Point Blue Report

Soil Health on Rangelands



Report prepared for the TomKat Ranch Educational Foundation

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Conservation science for a healthy planet

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Purpose of this Document

The purpose of this document is to explore the definition of soil health, discuss how this concept applies to rangelands, and illustrate how monitoring can be used to understand rangeland soil health across California.

Soil Health Defined

The term soil health derives from preceding concepts such as soil quality and soil condition. Today, soil health is most popularly defined as "*the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans*" (USDA NRCS 2014). This definition is purposefully broad and applicable to a number of situations. Other definitions are more specific (see Appendix Table 1), but all share some commonalities that tie them together. These include referencing the soil system as a living entity and emphasizing the ability of that entity to function at its maximum potential, sustain that maximum functioning, and provide ecosystem services (Brown & Herrick 2016). Similar to human health (defined by the World Health Organization as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity"), soil health is not defined merely by the absence of disease but by the soil's emergent properties that confer a state of sustained optimal functioning.

Soil health integrates a range of biological, chemical, and physical components of soil (Fig. 1) – focusing primarily on those properties that are dynamic rather than inherent. Inherent properties as those that remain relatively constant over time and are not easily changed by management. Examples include texture (i.e. % sand, silt, and clay), and mineral content and composition. Dynamic properties emerge from inherent properties, but can be altered over relatively short time periods (months or years) through management. Examples include soil organic matter, bulk density (weight per volume, which is an indicator of soil compaction), water infiltration, aggregate stability, and microbial community characteristics such as mycorrhizal colonization of roots.

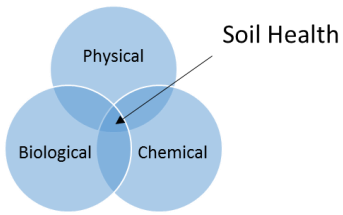

Figure 1 Soil health integrates the biological, physical, and chemical aspects of a soil

Soil Health versus Soil Quality

Soil health emphasizes the soil as a living system with emergent properties, and focuses on the current and future conditions of soil dynamic properties as affected by management. In contrast, soil quality has often been used to discuss the capacity for a soil to support a given use based on its inherent properties – deemphasizing the biological aspect of the system (Bennett et al. 2010). Despite these distinctions, soil health and soil quality are often used interchangeably. See Appendix Table 2 for some example comparisons of soil health and quality taken from the literature.

Considering Refinement of the Soil Health Definition

Do we need a new definition of soil health for rangelands? According to Johnson et al. (1997), "Ideal scientific definitions are short, logical, preferably nontheoretical (i.e., not intimately linked to any theory or explanatory framework--unless the definition defines that theory or framework), conceptually uncomplicated, comprehensive, all inclusive, and useful (i.e., practical, applicable). Their meanings should be easily communicated and easily remembered, because long and complicated definitions are hard to remember, thus less useful." The commonly-used Natural Resource Conservation Service (NRCS) definition of soil health ("*the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans*") fulfills many of these requirements. However, as a result of its broad nature, this definition falls short of being useful, practical, and applicable. For this reason, some scientists and practitioners argue for a more detailed definition – one that includes tangible components that can be measured through time.

There will always be tension between the generality and applicability of a definition; the more general a term is, the less applicable it will be. For soil health, keeping a general definition that can speak to many situations both within and across land-use types is more beneficial than narrowing the term to include only certain components, functions, or outcomes. The general definition can be supplemented with specific targets and concrete objectives that inform indicator selection and implementation of management practices on rangelands. However, even a general definition of soil health should have the ability to broadly differentiate between conditions, and we therefore recommend the following definition that draws from preexisting ones (Appendix Table 1):

The capacity of the soil to function as a vital living ecosystem that maintains biodiversity and maximizes provision of multiple ecosystem services within ecosystem boundaries in a sustainable way

As this definition suggests, whether a particular soil is healthy or not will depend on the ecosystem context and ecosystem services of interest. The same soil can be deemed healthy in

one context and unhealthy in another. For example, serpentine soils, which have inherently low nutrient availability and high concentrations of heavy metals, are healthy in the sense that they support unique and diverse plant communities. However, these soils also support inherently low plant biomass, such that they would be considered unhealthy as measured by the ecosystem service of forage production. Therefore, whether or not serpentine sites are targeted for management activities that try to improve soil health would depend on the management goals. Incorporating knowledge regarding the inherent capacity of a soil to maintain biodiversity and provide particular ecosystem services will be critical for setting management goals and evaluating soil health.

Assessing Soil Health on Rangelands

How does one know if their soil has ***the capacity to function as a vital living ecosystem that maintains biodiversity and maximizes provision of multiple ecosystem services within ecosystem boundaries in a sustainable way***? One way is by digging a pit and observing characteristics such as plant roots, soil texture, color, and moisture visually in the field. However, while the physical aspects of soil are important to consider, visual assessment methods alone cannot determine the state of biological and chemical properties and how they relate to ecosystem processes and management goals over time. Measuring biological and chemical properties typically requires instruments and some degree of analysis. Ideally, analytical indicators can be paired with visual assessments to provide a holistic picture of soil health. Many analytical indicators exist, and care should be taken to select indictors that address particular resource concerns and relate to desired outcomes.

Indicators of soil health generally measure dynamic soil properties, but inherent properties are also important to consider for context and interpretation. To determine which dynamic soil properties should be chosen as indicators, we must first ask the question: what are the outcomes I am managing for? And then: what separates a good indicator from a poor indicator? In their Action Plan, the Soil Health Institute (SHI) outlines some criteria. Good indicators are:

- Sensitive to changes in management systems
- Representative of soil processes relevant to agricultural production and environmental outcomes
- Indicative of agriculturally significant changes within 5 years
- Available for use in commercial production laboratories (reproducible, economical, directionally interpretable)

Increasingly, soil health indicators are being categorized into tiers. Tier 1 indicators are known to be effective indicators, defined regionally and by soil groupings across the nation. Thresholds are known to indicate “poor”, “adequate” and “good” conditions based on outcomes, and their relationship to specific management practices are known. Tier 2 indicators lack one or more of

these qualifications, but otherwise show promise as an effective indicator of soil health. Tier 3 indicators have the potential to add significant information on soil health but are still in the research and development phase (SHI Action Plan). Appendix Table 3 shows a list of the Soil Health Institute's official Tier 1 indicators, along with a number of candidate Tier 2 and Tier 3 indicators. **These indicators have been ranked primarily based on their understanding within row-crop agricultural systems and most of them still need to be tested rigorously on rangelands.** Some examples of Tier 1 indicators include soil organic carbon, bulk density, water infiltration, and cation exchange capacity.

Exhaustive assessments of soil health indicators on rangelands are much less common than in row crop systems. One example framework for assessing rangeland soil health is presented in the guide to Interpreting Indicators of Rangeland Health developed by the Bureau of Land Management and other government agencies. This guide focuses on three components, or attributes, of rangeland health, namely soil/site stability, hydrologic function, and biotic integrity. Below you will find a list of quantitative indicators provided in that guide, which can help to assess soil/site stability (Fig. 2). These indicators have been used widely to develop the National Resources Inventory Rangeland Resource Assessment, a national assessment of rangeland health on non-Federal lands. While these indicators are certainly useful for assessing erosion potential of a site, by focusing almost solely on soil physical attributes, they fall short of adequately capturing the biotic/chemical components of soils and thus of holistically assessing soil health.

Attribute	Qualitative Assessment Indicators	Key Quantitative Assessment Indicators	Selected Measurements and References
Soil/Site Stability	• Rills • Water flow patterns • Pedestals and/or terracettes • Bare ground • Gullies • Wind-scoured, blowout, and/or depositional areas • Litter movement • Soil surface resistance to erosion • Soil surface loss or degradation • Compaction layer	Bare ground	Line point intercept (2, 3) Point frame (2)
		Proportion of soil surface covered by canopy gaps longer than a defined minimum	Canopy gap intercept (3) Continuous line intercept (2)
		Proportion of soil surface covered by basal gaps longer than a defined minimum	Basal gap intercept (3) Continuous line intercept (2)
		Soil macro-aggregate stability in water	Soil stability kit (3)

Figure 2 From the Bureau of Land Management's Interpreting Indicators of Rangeland Health, key quantitative indicators and measurements relevant to soil/site stability. In the document, this table also provides similar information for two other attributes: biologic function and biotic integrity. See Table 2 from Interpreting Indicators of Rangeland Health Technical Reference.

Rangeland management would benefit from a more comprehensive approach to measuring soil health, which will require testing, validating, and generating information to help interpret biological and chemical soil health indicators across these extensively managed landscapes. Having this information will allow producers to carefully select indicators that are informed by resources needs and desired outcomes, using them to monitor within an adaptive management

framework to assess the trajectory of soil health at their ranch over time (Fig. 3). Because there is no "one-size fits all" approach to building soil health, and because we still have much to learn about how to achieve soil-based goals on rangelands, this type of data-informed adaptive management approach (where carefully chosen indicators of soil health are tracked over time and management practices are modified accordingly) will be an important way to assess whether a soil has *the capacity to function as a vital living ecosystem that maximizes provision of multiple ecosystem services in a sustainable way.*

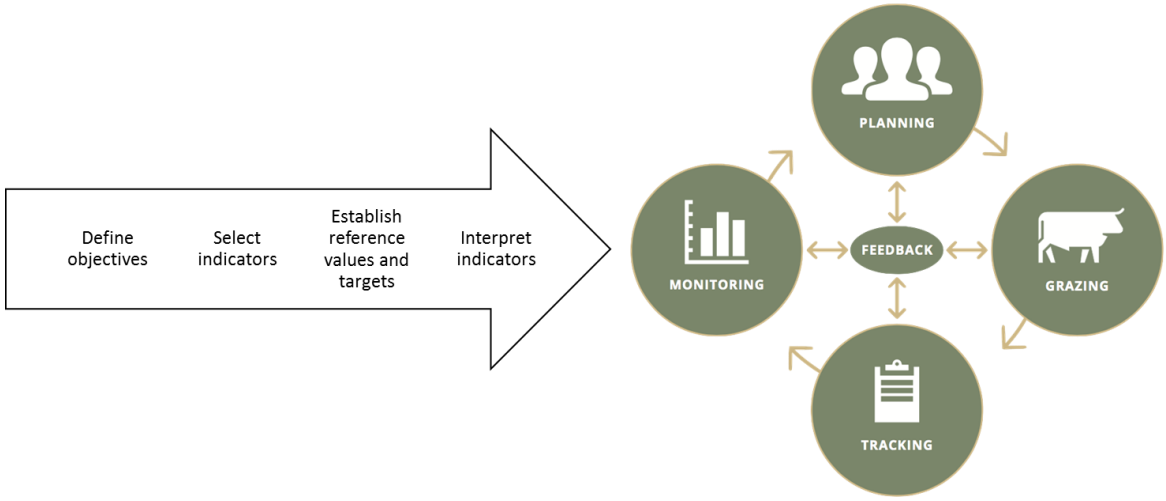

Figure 3 Main steps to assess soil health within an adaptive management framework

Challenges and Opportunities to Managing Soil Health on Rangelands

In California, rangelands -which can include grasslands, scrub, and woodland - are typically found in semiarid and arid regions, relatively poorer soils (inherently), and on hillier terrain where crop production has historically been restricted. These rangelands are managed extensively, rather than intensively, meaning they receive minimal inputs like irrigation or fertilizer. Their biological composition and productivity (including for forage) is largely driven by climate conditions and underlying geology, which are highly variable, and our ability to influence their health through management activities is more limited than in croplands or intensively managed pastures. The natural variability of rangelands across space (both within a ranch and across ranches) and time is at once an asset and a challenge: landscape-scale variability is important for biodiversity and can facilitate resilience of an ecosystem, but increases the difficulty of identifying limits of soil health that can be used to inform expectations. Further complicating the picture, rangelands are often managed for multiple outcomes, not just yield of a single crop commodity, and these

systems can shift from one stable state (e.g., shrub-native perennial grassland) to another (e.g., exotic annual grassland) – a transition that may be difficult to reverse.

Despite these challenges, as soil health continues to gain visibility amongst producers, land managers, politicians, and scientists, opportunities to address questions surrounding soil health on rangelands also grow. There are ample opportunities to tackle key challenges through partnership, which will help to advance our ability to assess soil health in these systems. Here are a few examples of high-level research topics that require attention:

- Identifying meaningful targets/thresholds for soil health indicators on rangelands.
- Assessing the ability of soil health indicators that are well-accepted in row crop agriculture to provide useful information for rangelands.
- Identifying and tracking new indicators of soil health that will detect the trajectory of the system, act as early warning signs of impending change, and inform management decisions in real-time.
- Determining linkages between management activities, soil dynamic properties, and ecosystem outcomes across space and time. Asking questions regarding the magnitude and direction of these links and doing so in a way that provides scalable and mechanistic information that can be used to inform management decisions.

References & Resources

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USDA NRCS: Soil Health definition. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

USDA Soil Health Literature Summaries: Summaries of peer-reviewed articles, including citations (2016). https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/mgnt/?cid=stelprdb1257753

Resources to Help with Indicator Selection

Karl, M.G., Pyke, D.A., Tueller, P.T., et al. 2006. Soil and water indicators of the sustainable rangelands roundtable. USDA Forest Service Proceedings RMRS-P-42CD. https://www.fs.fed.us/rm/pubs/rmrs_p042/rmrs_p042_121_131.pdf

USDA NRCS & University of Illinois: Soil quality and environmental health. http://soilquality.org/home.html

USDA NRCS: Soil quality indicator sheets and how-to guide. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/assessment/?cid=stelprdb1237387

Resources to Help Measure & Interpret Indicators

Cornell Soil Health Testing Laboratory. https://soilhealth.cals.cornell.edu/

Porzig, E., Seavy, N.E., DiGaudio, R.T., Henneman, C., and T. Gardali. 2016. The rangeland monitoring network handbook V1.0. Point Blue Conservation Science, Petaluma, California.

Pellant, M., Pyke, D.A., Shaver, P., and J.E. Herrick. 2005. Interpreting indicators of rangeland health. Bureau of Land Management, Technical Reference 1734-6. https://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf

Trace Genomics. https://www.tracegenomics.com/#/products

USDA NRCS: Soil quality test kit. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/assessment/?cid=nrcs142p2_053873

Ward Laboratories. https://www.wardlab.com/

Appendix

Appendix Table 1 List of soil health definitions taken from the literature.

CITATION	TITLE	SOIL HEALTH DEFINITION
FINE ET AL. 2017. SOIL SCI. SOC. AM. J.	Statistics, scoring functions, and regional analysis of a comprehensive soil health database	Soil health represents the emerging understanding of soil quality. Both terms refer to the ability of a soil to function and provide ecosystem services based on its inherent characteristics and environmental conditions. A soil's health status, within the context of land use and management goals, however, is consistent with the understanding of soils as a dynamic, complex, and living system.
MOEBIUS-CLUNE ET AL. 2016. COMPREHENSIVE ASSESSMENT OF SOIL HEALTH – THE CORNELL FRAMEWORK MANUAL, EDITION 3.1, CORNELL UNIVERSITY, GENEVA, NY.	A comprehensive assessment of soil health: The Cornell framework manual	Cites NRCS definition of soil health; "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans." Soil health and quality are synonymous, except soil quality includes both inherent and dynamic properties while soil health includes only those that are dynamic.
ALLISON THOMSON. FIELD TO MARKET. WHITE PAPER.	Exploring opportunities to advance soil health: The role of commodity crop supply chains in maintaining and improving the health of our nation's soil	Soil health involves the capacity of a soil to maintain system stability and resiliency to buffer against stressors within the soil ecosystem. Cites NRCS definition but also SSSA, which does not define healthy soil separately from quality: “The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health.”
BISWAS ET AL. 2017. INT. J. CURR. MICROBIOL. APP. SCI. 6: 2546-2556.	Assessment of soil health under protected cultivation by soil quality indexing and variability analysis	Soil health is defined as the continued capacity of a soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. (FAO definition)
DORAN AND ZEISS. 2000. APPLIED SOIL ECOLOGY 15: 3-11.	Soil health and sustainability: managing the biotic component of soil quality	Cites Doran and Parkins (1994) definition of soil quality. Soil health...indicate[s] the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health. In this sense soil health is synonymous with sustainability.
ARIAS ET AL. 2005. INTERNATIONAL MICROBIOLOGY 8: 13-21.	Soil health - a new challenge for microbiologists and chemists	Soil health refers to the biological, chemical, and physical features of soil that are essential to long-term, sustainable agricultural productivity with minimal environmental impact.
SHERWOOD AND UPHOFF. 2000. APPLIED SOIL ECOLOGY 15: 85-97.	Soil health: research, practice and policy for a more regenerative agriculture	Soil quality and soil health can be analytically differentiated by associating soil health with holistic soil management, while using soil quality to describe the constituent parts of the soil (i.e., biological, chemical) characteristics.
KATYAL ET AL. 2016. BULLETIN OF THE INDIAN SOCIETY OF SOIL SCIENCE 30: 1-98.	Soil health: concept, status, and monitoring	A soil that is able to optimally sustain its native/acquired productivity potential and render ecological services is said to be in good health.

BRADY AND WEIL. 2008. PEARSON PRENTICE HALL, NEW JERSEY, USA.	The Nature and Properties of Soils, 14th edition	Soil health refers to self-regulation, stability, resilience, and lack of stress symptoms in a soil as an ecosystem. Soil health describes the biological integrity of the soil community -- the balance among organisms within a soil and between soil organisms and their environment. The utilitarian concept of soil quality is best applied to a soil as a component of a larger ecosystem that supports plant growth, regulates water flows, and so forth. Soil quality describes the properties that make a soil fit to perform particular functions.
FAO. 2008. INTEGRATED CROP MANAGEMENT 6.	An international technical workshop investing in sustainable crop intensification: the case for improving soil health.	The capacity of a soil to function as a living system, with ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations w/ plant roots; recycle essential plant nutrients; improve soil structure w/ positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production. A healthy soil does not pollute its environment and does contribute to mitigating climate change by maintaining or increasing its carbon content.
FERRIS AND TUOMISTO. 2015. SOIL BIOLOGY AND BIOCHEMISTRY 85: 101-109.	Unearthing the role of biological diversity in soil health.	The provision of ecosystem services is a prominent theme among definitions of soil health….When conditions are such that one or more ecosystem functions of interest are no longer operative, the soil is in an unhealthy condition relative to that function.
BROWN AND HERRICK. 2016. JOURNAL OF SOIL AND WATER CONSERVATION 71: 55A-60A.	Making soil health a part of rangeland management	Cite NRCS definition of soil health: "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans".
KIBBLEWHITE ET AL. 2008. PHIL. TRANS. R. SOC. B 363: 685-701.	Soil health in agricultural systems	A healthy agricultural soil is one that is capable of supporting the production of food and fiber, to a level and with a quality sufficient to meet human requirements, together with continued delivery of other ecosystem services that are essential for maintenance of the quality of life for humans and the conservation of biodiversity.

Appendix Table 2 Comparisons of soil health and quality definitions from the literature.

Soil Health	Soil Quality	Citation
Soil health focuses on the "ecological attributes of soil" with an emphasis on biodiversity, food web structure, biotic activity and transformation of solar energy to biochemical energy.	Soil quality emphasizes physical, chemical, and biological attributes with a focus on the "capacity of soil to function" with regard to maintaining productivity, storing and cycling nutrients, regulating and partitioning water flow and filtering, buffering, and detoxifying applied organic and inorganic materials.	Karlen, D.L. 2012. Soil Health: The concept, its role, and strategies for monitoring. In: Soil Ecology and Ecosystem Services, D.H. Wall (Eds). Oxford University Press.
The term soil health refers to self-regulation, stability, resilience, and lack of stress symptoms in a soil as an ecosystem. Soil health describes the biological integrity of the soil community – the balance among organisms within a soil and between soil organisms and their environment.	The more utilitarian concept of soil quality is best applied to a soil as a component of a larger ecosystem that supports plant growth, regulates water flow, and so forth. Soil quality therefore describes the properties that make a soil fit to perform particular functions in support of the six broad ecological roles soil.	Brady & Weil. 2008. The Nature and Properties of Soil. Pearson Prentice Hall.
Conceptually, soil health (SH) represents the emerging understanding of soil quality. Both terms refer to the ability of a soil to function and provide ecosystem services based on its inherent characteristics (e.g., texture, mineralogy) and environmental conditions (Karlen et al., 1997; Andrews et al., 2004; Idowu et al., 2009). A soil's health status, within the context of land use and management goals, however, is consistent with the understanding of soils as a dynamic, complex, and living system (Doran and Zeiss, 2000).		Fine, A.K., van Es, H.M., and R.R. Schindelbeck. Statistics, scoring functions, and regional analysis of a comprehensive soil health database. SSSA Journal 81: 589-601.
The terms soil quality and soil health will be used synonymously throughout this paper. However use of the term soil quality will generally be associated with a soils' fitness for a specific use and the term soil health used in a broader sense to indicate the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health. In this sense soil health is synonymous with sustainability.		Doran et al. 2000. Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15: 3-11.
In contrast to soil quality, soil health captures "the ecological attributes of the soil which have implications beyond its quality or capacity to produce a particular crop. These attributes are chiefly those associated with the soil biota; its biodiversity, its food web structure, its activity and the range of functions it performs"		Pankhurst et al. 1997. Biological indicators of soil health: synthesis. In: Pankhurst et al. (eds), Biological Indicators of Soil

	Health. CAB International, Wallingford, Oxon: 419-435.

Appendix Table 1 List of the Soil Health Institute's official Tier 1 indicators, along with a number of candidate Tier 2 and Tier 3 indicators. These are defined primarily from row-crop agriculture systems and require additional testing/validation on rangelands.

Soil Health Institute –Tiered Indicators

Tier 1	Tier 2	Tier 3
Organic carbon	B-glucosidase activity (biological activity)	DNA sequencing (microbial community composition)
pH	Macro-aggregate stability	
Water-stable aggregation	Permanganate oxidizable carbon (active C)	
Crop yield	Soil protein & Solvita Test (bioavailable N)	
Soil texture	FAME; PLFA (microbial community composition)	
Penetration resistance	Nematode population densities	
Cation Exchange Capacity	Pathogenic fungi, pathogen bioassays	
Electrical Conductivity		
Nitrogen		
Phosphorus		
Potassium		
Carbon mineralization		
Nitrogen mineralization		
Erosion rating		
Base saturation		
Bulk density		
Available water holding capacity		
Water infiltration rate		

Micronutrients		