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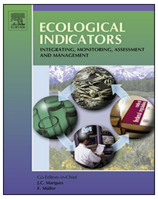

A strategy for defining the reference for land health and degradation assessments

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ABSTRACT

Much of the confusion about the definition of reference conditions for land health and degradation assessments is due to differences in policy and management objectives. Selection of a historic reference where it is not necessary, such as in the definition of future land degradation neutrality, can add significant cost and uncertainty to land management projects that require some knowledge of the current status of the land relative to its potential. This paper (1) provides a review of conditions under which historic reference information is and is not required to meet management and policy objectives, (2) summarizes current approaches to defining the reference for land health and degradation assessments, and (3) presents a protocol, “Describing Indicators of Rangeland Health” (DIRH) for collecting and organizing data that can be used to define a historic reference. This protocol builds on the framework and indicators presented in the “Interpreting Indicators of Rangeland Health” (IIRH). IIRH uses a combination of scientific and local knowledge to generate soil- and climate-specific assessments of three attributes of land health. It is used in a number of countries. In the United States, data are aggregated over 30,000 locations to provide national assessments.

1. Introduction

The “Interpreting Indicators of Rangeland Health” (IIRH) assessment protocol (Pyke et al., 2002; Pellant et al., 2005) has been used in the United States since 2004 at over 30,000 locations. Data have been successfully used, together with quantitative soil and vegetation measurements, to generate national assessments of rangeland health (Herrick et al., 2010) based on localized soil- and climate-specific reference information reflecting the land’s long-term potential (International Resource Panel, 2016). The protocol can also provide a historic context for more precise baselines established using more recently-collected quantitative data (e.g. Herrick et al., 2010).

However, the application of IIRH in other countries, and in some areas of the US, has been limited by the requirement for historic reference information that includes the natural range of variability for each indicator across the range of spatial and temporal variation for similar soil and climate combinations (reference conditions). Because this requires both a completed soil survey and development of a “reference sheet” describing reference conditions for each of the 17 indicators (Pyke et al., 2002), the requirement has limited the application of IIRH in nations or portions of the US where this information does not exist.

The objectives of this paper are to (1) briefly review conditions under which historic reference information is and is not required to meet management and policy objectives, (2) summarize current approaches to defining the reference for land health and degradation assessments, and (3) present a protocol for collecting and organizing data that can be used to define a historic reference, building on the framework and indicators presented in IIRH (Pellant et al., 2005). This protocol is designed to allow the data to be used in two ways. First, by linking indicators to characteristics that define land potential, it can be used to help inform the definition of land potential by defining the historic natural range of variability for specific types of land. Second, once the reference is defined, the data can be used to complete the IIRH assessment for the specific location.

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Table 1
References and metrics for land degradation assessments based on objective.

Objective		Reference	Metrics	Historic reference required?
1.1	Quantify *historic* degradation	Land condition (e.g. "natural capital" *sensu* Cowie et al., 2018) on specified date	Soil profile loss and/or degradation (e.g. organic carbon decline, change in pH), or land cover change	Yes
1.2	Monitor to prevent *future* degradation			No
2.1	Quantify *impacts* of *historic* degradation	Level of ecosystem service(s) (e.g. crop or forage production, biodiversity) on specified date	Change in ecosystem service(s)	Yes
2.2	Monitor to prevent *future* degradation			No
3	Define long-term restoration objectives (what is *possible*)	Land potential (long-term)	Current relatively static or inherent soil properties (depth, texture, mineralogy) + topography + climate	Possibly (see text)
4	Define short-term restoration objectives (what may be *realistic*)	Land potential (short-term)	As for long-term + relatively dynamic or manageable soil properties (e.g. organic matter content, structure, nutrient availability)	Possibly (see text)

2. Historic reference information: when is it (not) needed?

Much of the confusion about the definition of reference conditions for land health and degradation assessments may be attributed to differences in policy and management objectives, which determine how results of assessments will be used. The majority of the existing scientific and popular press articles have focused on historic degradation (Table 1, Objectives 1.1 and 2.1), over which policymakers and managers have no control. This morbid fascination with historic degradation has had two unintended and unfortunate consequences. The first is wasting resources on assessment efforts that fail because they are unable to establish a reliable historic reference. The second is that assessments of historic degradation provide results with less value for sustainable land management than assessments designed to either monitor future degradation (early warning indicators), as is required for land degradation neutrality (Table 1, Obj. 1.2 and 2.2; Cowie et al., 2018) or to spatially target and prioritize land restoration investments (Table 1, Obj. 3 and 4).

While targeting land restoration investments *can* be informed by a determination of how much degradation has occurred, it can also easily lead to a misallocation of resources because the return on restoration investment (ROI) for restoration of highly degraded land can be quite low where the land has crossed a threshold (Cowie et al., 2018). Examples include severe reductions in soil depth, salinization in areas where salts cannot be flushed below the rooting zone with freshwater, and replacement of the native plant community with invasive species which modify the fire regime in ways that make it virtually impossible for the native species to reestablish and persist (Brooks et al., 2016).

3. Current approaches to defining the reference

A number of different approaches have been applied to define historic reference conditions including: (1) expert opinion, (2) potential natural vegetation, (3) remote sensing-based indices, and (4) integrated approaches that predict soil and vegetation for a hypothetical "undisturbed state" based on (a) models, and (b) integration of soil-specific data and expert knowledge.

(1) Expert opinion. GLASOD (Global Assessment of human-induced Soil Degradation; Oldeman et al., 1991), a widely cited global land degradation assessment, was based on expert opinion. These opinions "were never tested for their consistency and could not be reproduced at unvisited sites" (Sonneveld and Dent, 2009). The expert opinion approach is also widely applied at the local level through the United Nations Food and Agriculture Organization's Land Degradation Assessment protocol (FAO-LADA; Nachtergaele and Licona-Manzur, 2008). Application of this approach at both global and local levels is limited by both variability in expert knowledge and difficulties in standardizing both the reference period and the definition of degradation across experts.

(2) Potential natural vegetation. Potential natural vegetation based on climate is commonly used as a baseline for assessments using land cover change, and is widely applied to studies of deforestation and fire (Rollins, 2009). This approach generally uses space-for-time substitution. Soil information can be integrated to refine predictions. Its application to both local and global land degradation assessments is limited by the relative insensitivity to degradation of land within a cover class.

(3) Remote sensing-based indices. Many of the more recent regional to global assessments have increasingly relied on changes in remote sensing-derived indices, such as the Normalized Difference Vegetation Index (NDVI). Interpretation of these indices is often supported by fine-scale weather and climate data, and other sources of information on land cover (Bai et al., 2008; Yengoh et al., 2014). These approaches are necessarily limited by the availability of historical imagery, and the interpretation of observed trends. For example, NDVI often increases with brush invasion of native grasslands, which is interpreted as a form of degradation in many parts of the world due to associated increases in soil erosion, and declines in forage production. The accuracy of NDVI-based assessments can be increased at local to regional scales by using local and scientific knowledge about the likely causes of spatial and temporal differences in reflectance to interpret the results.

(4a) Integrated approaches – modeling. The most recent and arguably most sophisticated approach to defining reference conditions uses a combination of potential natural vegetation and remote sensing-based vegetation indices together with modeled predictions of soils in their undisturbed state based on soil forming factors. A summary of the results of the most comprehensive attempt to implement this approach at the global scale was presented in the first "Global Land Outlook" (UNCCD, 2017; details in Van der Esch et al., 2017). Application of this promising approach at the national- to sub-national scales is currently limited by data availability.

(4b) Integrated approaches – soil-specific data and expert knowledge. A related approach uses local and scientific experts to generate predictions of land potential. It uses a qualitative integration of soil-specific data from sites that are believed to be relatively undegraded, and combines this with an understanding of soil forming processes, potential natural vegetation, and ecosystem processes for specific combinations of climate, soils, and topography (Herrick et al., 2010).

4. Reference period and soil profile assumptions

One of the most significant differences among, and sometimes within, the five approaches described above is the assumption they make about the reference period and soil profile characteristics (Table 2). The impact of these assumptions on land degradation assessments can be particularly significant in areas where soil loss has dramatically changed land potential, as reflected in both the plant community types and productivity. For example, the "red roads clay …

Table 2
Reference period and soil profile assumptions for each of the approaches to defining the reference.

Approach	Reference period	Soil carbon	Soil texture and depth
1. Expert opinion	Varies with expert	Varies with expert	Varies with expert
2. Potential natural vegetation based on climate, historic records and space-for-time	Pre-human	Undefined	Undefined
3. Remote sensing	Beginning of remote sensing record	Undefined	Undefined
4a. Integrated approaches – modeling (PBL)	Undefined	At reference period	Current
4b. Integrated approaches – soil-specific data and expert knowledge based on space-for-time (IIRH)	Varies by country (e.g. pre-European settlement in the US)	At historic reference period	At reference period

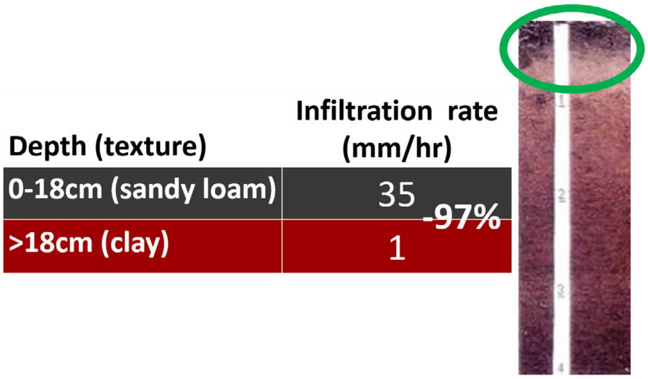

Fig. 1. Approximate change in saturated water infiltration when the top 18 cm of soil is lost from a Luverne sandy loam soil in Alabama, USA based on Saxton and Rawls (2005) and soil profile data from NRCS (2017).

that plowed up ground that your dad damned his luck on” described in the Florida Georgia Line song “Dirt” probably wasn’t red at the soil surface when the southeastern US was colonized by Europeans. The subsequent soil loss resulted in both a reduction in soil organic matter and infiltration capacity due to the exposure (erosion) or intermixing (tillage) of subsurface clay (Fig. 1). Because this change occurred before satellite imagery became available, assessments based on remote sensing based approaches must necessarily assume a reference that would be classified as already degraded by the integrated approaches (Table 2). A similar situation exists throughout much of the Mediterranean region, where light-colored soils reflect the often centuries-old loss of the A horizon.

5. *Describing indicators of Rangeland health* (DIRH): A strategy for defining the reference for land health and degradation assessments

The Interpreting Indicators of Rangeland Health (IIRH) protocol uses 17 indicators to evaluate three ecosystem attributes: soil and site stability, hydrologic function, and biotic integrity (Pellant et al., 2005). The protocol was developed for rangelands, but can be easily adapted for planted pastures (Toledo et al., 2014) and many of the indicators are also relevant to other land cover types including cropland and forest.

The reference used for IIRH is based on integrated approach (4b) above. First, soils are grouped based on their potential to support similar types and amounts (production) of vegetation, and their response to management (e.g. ecological site, Bestelmeyer et al., 2009; Caudle et al., 2013). Then the natural range of variability is defined for each indicator based on available data and local knowledge of undegraded sites. An understanding of soil formation processes and soil-plant relationships is also extremely helpful for both grouping the soils, and defining the natural range of variability for each indicator.

The *Describing Indicators of Rangeland Health* (DIRH) protocol is designed to be used in two ways. First, where the protocol is completed on what are believed to be relatively undegraded lands based on other evidence (e.g. knowledge of historic disturbance regimes), data from similar intact sites can be combined and used to help develop or revise the reference. Second, DIRH data can be collected on land with no known reference, regardless of its level of degradation, and then used at a later date to support completion of an IIRH assessment after a reference has been established.

Of the 17 indicators included in the IIRH protocol (Table 3), DIRH uses quantitative data collected to describe 6, while 10 are described using categorical variable descriptions in Table 3, and 1 (bare ground) is described using a combination of quantitative data and categorical variable descriptions. The following steps are used to characterize the site and describe the indicators.

Step 1. Describe site characteristics that determine land potential, including climate, topography and relatively static soil properties. Climate information can generally be obtained with location alone using models. For example the LandPKS, a cellular phone/tablet app provides one-click access to long-term monthly temperature and precipitation averages based on the device’s internal GPS and public databases derived from modeled output. Ideally these monthly averages should be supplemented with more detailed information on the size and frequency of extreme weather events. Topographic information should include slope and slope shape (concave, convex or linear) and ideally landscape position. Sufficient soil information should be collected to identify the soil where a soil survey exists. For most regions, the minimum dataset includes soil depth, texture by depth and whether or not vertical cracks over ¼’ wide form when the soil dries. Soil identification can be improved with additional data, especially for subsurface layers, including pH, electrical conductivity and color. Most of these properties can be recorded using widely available tools such as LandPKS and DIMA (Database for Inventory Monitoring and Assessment; Courtright and Van Zee, 2011).

Step 2. Collect quantitative data. Sufficient quantitative data should be collected to characterize plant and soil surface cover, plant community composition and structure, and soil surface aggregate stability. In the United States use of standard BLM-AIM/NRCS-NRI (Bureau of Land Management-Assessment Inventory and Monitoring/Natural Resources Conservation Service National Resource Inventory) methods (Herrick et al., 2005) facilitates integration and comparison with other datasets. Use of these protocols globally also allows for comparison to data collected on similar sites in the United States. For example, soil, climate and topography combinations in southern Africa are replicated in Texas and the southwestern US, while analogs for much of northern Asia can be found in the US northern Great Plains. The “stick” protocol (Riginos et al., 2011) can be used to generate relatively compatible data using a simpler method.

Step 3. Assign each of the remaining 11 indicators to a class using Table 3. Where there are sub-criteria (e.g. for rills and bare ground), select a class for each of the components. Where there are multiple criteria described, choose the class with the best match. For example, #2-Water Flow Patterns, includes three criteria: length, density, and intensity of water flow patterns. A site with long, common, occasionally connected water flow patterns would fall into Class 3.

Table 3

Describing Indicators of Rangeland Health (DIRH) Matrix based on indicators included in Interpreting Indicators of Rangeland Health Version 4 (Pellant et al., 2005) with indicator names updated based on Version 5 (Pellant et al., In Prep). Quantitative methods (*) are described in the Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems (Herrick et al., 2005). Unless otherwise noted, the classes are based on observations or measurements completed in a 0.4 ha (50 m diameter or 1 acre) circular plot.

Indicator	Class 5	Class 4	Class 3	Class 2	Class 1
1. *Rills*. Small, shallow intermittent watercourses with steep sides. Rills are generally linear.	Numerous (> 10/0.4 ha plot) AND long (> 60 cm)	Moderate in number (> 5) AND long (> 60 cm).	Few (> 5) OR long (> 60 cm).	Very few (< 5) AND short (< 60 cm).	Not present.
Rill connectivity.	Very long (> 5m)	Long (2–5 m)	Short (0.5–2 m)	Very short (0.25–0.5 m)	Extremely short (0.1–0.5 m)
2. *Water Flow Patterns*. Soil surface patterns caused by runoff. Indicated by litter, soil, and gravel redistribution. Steep cuts may occur on one side (see #1).	Very long (15 m) numerous; unstable with active erosion; almost always connected.	Long (6–15 m), very common, and usually connected. Erosion and deposition areas very common.	Moderately long (1.5–6 m), common and often connected. Erosion and deposition areas common.	Very short, (< 1.5 m), rare and occasionally connected. Erosion and deposition areas rare.	None.
3. *Pedestals and/or Terracettes*. Plants or rocks appear elevated because of soil loss around them. Does not include deposition of soil on top of plant (check level of root-shoot interface).	Widespread throughout area. Common exposed roots.	Common, in flow paths. Occasional exposed roots.	Common, in flow paths. Roots rarely exposed.	Few in flow paths and interspaces only. No exposed roots.	None.
4. *Bare Ground*. (a) Percent soil surface *not* covered by vegetation, rock, plant litter, mosses, lichens or dark algal crusts.	Record point-intercept data for at least 100 points, and canopy gap intercept for at least 75 m (may be divided among up to 4 transects)*.				
(b) Bare patch size. A bare patch is an area where bare ground is greater than expected and greater than the overall average of the area of interest. It may include some ground cover (plants, litter, rock, and biological crusts) within the patch	Very large (> 2m diameter)	Large (1–2 m diameter)	Moderate (0.25–1 m diameter)	Small (0.1–0.25 m diameter)	Very small (< 0.1 m diameter)
(c) Bare patch (defined as for 4b) connectivity.	Generally connected.	Occasionally connected.	Sporadically connected.	Rarely connected.	Never connected.
5. *Gullies*. Large, deep intermittent watercourses with steep sides. Stable gullies have less steep sides with plants and no active erosion at the headcut (top) or top of sides.	Active headcut, whether or not in evaluation area, unstable sides.	Active headcut, whether or not in evaluation area, partially stable sides.	Active headcut, whether or not in evaluation area, stable sides with a few nickpoints.	Inactive. Stable throughout.	None.
6. *Wind-Scoured and/or Depositional Areas*	Widespread throughout area (> 50% area affected)	Many (25–50% of area affected)	Common. (10–25% of area affected)	Few.	None.
7. *Litter Movement (wind or water)*. Distance moved by different sizes of plant litter (needles, leaves, bark, branches). Indicated by litter accumulation in low, flat (water) or protect (wind) areas.	Fine litter moved very long distances (> 6m). Large litter moved moderate distances (< 3m).	Fine litter moved long distances (< 6m). Large litter moved short distances (< 1.5 m).	Fine litter moved moderate distances (< 3m) Large litter moved very short distances (< 0.6 m).	Fine litter moved short distances (< 1.5 m).	Fine litter moved very short distances (< 0.6 m).
8. *Soil Surface Resistance to Erosion.*	Average soil aggregate stability values under plant canopies and in plant interspaces based on the soil aggregate stability kit*.				
9. *Soil Surface Loss and Degradation*.	Take at least 1 photo of the top 30 cm under a typical plant or patch of plant, and in an interspace and (a) measure depth of the A horizon (organic matter-rich layer - if any), (b) record its color and the color of the soil at 35 cm or 10 cm below the bottom of the A horizon (whichever is greater), and (c) record the type, size and strength of soil structure using the photos in Schoeneberger (2012).				
10. *Effects of Plant Community Composition and Distribution on Infiltration and Runoff*	Use point-intercept and canopy gap data from #4 above, or record production by species or functional/structural group.*.				
11. *Compaction Layer*. Dense soil layers below the soil surface with horizontal (platy) structure at least 2″ (can be up to 8–10″) below the soil surface, which affect or reduce root penetration (e.g. grow horizontally.)	Extensive; severely restricts water movement and root penetration.	Common. Greatly restricts water movement and root penetration.	Moderately widespread, moderately restricts water movement and root penetration.	Rarely present or thin and weakly restrictive to infiltration and root penetration.	None.
12. *Plant Functional/Structural Groups.*	Use point-intercept data from #4 above* or record plant production by species.				
13. *Dead or Dying Plants or Plant Parts.* Proportion of aboveground biomass that is dead or decadent (may also use point-	> 50%	25–50%	10–25%	2–10%	< 2%

(*continued on next page*)

Table 3 (*continued*)

Indicator	Class 5	Class 4	Class 3	Class 2	Class 1
intercept data from #4 above is mortality is included).					
14. Litter Cover and Depth.	Use point-intercept data from #4 above*.				
15. Annual Production.	Weigh biomass for at least 4 locations in the plot and estimate annual production by adjusting for moisture content, growth stage and utilization*.				
16. Invasive Plants.	Use point-intercept data from #4 above*.				
17. Vigor with an Emphasis on Reproductive Capability of Perennial Plants. Reflected in ability of PERENNIAL plants, but not invasive plants, to produce seeds or tillers, and to recover following grazing, drought or other disturbance.	At least 10% of the individuals of < 50% of the species capable of reproduction, including < 50% of the species that are dominant or sub-dominant.	At least 10% of the individuals of 50% of the species capable of reproduction, including 50% of the species that are dominant or sub-dominant.	At least 10% of the individuals of 75% of the species capable of reproduction, including 75% of the species that are dominant or sub-dominant.	At least 10% of the individuals of 90% of the species capable of reproduction, including 90% of the species that are dominant or sub-dominant.	Nearly all perennial species capable of reproduction, including all that are currently dominant or sub-dominant.

6. Summary and conclusions

Definition of reference conditions is a necessary first step for completing land health and degradation assessments. Current approaches rely on various combinations of expert opinion, historic plot data, space-for-time interpretations, and analyses of remote sensing time series. None of these systems, however, includes a method for generating soil-specific references for field-based land health, including soil health, and degradation assessments.

The Describing Indicators of Rangeland Health protocol for collecting data necessary to define reference conditions is based on a protocol that has already been widely used to complete soil-specific assessments. It is designed to be implemented at plot to landscape (e.g. Miller, 2008) scales. It is not designed to be used at global scales. However, the IIRH protocol that it supports has been used to generate national assessments in the United States based on analyses of large numbers of plots selected using a statistical sampling design. It has also been used to assist in the planning process to restore degraded lands (Pyke, 2011). Perhaps the most important principle applied in the development of this protocol is matching each evaluation with a specific set of soil, climate and topographic conditions that determine land potential.

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