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FEATURE

Making soil health a part of rangeland management

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Soil health describes the ability of a soil to function at its potential, specifically "the capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans" (USDA NRCS 2014). There is a long history of thoughtful consideration of the soil by philosophers, political leaders, and scientists. Political leaders from Chief Seattle to Franklin Roosevelt and philosophers from Homer to Aldo Leopold have referred to the health of the soil as a basis for sustaining civilizations. Clearly, an appreciation of the importance of soil is a part of the ethos of most modern societies. However, that philosophical and cultural commitment frequently is lost among other, more expedient desires as agricultural and land management policies are developed and implemented. Ensuring that soil and ecosystem health are essential components of land use and management decision making remains a challenge. The renewed emphasis on the concept of soil health as an indicator of healthy agricultural ecosystems is one step toward answering that challenge.

While there are a host of definitions for soil health (Doran 2002; Cornell 2009; FAO 2014), they all have three major points in common: capacity to function, sustainability, and meeting human needs. The idea of soil health is intuitively appealing to a wide variety of users with a range of interests. However, soil health, like many other powerful ideas, has a host of devils in the details. The last two decades have seen significant advancement in the development of qualitative and quantitative indicators of soil health that are accessible to many users. However, the goal of any resource condition assessment methodology or technique has to be to contribute to improved decision-making and, ultimately, improved resource and human conditions. In summarizing the outcomes of a 1998 global soil health conference, Doran and Zeiss (2000) said "the challenge for the future is to develop sustainable management…soil quality indicators are merely a means toward this end."

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In this paper, we explore some of the key elements of soil health on rangelands, discuss what the ideas mean in real-world settings, and synthesize some of the conclusions in the scientific literature about how soil health can be measured, communicated and more importantly, managed. One of our key assumptions in reviewing current applications of soil health on rangelands is that our ultimate goal is to develop a soil health assessment system that can be used as an evidence-based guide to making management changes and to developing policies and programs, not merely to track the impacts of activities implemented largely to meet other management and production objectives. Another key assumption is that rangeland ecosystems present challenges and opportunities that differ from croplands. Rangelands are largely extensively managed as natural(ized) systems with minimal cultural inputs, largely relying on the manager's ability to recognize impending changes (desirable or not) and adjust actions to avoid or take advantage of conditions beyond their control (primarily climate). Finally, rangelands are mainly managed for multiple use objectives that may or may not include livestock grazing as a primary objective. The variety of ecosystem services extracted from rangelands requires an assessment philosophy that does not assume an explicit link between soil health attributes and the yield of a single commodity.

In this paper, we (1) contextualize rangeland soil health by examining the common definition and the ways important concepts apply to rangelands, (2) review the recent progress and ongoing directions in applying soil and ecosystem health concepts to rangelands, and (3) identify and better define opportunities to move soil health forward as an important part of rangeland management.

SOIL HEALTH DEFINED FOR RANGELANDS

Capacity to Function. The capacity of a soil to function, which is the core question to developing a credible approach to soil health assessment, is difficult not only to measure, but also to communicate. Soils are different—different in their parent material, their climate, their biology, their age, their landform position, and most importantly, different in their behavior (Jenny 1980). While this truism is often repeated, it really is what forms the basis of our modern soil survey and conservation programs. It is important that real differences in how soils function (including their limits) be acknowledged and accounted for and that diversity becomes an important part of land health evaluation protocols and in the policies that we construct. It goes without saying that Great Basin shrubland soils are very different from tallgrass prairie soils, and it follows that our assessment protocols, and more importantly, our expectations about the behavior of those soils in response to management and climatic variability, quantitatively account for those inherent differences (Herrick 2000; National Research Council 1993, 1994).

Diversity of rangeland soils is also local and typically not particularly subtle. An individual ranch or allotment often contains a similar level of variability in soil texture and depth as an entire region. While these differences can be, and frequently are, treated as management challenges, they are also what make rangelands aesthetically attractive and valuable. This diversity also contributes to the functional stability of rangeland landscapes (Bestelmeyer et al. 2011). Thus, an understanding of the importance of diversity in rangeland function is a key to credibly apply and interpret soil health measures.

Regardless of the land use, a soil health assessment system that purports to measure the capacity of a specific soil body to function must be based on a realistic baseline or standard, and it must have a means of communicating what departure from that standard means. Static properties of the soil profile (texture × depth) define the range of possibilities for soil function (Herrick et al. 2012), but are not a sufficient framework for a system that can be used to guide policy and management decisions. Just knowing that a soil body is not healthy is not particularly helpful unless there is an understanding of how it got that way and, more importantly, what the options are to improve. A benchmark or set of standards is a good place to start, but a functional model of the dynamics of the particular soil system is necessary as well.

While a single indicator may be appealing, establishing functional relationships between a single measure or even an array of attributes, causes of the departure, and more importantly, a corrective management intervention is difficult at best. In rangeland ecosystems, this particular challenge is well-understood. For many years, equilibrium ecology and the programmatic application, range condition, drove both on-the-ground management decisions and program/policy decisions (Joyce 1993). Although this system was relevant when deployed within the limited geographic/ecological range of prairies and in the hands of skilled technicians, its narrowness with regard to other ecosystems and alternative land management goals eventually proved its downfall. Even though academia and research agencies have largely abandoned the more simplistic range condition model, variants continue to emerge as applications for conservation program-driven comparisons and assessments (Archer et al. 2011). A single value is especially appealing when the ultimate goal of programs (improved ecosystem health) can be aligned with institutional accountability—one number serves two purposes.

A much more realistic, albeit more complex, approach for rangeland ecosystems is the development of assessment of multiple functions that accurately reflect soil health within the context of the driving soil:vegetation interactions. Capacity to function cannot be considered a precise number or an index, but rather a space within which natural variability can cause minor changes, and the goal is to better anticipate future disturbances that can trigger major change. The objective of management is not to increase an index value, but instead to work to achieve and maintain the potential of a particular soil by continually adjusting management inputs to respond to changes in external drivers. This approach is summarized well by the principles employed in adaptive management (Walters 1986).

Sustainability. A sustainable system, whether ecological, economic, or social, implies endurance (Millennium Ecosystem Assessment 2005). Frequently, discussions of sustainability are confounded and confused by an absence of a specified time frame for the assessment. While there is little to be gained from defining sustainability in time frames that exceed imagination, there is also a downside to trying to assess the endurance of a system in a time frame that is too short to encompass natural variability. Thus, a soil health assessment that can define departure from a standard and identify threats to sustainability and opportunities for improvements must include at least qualitative estimates of time. The importance of time in soil development has always been recognized (Jenny 1961), and it follows that some understanding of the role of time in governing the expression of soil behavior is necessary (Doran 2002), although at a much reduced scale.

In the particular case of rangeland soil health, selecting the appropriate indicators of soil health change can be the difference between an assessment that reflects process change, with links to appropriate management, and an inventory of conditions that lacks a connection to actions (de Soyza et al 1998). Rangeland soil health investigations have consistently identified vegetation as a critical inventory component. In addition to soil-based indicators such as organic matter, aggregate stability, and bulk density, vegetation is essential to interpreting current status and trends (SQI 2001). While static properties of the soil body may determine the long-term (decadal) potential of a rangeland ecosystem, the current vegetation, complemented by a limited set of dynamic soil property attributes, is frequently the most accurate and accessible indicator of trend and short-term potential, with a greater utility as a basis for establishing management objectives, implementing conservation practices, and assessing progress.

Realistically, the factors that degrade rangelands are generally associated with inappropriate livestock grazing pressure. There is a very well-developed literature establishing a strong, repeatable, and logical relationship between livestock management (particularly stocking rate), vegetation change, and soil behavior (Briske et al. 2011). Although other factors, such as shrub increase (Archer et al. 2011) or exotic plant species invasion (Sheley et al. 2011), often elicit policy and management responses as land degrading processes, inappropriate grazing management is usually directly or indirectly linked to the initial stages of undesirable change. Although there is a great deal of complexity inherent in managing most rangeland systems, many of the soil and vegetation degrading factors can be linked in some fashion to poor grazing management. Likewise, improved grazing management frequently is the most cost-effective means of avoiding soil health degradation or reversing a downward trend in soil health on rangelands. Thus, early warning indicators of deleterious changes in rangeland soil health are most likely to be found in some aspect of grazing livestock management as expressed in the vegetation (Briske et al. 2011).

The adoption of a nonequilibrium basis for assessing (Pellant et al. 2005; Pyke et al. 2002) and managing (Bestelmeyer et al. 2013) rangelands has provided a solid foundation for the important role that early detection and response have in achieving sustainability. The nonequilibrium dynamics and the accompanying state and transition models are site-specific catalogs of the relationships between disturbance factors (in this case, livestock grazing management), vegetation change, and soil behavior on a time frame relevant to management decision making. The identification of multiple states in a rangeland ecosystem is an explicit acknowledgement that extensive management changes are usually necessary and sufficient to avoid degradation, and that minor management changes are not sufficient to reverse degradation. Vegetation and soil properties and behavior are closely coupled in rangelands. However, the time lag between inappropriate management actions, vegetation change, and detectable soil health degradation implies that a solely soil-based assessment methodology will seldom, if ever, detect changes in a timescale that can effectively guide management or policy changes.

Meeting Human Needs: Ecosystem Services. The final aspect of the soil health definition, meeting human needs, is perhaps the more challenging to put into a management context, even qualitatively. The imperative to provide a variety of goods and services from agricultural ecosystems has benefited tremendously from an increased attention to ecosystem services, but developing a systematic approach to assess and communicate the value of management in rangeland systems has proven difficult (MacLeod and Brown 2014). When the value of management actions and ecosystem outputs was viewed strictly as a single commodity (food or fiber) with transparent markets, it was relatively simple, intellectually, to evaluate the importance of soil and ecosystem health (Tanaka et al. 2011). However, as the market demands and societal expectations of land managers expand in both time and space and increase in complexity, we lack a widely accepted framework for evaluating the links between ecosystem health and ecosystem services. Many of the markets for commodities (food, fiber, and forage) are transparent and responsive but lack even a remote connection to concepts of sustainability or human well-being. Conversely, subsistence and local market systems that are more sensitive to environmental and social aspects of production tend to be complex, quirky, and difficult to quantify (Martinez et al. 2010).

While advances in technology have supported an increased emphasis on commodity quality in existing markets (e.g., moisture and protein analysis in grain samples), there has not been a concurrent emphasis on quality of production systems in agriculture. Although there have been laudable attempts to certify management systems that provide a greater array of ecosystem services while still producing fungible commodities (Von Hagan et al. 2010), linking producers and consumers via a greater array of ecosystem services has proven elusive. Given that a healthy soil is probably the most universal biophysical attribute that supports all of the basic ecosystem services in rangeland-based production systems, there should be an increased emphasis on developing a more systematic and consistent approach to the quantitative assessment of the connections between management, soil health, and a broad array of ecosystem services.

THE CONTINUING DEVELOPMENT OF RANGELAND SOIL HEALTH CONCEPTS

History. The rangeland and soil science professions have made significant progress in developing the concepts, methodologies and tools necessary to evaluate soil health during the past two decades. As early as the mid-1990s, the USDA Agricultural Research Service (ARS) and Natural Resources Conservation Service (NRCS) collaborated extensively to develop a basis for inventory methods and management responses to manage for soil condition or soil quality, the previous names for soil health. The NRCS Soil Quality and the NRCS Grazinglands Technology Institutes developed a series of soil health and rangeland soil health fact sheets describing the importance of aggregate stability, compaction, infiltration, organic matter, physical and biological soil crusts, soil biota, water erosion, and wind erosion as elements and indicators of the condition of rangeland soil relative to an inherent and unique capacity to function (USDA NRCS 2014).

Most importantly, the contribution of these working groups went beyond concepts to include a robust set of indicators, protocols for qualitatively and quantitatively estimating those indicators, and physical toolkits to improve the consistency of measurements (Pellant et al. 2005). Since, there has been a consistent and productive effort to develop data handling products and analytical techniques. The result has been a successful effort to collect soil health data, both systematically and ad hoc across a variety of rangeland ecosystems and management emphases. The effort has borne fruit, both providing a focus for management and a quantitative relationship between vegetation and soil attributes that can be interpreted at a site-specific scale. The result of this two-decade effort has been the inclusion of soil health as an integral component of rangeland assessment and monitoring protocols (Pellant et al. 2005; Herrick et al. 2012b), both in concept and in practice.

The importance of the effort to date should not be underestimated. However, it is not yet a sufficient basis for a precise, quantitative application that can be used to systematically assess program and practice efficacy. While many of these links are relatively well-established on croplands, these relationships need to be better quantified for rangelands. It is difficult to justify financial and technical assistance to "improve" soil health by increasing the values of universal-specific soil health attributes independent of changes in the vegetation that largely control and precede changes in soil health.

Integrating Resilience into Rangeland Soil Health Assessment. A good indicator (or set of indicators) can both quantitatively reflect meaningful changes and be a way to communicate with users and other professionals. Perhaps the most promising way to link soil health to capacity to function is to integrate resilience (Seybold et al. 1999, Bestelmeyer and Briske 2012). Resilience management and assessment have some high profile proponents and applications (the Resilience Alliance [www.resilience.org] and the Resilience Research Centre's Logic Model [http://www.resilienceproject.org/evaluation/toolbasket]), but the approach has met with limited success due to its complexity. While we do not recommend the adoption of the specifics of the approach advocated by the Resilience Alliance, it is clear that a more quantitative approach to defining resilient systems, recognizing threats to sustainability, and identifying actions that can increase resiliency is an important step forward.

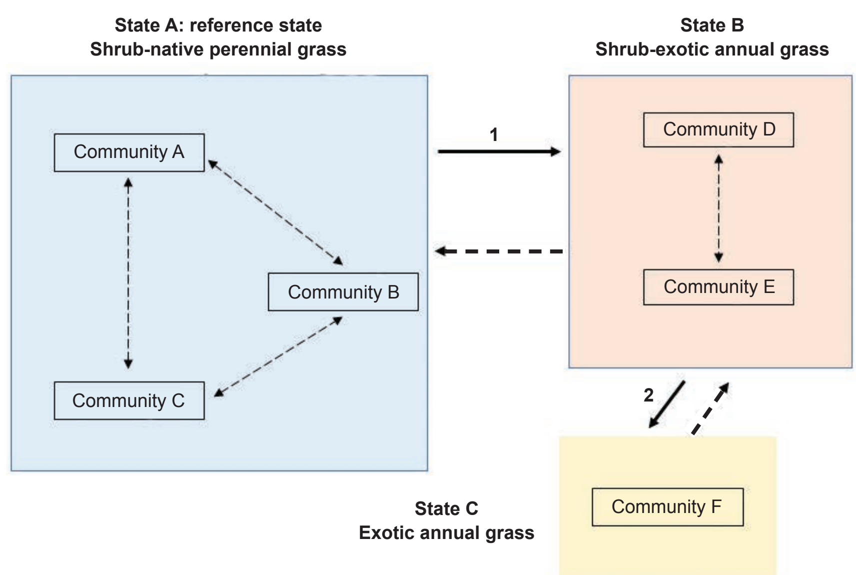
An improved understanding and a more robust definition of the link between various soil health attributes and management also requires an explicit link to time frames of change. In many, if not most rangeland situations, the time lags between changes in the driving factors associated with changes in dynamic soil and vegetation properties are sufficiently long enough that even institutional-based monitoring fails to detect change with enough precision to warrant management response (Karl and Herrick 2010). Early warning indicators, based on multiple lines of evidence, are critical to detecting impending change, formulating realistic management response, and evaluating effectiveness (Brown 1994).

A Rangeland Health Approach. A concerted, collaborative effort on the part of NRCS, ARS, the Bureau of Land Management (BLM), and the US Geological Survey has resulted in the development and application of the concept of rangeland health via a series of supporting documents, training sessions, reports, and agency programs (Pellant et al. 2005; Herrick et al. 2012b). This integrative approach to rangeland health considers three, interacting attributes of ecosystem health: soil/site stability, hydrologic function, and biotic integrity. Rangeland health, both as a concept and a series of practical applications, emerged from the realization by the profession that concepts and techniques previously guiding rangeland management decisions (Clementsian ecology and Dyksterhuis's range condition as discussed previously) were neither ecologically accurate nor conservation program-relevant. Rangeland health was defined as the "degree to which the integrity of the soil and ecological processes of rangeland ecosystems are maintained" (National Research Council 1994). Specifically, they defined integrity in terms of ability to function (defined as "capacity to produce commodities and satisfy values") and illustrated the concept using functional domains (healthy, at risk, and unhealthy) separated by thresholds (National Research Council 1994). The rangeland health assessment approach that was developed rates each indicator based on its departure from potential (Pellant et al. 2005), providing information necessary to determine the functional domain. The authors strongly emphasized that within each of the broad domains of ability to function, there were multiple possible combinations of plant:soil communities that were both stable and functional.

The refinement of the rangeland health approach (Pellant et al. 2005) has resulted in the identification of 17 indicators and techniques for qualitative and quantitatively estimating each against a standard for the specific ecological site (Pellant et al. 2005). The document also includes guidance on the spatial context for the application of the technique and for the integrated interpretation of spatial and temporal variability. Importantly, the authors of the Interagency Guide relied heavily on and insisted that both reference condition definitions (in ecological site-specific reference sheets) and management applications be guided by the use of site-specific ecological site descriptions, including state-and-transition models for specific soil groupings (figure 1). The individual states are the temporal domains within which soil and plant indicators may vary without crossing a threshold. For instance, a shift from Community A to Community B may result in changes of rangeland health attributes, but these changes can be reversed relatively easily. On the other hand, a shift from State A to State B represents a change in the attributes of the site that result in substantially different ecological functions (reduced soil health, less stable vegetation cover, hydrology, etc.). Also, the existence of a defined transition indicates that only major investments in energy and technology can restore the original state. One of the core principles laid out by the developers was that rangeland health should not be used alone to identify cause(s) of resource problems or guide management responses (Pellant et al. 2005).

Figure 1

Generic state and transition diagram. Dashed lines between communities within an ecological state are community pathways, solid lines between ecological states are transitions, and dotted lines between states indicate unlikely reverse transitions (redrawn from Pellant et al 2005). Each state has a unique set of values for soil health indicators that are functionally different from other states. Communities may or may not have different soil or ecosystem health values, but they are functionally equivalent.



Community	Indicators
A	Shrubs and native perennial grasses codominate
B	Native perennial grasses dominant; shrubs subdominant
C	Shrubs dominant; perennial grasses subdominant
D	Shrubs dominant; exotic grasses subdominant
E	Exotic grasses dominant; shrubs subdominant
F	Exotic annual grasses dominant

Transition	Mechanisms
1	Wildfire; introduction of exotic, invasive annual grasses
2	Repeated wildfires outside of natural fire regime interval

The rangeland health approach has been widely applied, tested, and refined for more than a decade and has been the basis for agency-specific applications for the BLM (Toevs et al. 2011). The BLM's applications of the assessment protocol in particular, and the rangeland health concept in general is especially instructive because they were developed in order to more specifically tie site-specific evaluations of multiple attributes of ecosystem health to a broader range of ecosystem services. A strong focus of the BLM approach and guidance document is to establish a more clearly defined link between the ecosystem health assessment protocols and management actions at a local, regional, and national scale.

These specific applications that cross agency boundaries clearly point to a need for an enhanced effort to link findings from a well-defined and accepted approach to evaluating ecosystem health assessments to management actions. While the original developers did not intend for the results of RH protocols to be used without additional information to identify the causes of departure from reference, the pressing management needs and the expected use of the information will require a more explicit link between soil and ecosystem health and management causes and effects (figure 2). Similarly, development and implementation of policies, program guidelines, and practice specifications can be greatly enhanced both as management and research tools with increased attention to systematic estimates from structured data collection and analysis.

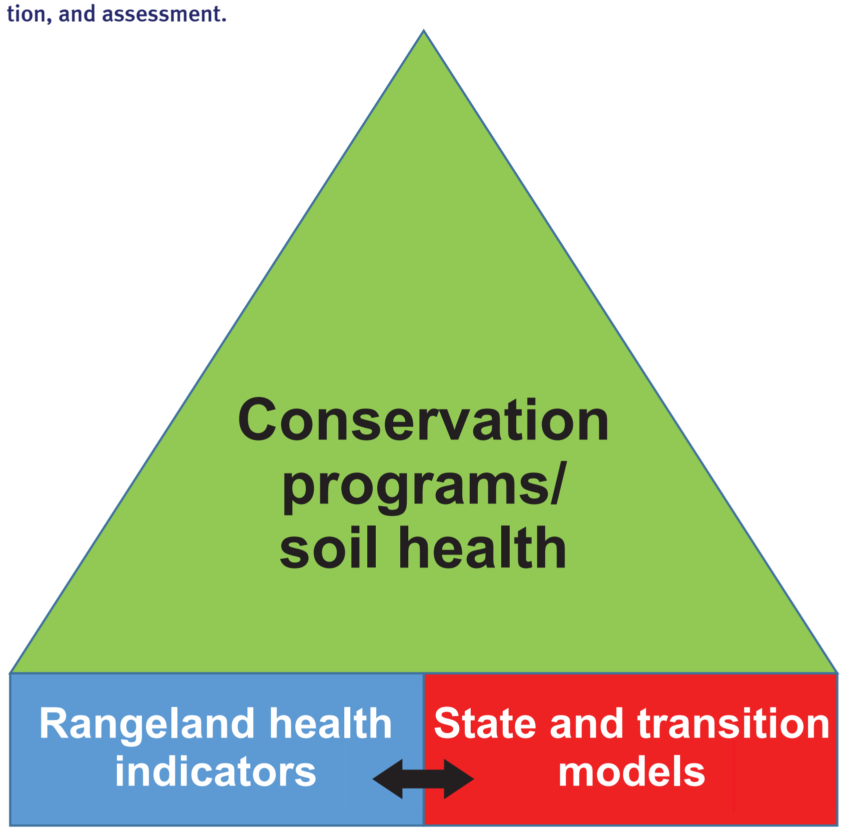
OPPORTUNITIES FOR IMPROVING RANGELAND SOIL HEALTH ASSESSMENT

It should be apparent from the foregoing discussion that rangeland soil health assessment has a well-documented history and has continually improved (albeit sporadically) over the past three decades, due largely to the efforts of a relatively small group of people. It is also abundantly clear that these efforts need to expand to both new rangeland ecosystems and to new working groups.

The existing approach to evaluation of rangeland soil health currently integrated into the Interpreting Indicators of Rangeland Health method has been sufficiently tested to provide the most logical basis for future work. This protocol is closely linked to a standard set of quantitative measurements and indicators, including soil aggregate stability, that have been adopted for use by both the National Resource Inventory and by the BLM's national Assessment, Inventory, and Monitoring initiative. This is the most cost-effective means of gaining the necessary information to test and refine site-specific indicators. We think continued testing and refinement of these 17 indicators, and the associated quantitative methods, guided by site-specific reference sheets offers the greatest probability of gaining a systematic understanding of rangeland soil health that can be both a management guide and a basis for program technical and financial assistance. This attempt to improve the systematic understanding of rangeland soil health also requires an increased emphasis on the development of a common database for soil, vegetation, and soil attributes derived from conservation program and technical assistance applications to refine the use of this approach. Both BLM and NRCS have already made significant progress on this issue. Interpretation of the results of this systematic approach could also benefit from a structured hypothesis testing on a network of experimental sites with known management histories and well-characterized soil and vegetation variables, such as those provided by the USDA ARS Long Term Agricultural Research network. Nodes in the test network should include a wide range of experimental treatments sufficient to quantitatively distinguish among indicators and methodologies to reflect soil health. Ultimately, data and relationships from the experiments should be systematically incorporated into mathematical models (e.g., Agricultural Policy/Environmental eXtender [APEX] and CENTURY) to estimate soil health changes in response to changes in management and climate across all rangelands.

Figure 2

The importance of state and transition models in defining opportunities to integrate rangeland health indicators in support of soil health program development, application, and assessment.



These opportunities, based on the existing work and emerging needs, are our interpretations of immediate next steps. Obviously, as with any good science, we expect that changes in priorities and directions could occur as new information is gained and new technologies become available. While we have made a substantial amount of progress and have established a solid base for future work, we are nowhere near a mature science, and continuing the work has both great promise and great value.

REFERENCES

Archer, S.R., K.W. Davies, T.E. Fulbright, K.C. McDaniel, B.P. Wilcox, and K.I. Predick. 2011. Brush management as a rangeland conservation strategy: A critical evaluation. *In* Conservation benefits of rangeland practices: Assessment, recommendations, and knowledge gaps, ed. D.D. Briske, 105-170. Washington, DC: USDA Natural Resource Conservation Service.

Bestelmeyer, B.T., J.R. Brown, S.D. Fuhlendorf, G.A. Fults, and X.B. Wu. 2011. A landscape approach to rangeland conservation practices. 2011. *In* Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps, ed, D.D. Briske, 337-370. Washington, DC: USDA Natural Resources Conservation Service.

Bestelmeyer, B.T., and D.D. Briske. 2012. Grand challenges for resilience-based management of rangelands. Rangeland Ecology and Management 65:654-663.

Bestelmeyer, B.T., M.C. Duniway, D.K. James, L.M. Burkett, and K.M. Havstad. 2013. A test of critical thresholds and their indicators in a desertification-prone ecosystem: More resilience than we thought. Ecology Letters 16:339-345.

Briske, D.D., J.D. Derner, D.G. Milchunas, and K.W. Tate. 2011. An evidence-based assessment of prescribed grazing practices. *In* Conservation benefits of rangeland practices: Assessment, recommendations, and knowledge gaps, ed, D.D. Briske, 21-74. Washington, DC: USDA Natural Resource Conservation Service.

Brown, J.R. 1994. State and transition models for rangelands. 2. Ecology as a basis for rangeland management: Performance criteria for testing models. Tropical Grasslands 28:206-213.

Cornell. 2009. Cornell Soil Health Assessment Training Manual. http://soilhealth.cals.cornell.edu/. Ithaca, NY: Cornell University.

de Soyza, A.G., W.G. Whitford, J.E. Herrick, J.W. Van Zee, and K.M. Havstad. 1998. Early warning indicators of desertification: Examples of tests in the Chihuahuan Desert. Journal of Arid Environments 39:101-112.

Doran, J.W. 2002. Soil health and global sustainability: Translating science into practice. Agriculture, Ecosystems, and Environment 88:119-127.

Doran, J.W., and M.R. Zeiss. 2000. Soil health and sustainability: Managing the biotic component of soil quality. Applied Soil Ecology 15:3-11.

FAO (Food and Agriculture Organization of the United Nations). 2014. Food and Agriculture Organization Soils Portal. http://www.fao.org/soils-portal/soil-degradation-restoration/global-soil-health-indicators-and-assessment/global-soil-health/en/.

Herrick, J.E. 2000. Soil quality: An indicator of sustainable land management? Applied Soil Ecology 15:75-84.

Herrick, J.E., J.R. Brown, B.T. Bestelmeyer, S.S. Andrews, G. Baldi, J. Davies, M. Duniway, K.M. Havstad, J.W. Karl, D.L. Karlen, D.P.C. Peters, J.N. Quinton, C. Rignos, P.L. Shaver, D. Steinaker, and S. Twomlow. 2012. Revolutionary land use change in the 21st Century: Is (rangeland) science relevant? Rangeland Ecology and Management 65:590-598.

Herrick, J.E., M.C. Duniway, D.A. Pyke, B.T. Bestelmeyer, S.A. Wills, J.W. Karl, and K.M. Havstad. 2012b. A holistic strategy for adaptive land management. Journal of Soil and Water Conservation 67:105A-113A, doi:10.2489/67.4.105A.

Jenny, H. 1961. Derivation of state factor equations of soils and ecosystems. Soil Science Society of America Journal 25:385-388.

Joyce, L.A. 1993. The life cycle of the range condition concept. Journal of Range Management 46(2):132-138.

Karl, J.W., and J.E. Herrick. 2010. Monitoring and assessment based on ecological sites. Rangelands 32(6):60-64.

Martinez, S., M. Hand, M. Da Pra, S. Pollack, K. Ralson, T. Smith, S. Vogel, S. Clark, L. Lohr, S. Low, and C. Newman. 2010. Local Food Systems: Concepts, Impacts, and Issues, ERR 97. Washington, DC: USDA Economic Research Service.

MacLeod, N.D., and J.R. Brown. 2014. Valuing and rewarding ecosystem services from rangelands. Rangelands 36(2):12-19.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Washington, DC: Island Press.

National Research Council. 1993. Soil and Water Quality: An Agenda for Agriculture. Washington DC: National Academies Press.

National Research Council. 1994. Rangeland Health: New Methods to Classify, Inventory and Monitor Rangelands. Committee on Rangeland Classification. Washington, DC: National Academies Press.

Pellant, M., P. Shaver, D.A. Pyke, and J.E. Herrick. 2005. Interpreting indicators of rangeland health, version 4. Technical Reference 1734-6. BLM/WO/ST-00/001+1734/REV05. Denver, CO: US Department of the Interior, Bureau of Land Management, National Science and Technology Center.

Pyke, D.A., J.E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. Journal of Range Management 55:584-597.

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Science 164:224-234.

Sheley, R.L., J.J. James, M.J. Rinella, D. Blumenthal, and J.M. DiTomaso. 2011. Invasive plant management on anticipated conservation benefits: a scientific assessment. *In* Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps, ed, D.D. Briske, 291-336. Washington, DC: USDA Natural Resources Conservation Service.

SQI (Soil Quality Index). 2001. Natural Resources Conservation Service Soil Quality Institute-Rangeland Soil Quality Information Sheets. http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/.

Tanaka, J.A., M. Brunson, and L.A. Torrell. 2011. A social and economic assessment of rangeland conservation practices. *In* Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps, ed, D.D. Briske, 371-422. Washington, DC: USDA Natural Resources Conservation Service,

Toevs, G.R., J.J. Taylor, C.S. Spurrier, W.C. MacKinnon, and M.R. Bobo. 2011. Bureau of Land Management Assessment, Inventory, and Monitoring Strategy: For integrated renewable resources management. Denver, CO: Bureau of Land Management, National Operations Center.

USDA NRCS (Natural Resources Conservation Service). 2014. Soil Health Home. http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/.

von Hagan, O., S. Manning, and J. Reinecke. 2010. Sustainable standards in the food industry: Global challenges and practices. Moderne Ernahrung Heute 4:1-9.

Walters, C. 1986. Adaptive Management of Renewable Resources. New York: McMillan Publishing Co.