Organisms:

This indicator would quantify the soil animals, including protozoa, nematodes, mites, springtails, spiders, insects, and earthworms, and soil microorganisms, including bacteria, fungi, and algae, and their changes through time (USDA, Natural Resources Conservation Service, 2001f). This indicator would assess the health of the soil food web structure, as a surrogate for soil productivity. Speculation is that this is an important indicator of rangeland sustainability, yet its large cost to measure at the present time, and its overlap with other indicators such as soil aggregate stability and soil organic matter in regard to indicating erosion resistance and infiltration, needs further investigation before it merits final consideration as an indicator. In addition, this indicator might appropriately be shifted to the Ecological Health and Diversity Criterion Group at a later time.

Change in Extent of Bare Ground:

Change in extent of bare ground, along with soil aggregate stability, have great potential to be indicators of erosion potential and rangeland sustainability. Change in extent of bare ground can be quantified over broad geographic areas of rangeland using remote sensing technology. However, the accuracy of the measured change is lessened by several factors that limit classification accuracy of bare ground, including soil moisture content, litter amount, organic matter content, and presence of biological soil crusts. The presence of biological soil crusts on the surface soil of otherwise bare ground confers some protection to the soil surface from water and wind erosion (Belnap et al. 2001). Therefore, bare ground with biological soil crusts will not equate to bare ground without biological soil crusts in its susceptibility to erosion from water and wind. The degree of influence of these accuracy-lessening factors needs further investigation by the Soil and Water Resources Criterion Group.

Water-Based Indicators

Percent of Water Bodies in Rangeland Areas with Significant Variation of Biological Diversity from the Natural Range of Variability:

Biodiversity of aquatic organisms is an indicator of water quality and habitat conditions. If water quality and habitat conditions change in streams, rivers, and lakes, some aquatic species might decline or disappear, whereas other species might increase. There could be a decline in biodiversity, with fewer species. Because water bodies are dynamic, some variability in biodiversity should be expected. We are concerned that using the historic range of variability as the standard for evaluation might not be appropriate, because we speculate there is not an accepted manner of ascertaining the historic range of variability of biodiversity within water bodies. We are investigating this issue and the substitution of natural range of variability, which conceivably can be measured, as the standard for evaluation.

Percent of Water Bodies in Rangeland Areas with Significant Variation from the Historic Range of Variability in pH, Dissolved Oxygen, Levels of Chemicals (Electrical Conductivity), Sedimentation or Temperature Change:

We have yet to expend effort applying the indicator framework questions to this indicator but intend to do so. Similar to the previous indicator on biodiversity in water bodies, the issue of using the historic range of variability as a standard for evaluation appears problematic, and we will be investigating the substitution of natural range of variability, which conceivably can be measured, as the standard for evaluation.

Quantifying Aquifer Change:

We have yet to expend effort applying the indicator framework questions to this indicator.

Area and Extent of Rangelands Occupied by Wetlands:

This indicator will measure changes in the extent of functional lotic or lentic wetlands through time on rangelands. We have yet to standardize what will be interpreted on-the-ground as functional lotic and lentic wetlands. This is imperative, because measuring wetland acreage alone without qualification can be problematic (e.g. man-made impoundments can obscure other changes occurring, such as reduced riparian flows and resulting changes in wetland/riparian communities). In regard to measuring and monitoring this indicator, wetland/riparian classifications exist. Remote-sensed imagery data are apparently available for some rangeland areas.

Percent Stream Miles in Rangeland Catchments in which Stream Channel Geometry Significantly Deviates from the Natural Channel Geometry:

This indicator measures changes in stream channel length associated with channel geometry that either deviates from a historic condition, or deviates from some other established baseline condition (on which we have not yet made a group decision). This indicator will represent departure of channel geometry from a baseline condition. Channel geometry is indicative of natural watershed functions of channels such as sediment transport, sediment filtering and retention, substrate composition, flood amelioration, fish and wildlife habitat, aquifer recharge, water temperature, and the season and duration of surface flow.

Change in Number and Duration of Dry Periods in Rangeland Intermittent Streams:

This is our most recently identified indicator. This indicator reports on the frequency and duration of intermittent stream flow within shrub/grassland regions. Specifically, this indicator presents the percent of streams that have some no-flow period in a year, and the percent of streams where the duration of zero-flow periods is substantially lesser or greater than the long-term average. We are seeking to obtain the analyses of U.S. Geological Survey's data conducted within Colorado to better understand the degree to which this indicator will be suitable at the national level.

Soil and Water-Based Indicator

Area and Percent of Rangeland Managed Primarily for Protective Functions:

The Soil and Water Resources Criterion Group recommended eliminating this indicator. Rationale for elimination was disseminated out to all SRR members through use of the Collaborative Delphi, to gauge the degree of agreement with eliminating this indicator. Enough disagreement with eliminating the indicator was presented such that we are revising this indicator rather than eliminating it.

Rationale for elimination was based on these points: (1) this indicator is mostly a measure of societal valuation of protection areas and proper management, rather than a guarantee of rangeland sustainability (Neary et al. 2000); (2) if managing for protective function tends to imply a passive, hands-off management approach, a passive hands-off management approach will not ensure rangeland sustainability. Case examples exist (Sydoriak et al. 2000/2001; Pringle 2000). Rangeland areas that are now being managed primarily for protective functions, but in the past were subject to land uses that achieved commodity production, pose dilemmas for managers because the vegetation, soil, and water changes that have occurred and were attributable to the commodity production, can remain on-going subsequent to a change to a more passive management approach. Although there were several points of disagreement received through the Collaborative Delphi, a salient point was that active, hands-on management to achieve conservation of soil and water, rather than passive hands-off, should be the underlying premise. We are currently considering modifications to this indicator that might make it more suitable as an indicator of rangeland sustainability.

Challenges and Opportunities

The soil compaction and soil toxic substances indicators challenge our thinking relative to their applicability over broad geographic areas. These indicators appear to be extant only over very small portions of rangelands and therefore are not a widespread problem. We will be challenged with answering the question, "Can an indicator detected over a small geographic portion of rangelands be a credible indicator for rangeland sustainability at a national level?"

The Soil and Water Resources Criterion Group has embraced the opportunity to utilize the Collaborative Delphi to assist in answering challenging questions that arise (for example, see indicator, Area and Percent of Rangeland Managed Primarily for Protective Functions). We will continue to do so, for the Collaborative Delphi permits our criterion group to solicit feedback on challenges we face with soil and water-based indicators.

Conclusion and Future Work

There is some likelihood that the fourteen indicators identified to date will be reduced to a fewer number during the next year. First, a Sustainable Water Resources Roundtable is being created. There is a high likelihood that water-based indicators we have

identified, or indicators quite similar, will be identified by the Sustainable Water Resources Roundtable. The SRR is beginning to discuss internally the ramifications of potential overlap of indicators between the two Roundtables. Within SRR, there also exists some overlap in indicator identification currently between the Soil and Water Group, and the Ecological Health and Diversity Criterion Group. Integration, both within the SRR, and between the various Roundtables, is critical to minimize indicator overlap. SRR leadership is networking with other Roundtables and the next SRR meeting in late March 2002 will devote time to inter-criterion group discussion of indicator overlap. Second, in some cases, more than one indicator appears to be indexing the same rangeland component. For example, Table 1 shows that we have identified soil erosion, soil aggregate stability, content of organic matter, and soil compaction as potential indicators, yet they are all related to soil erosion. The question exists as to whether we need to retain all four of these indicators or are fewer adequate to indicate the soil portion of rangeland sustainability.

Soil and water remain as basic resources for rangeland sustainability. The identification and eventual quantification of rangeland indicators related to soil and water might provide an approximation of status of rangeland sustainability for our nation and provide a blueprint for evaluating rangeland sustainability worldwide.

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