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A proposal for simplifying and increasing the value of local to global land degradation monitoring

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Perspective

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Abstract

Land degradation is reducing biodiversity and crop yields, and exacerbating the impacts of climate change, throughout the world. Monitoring land degradation is required to determine the effectiveness of land management and restoration practices, and to track progress toward reaching land degradation neutrality (LDN). It is also needed to target investments where they are most needed, and will have the greatest impact. The most useful indicators of land degradation vary among soils and climates. The United Nations Convention to Combat Desertification (UNCCD) selected three widely accepted land degradation indicators for LDN: land cover, net primary production (NPP) and soil carbon stocks. In addition to non-universal relevance, the use of these indicators has been limited by data availability, especially for carbon. This article presents an alternative monitoring framework based on the definition and ranking of *states* in a degradation hierarchy. Unique classifications can be defined for different regions and even different landscapes allowing, for example, perennial cropland to be ranked above a highly degraded grassland. The article concludes with an invitation to discuss the potential value of this approach and how it could be practically implemented at landscape to global scales. The ultimate objective is to support decision-making information at the local levels at which land degradation is addressed through improved management and restoration while providing the information necessary for reporting on progress toward meeting goals.

Impact statement

The alternative land degradation monitoring framework presented in this article addresses four limitations of the current approach used to report on land degradation neutrality. The current approach relies on indicators of land cover, primary productivity (NPP) and soil carbon stocks. First, these indicators often do not reflect local understanding of land degradation and recovery. Second, global land cover categories are too broad. Third, land degradation and recovery *within* land cover types is often uncorrelated, or even negatively correlated, with NPP indicators. Perhaps the most widely cited example is woody species invasion of grasslands, which often results in an improvement in NPP indicators (including satellite-based "greening"), but is associated with degradation in many ecosystems, including much of southern and eastern Africa. Other examples include the replacement of heavily fertilised and often irrigated annual monocultures with more diverse polyculture farming systems, including perennials. Another concern is the difficulty of calculating the indicators. The framework proposed here allows for the definition of degradation hierarchies based on "states," which can be as broad or as narrow as required for the monitoring objective. Unique land classifications can be developed for different countries and even different landscapes allowing, for example, perennial cropland to be ranked above a highly degraded shrubland. The proposed framework will allow for more accurate reporting at national scales, and more useful information at the local levels at which land degradation is addressed through improved management and restoration.

Introduction

Land degradation is widely recognised as a global challenge negatively affecting both individual livelihoods and global food security. It is also severely limiting our ability to adapt to climate change (Webb et al., 2017). Soil erosion compromises air and water quality and releases stored soil organic carbon (SOC) to the atmosphere. Declines in soil water infiltration and storage capacity associated with degraded soil structure and the exposure of clay-rich soil at the surface reduce rainfall use efficiency (or the ratio of annual primary production to annual rainfall). Soil temperature increases are exacerbated by the loss of protective vegetation and plant litter cover.

The objective of this article is to define an approach to land degradation monitoring that accurately reflects changes in the land for reporting progress to the United Nations Convention to Combat Desertification (UNCCD). The proposed approach increases the value of reporting by generating information that can also be used to guide the development and prioritisation of programs designed to avoid, reduce and reverse land degradation. Furthermore, it explicitly addresses a recent decision by the UNCCD 16th Conference of the Parties to, "more effectively reflect changes in the health of agricultural lands and soils" (UNCCD, 2024a).

The approach is conceptually based on the way in which "state and transition models" are currently used to inform the management of rangelands (Bestelmeyer et al., 2017). State and transition models are simple tools that allow practitioners to easily document the soil and vegetation indicators associated with different types of degradation on different types of land, and to share their understanding of the drivers of transitions among states, the extent to which these transitions are possible or likely, and the methods and costs of reversing undesired transitions (i.e., degradation). Furthermore, several countries are already developing these models (e.g., Barrio et al., 2018; Altesor et al., 2019; Sato and Lindenmayer, 2021; Han et al., 2022; Dashbal et al., 2023; Hernández-Valdez et al., 2023) Tools necessary to organise and store this information are already available (Bestelmeyer et al., 2021).

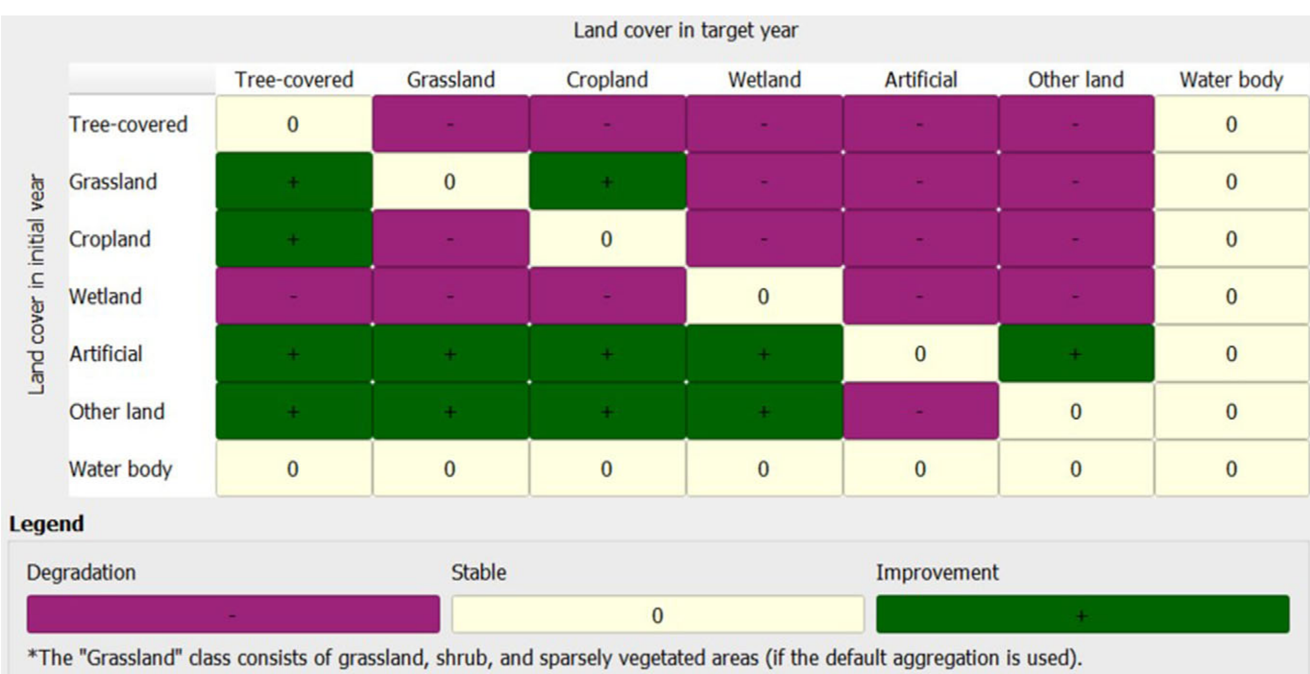
Land degradation neutrality

The Parties (countries) to the UNCCD identified land degradation neutrality (LDN) as a goal that could help focus attention on solutions to land degradation, rather than simply documenting the problem. LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (Orr et al., 2017). LDN was subsequently adopted by the United Nations as Sustainable Development Goal (SDG) 15.3. To support countries in their pursuit of LDN, the UNCCD's Science-Policy Interface developed the LDN Conceptual Framework (Orr et al., 2017; Cowie et al., 2018). The Framework prioritises actions to avoid, reduce and recover degraded land based on the relative return on investment (avoid > reduce > recover). A number of recent publications have subsequently provided conceptual frameworks on how to translate indicators of land degradation neutrality into action, taking into account local knowledge and social and environmental contexts (e.g., Kust et al., 2017; Crossland et al., 2018; Chasek et al., 2019).

LDN is now included in national reporting to the Convention. There are three indicators used to determine whether the land has been recovered or restored, degraded or has remained unchanged: land cover, net primary production (NPP) and soil carbon stocks. Default data are provided to every country based on standard analyses. Parties have the option to accept the default data, substitute their own data, or not report.

The default dataset is generated using the Trends. Earth platform based on a set of rules (Conservation International, 2022) that ensure that the indicators are generated consistently. These rules are also reflected in the "Good Practice Guidance" (Sims et al., 2021) for Parties that wish to generate their own indicators. Land cover is evaluated using a default transition matrix (Figure 1), which can be modified based on local conditions. NPP is determined using satellite imagery. SoilGrids is used to estimate baseline soil carbon stocks, and positive or negative changes in soil carbon are determined using the land cover matrix, which means that the soil carbon indicator mirrors land cover.

A "one out, all out" rule is applied, meaning that land is considered to have degraded during the reporting period if any one of the indicators reflects degraded conditions. For example, if land cover (and therefore SOC) is unchanged, but NPP has declined, the land would be considered to have become degraded. Achieving LDN would require that another similar area of land must show improvement or recovery during the reporting period, such as an



Land cover in target year

Land cover in initial year	Tree-covered	Grassland	Cropland	Wetland	Artificial	Other land	Water body
Tree-covered	0	-	-	-	-	-	0
Grassland	+	0	+	-	-	-	0
Cropland	+	-	0	-	-	-	0
Wetland	-	-	-	0	-	-	0
Artificial	+	+	+	+	0	+	0
Other land	+	+	+	+	-	0	0
Water body	0	0	0	0	0	0	0

Legend

Degradation	Stable	Improvement
-	0	+

*The "Grassland" class consists of grassland, shrub, and sparsely vegetated areas (if the default aggregation is used).

Figure 1. Current UNCCD default land cover transition matrix (Conservation International, 2022).

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area where NPP increased or was unchanged, and land cover changed from an artificial surface, such as asphalt, to grassland (Figure 1).

During the first reporting period, 115 countries reported on the proportion of land that is degraded over total land area, with the majority also reporting on all three sub-indicators (UNCCD, 2023). Thirty-five to fifty percent of the countries accepted the default data depending on the indicator and the remainder generated their own indicator values (ibid). Based on these data, land degradation was estimated to have increased from 14.7% in the baseline period to 18.9% between 2015 and 2019 (ibid).

Challenges and limitations of the current reporting system

A number of challenges and limitations have been identified for the current reporting system, including through the UNCCD's recent Mid-Term Evaluation (UNCCD, 2024b). The first three concerns are related. First, Parties to the Convention indicated that the reporting often did not accurately reflect local understanding of land degradation and recovery, particularly when the default data were used. These concerns ranged from differences in interpretation of the land cover classes to soil degradation and recovery that were not reflected in any of the indicators. Second, land cover categories are too broad. Lumping all croplands into one category was of sufficient concern that it was explicitly addressed in a UNCCD-negotiated decision (UNCCD, 2024a). Third, land degradation and recovery *within* land cover types is often uncorrelated, or even negatively correlated, with NPP indicators.

Perhaps the most widely cited example is woody species invasion of grasslands, which often results in an improvement in NPP indicators (including satellite-based "greening"), but is associated with degradation in many ecosystems, including much of southern and eastern Africa (Li et al., 2020; Morford et al., 2024). Other examples include the replacement of annual monocultures with more diverse polyculture farming systems, including perennials. Another concern is the difficulty of calculating the indicators. Many Parties that did not report, indicated that they were neither satisfied with the default indicators, nor did they have the technical capacity, budget, or both, necessary to generate their own indicators.

Together these challenges and limitations contributed to the relatively low rate of 115 of 197 Parties to the Convention reporting on land degradation neutrality. Perhaps even more significantly, many of those that did report indicated that while the data were useful at the national level, they could not be used to make local decisions about how to prioritise land for land degradation avoidance, reduction or recovery.

Five criteria for an alternative monitoring system

Our objective is to define an approach to land degradation monitoring that addresses the limitations of the current system and meets five specific criteria. First, it should be ***as compatible as possible*** with the current system. Second, it should allow Parties to ***more accurately and usefully define when land has become degraded or restored relative to the criteria established by the users***. Third, it should be ***applicable at any scale***. Fourth and fifth, it should be ***intuitive and simple***, allowing it to be implemented by virtually any land manager, consultant or policymaker with basic geospatial and land evaluation skills.

The system proposed here is based on the concept of an ecological "state" (Suding et al., 2004; Bestelmeyer et al., 2015; Maestre et al., 2016). While there are several definitions of alternative states in ecological science (e.g., Petraitis, 2013), for purposes of land degradation monitoring we recommend that a state be defined based on any one or more indicators that reflect the status of the land relative to its inherent potential (see Bestelmeyer et al., 2017). Potential plant productivity is defined as a function of soil, topography and climate (UNEP, 2016). Potential with respect to non-vegetation indicators, such as soil carbon, is based on predicted or observed values associated with undegraded plant communities for the particular combination of inherent or relatively static soil, topographic and climate properties. These indicators could include, or all, of the three current LDN indicators (land cover, NPP and SOC), as well as others such as species composition, diversity and modelled or measured soil erosion rates. Land degradation, recovery, or avoided degradation is then identified as transitions between alternative land states.

Different indicators can be applied at different scales. Ideally, these indicators should be hierarchical up to the coarsest reporting scale (e.g., nation). For example, for a hypothetical and relatively homogenous country at the national scale, a simple land cover classification could be used, such as assigning grassland to the undegraded state and defining all shrublands and farmlands to be equally degraded. At the landscape scale, multiple grassland states could be defined, and a shrub-invaded grassland state could be identified, focusing attention on those lands that are approaching a degradation threshold, where a restoration treatment or even a simple change in management could return them to the undegraded state (Figure 2a, b). We note that caution is required when classifying land cover in terms of vegetation types, such as grassland or shrubland, that do not have clear definitions because the terms often have quite different meanings for different people.

Similarly, multiple cropland states could be defined, reflecting the fact that well-managed cropland may be healthier than degraded grassland in a particular ecosystem (Figure 2b). Benchmarks, defined as indicator values or ranges of values for states, can then be established to enable objective and actionable assessment of risks, degradation status and management success (Webb et al., 2024).

However, hierarchical fidelity is not absolutely required by the system, provided that the states and assignment of changes in state (state transitions) to one of the three categories (degrade, no change, recover) is not modified between the beginning and end of the reporting period. There are two major advantages of this approach. The first is that it allows the same state transition to be assigned to different categories in different landscapes or regions, or even different soils within the same region. For example, in the Great Basin of the United States, shrubs are key components of undegraded plant communities on most soils, while in much of the Chihuahuan Desert, replacement of grasslands by shrublands is associated with degradation due to increased soil erosion and reduced forage availability. And yet even within the Chihuahuan Desert, there are soils that cannot support perennial grasslands. On these soils shrub-dominated plant communities are generally viewed as an undegraded state despite the fact that grasslands are typically more highly valued in the region.

Mongolia: a simple example that works

While the basic principles underlying the approach described here are well established and applied through state and transition models (Bestelmeyer et al., 2017), there are relatively few examples of where it has been applied to monitoring beyond the project level. Mongolia has implemented a relatively simple national *rangeland*

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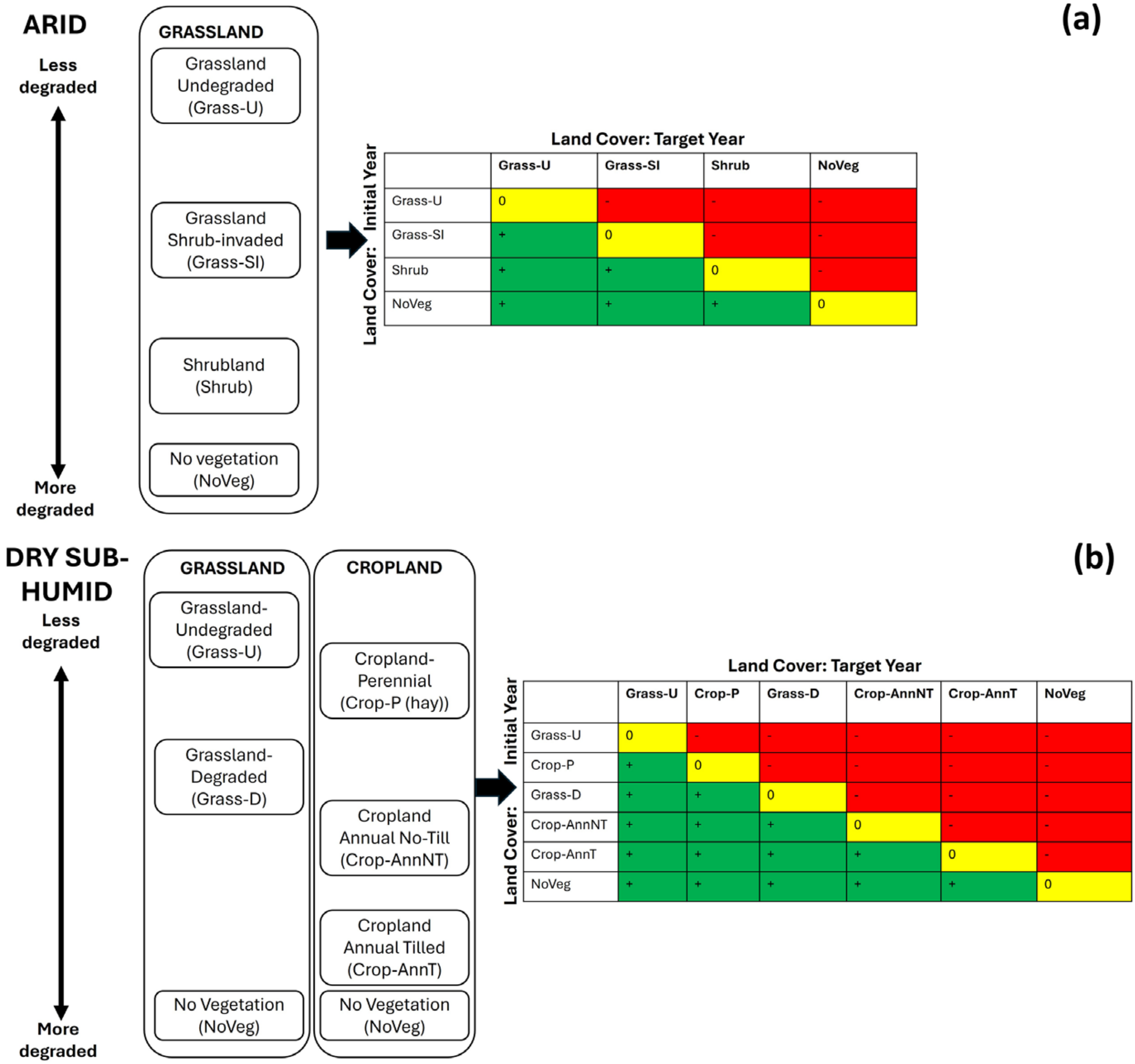

	Grass-U	Grass-SI	Shrub	NoVeg
Grass-U	0	-	-	-
Grass-SI	+	0	-	-
Shrub	+	+	0	-
NoVeg	+	+	+	0

	Grass-U	Crop-P	Grass-D	Crop-AnnNT	Crop-AnnT	NoVeg
Grass-U	0	-	-	-	-	-
Crop-P	+	0	-	-	-	-
Grass-D	+	+	0	-	-	-
Crop-AnnNT	+	+	+	0	-	-
Crop-AnnT	+	+	+	+	0	-
NoVeg	+	+	+	+	+	0

Figure 2. Example of how states within different land cover classes can be created and ranked relative to each other and converted to a transition matrix for (a) an arid region in the southwestern United States, and (b) a dry sub-humid region in the north-central United States. In both cases the undegraded state is a grassland. Green, yellow and red represent positive, no and negative change, respectively, from initial to target year.

monitoring system based on the principles described above. For each major region, a unique set of five classes of states has been defined, incorporating local knowledge. The states are ranked from undegraded to degraded, specifying the actions needed and timelines for recovery, and standardised vegetation monitoring data are used to assign each location to one of the classes (Dashbal et al., 2023). The data are so easy to understand that they are frequently referenced by the Mongolian Parliament and news media, and can be easily communicated to pastoralists (Figure 3).

Does the system meet the five criteria for an alternative monitoring system?

1. ***As compatible as possible with the current system: it depends.*** The extent to which the system is compatible with the current system will depend on how it is applied in each country. The fact that the land cover and SOC indicators are essentially redundant under the current default reporting system simplifies the problem for those countries that wish to be able to compare future data with data reported on LDN through 2030. These countries would need to continue to apply the same broad land cover classes and NPP analyses for national reporting. However, to make their monitoring more useful at landscape to regional scales, they could define additional states within the land cover classes and could define different states in different regions. Some of these states could even be defined based on measured or modelled changes in soil carbon, allowing changes in this important indicator to be documented. Finally, backward compatibility would be increased by limiting the indicators adopted to observable and previously used

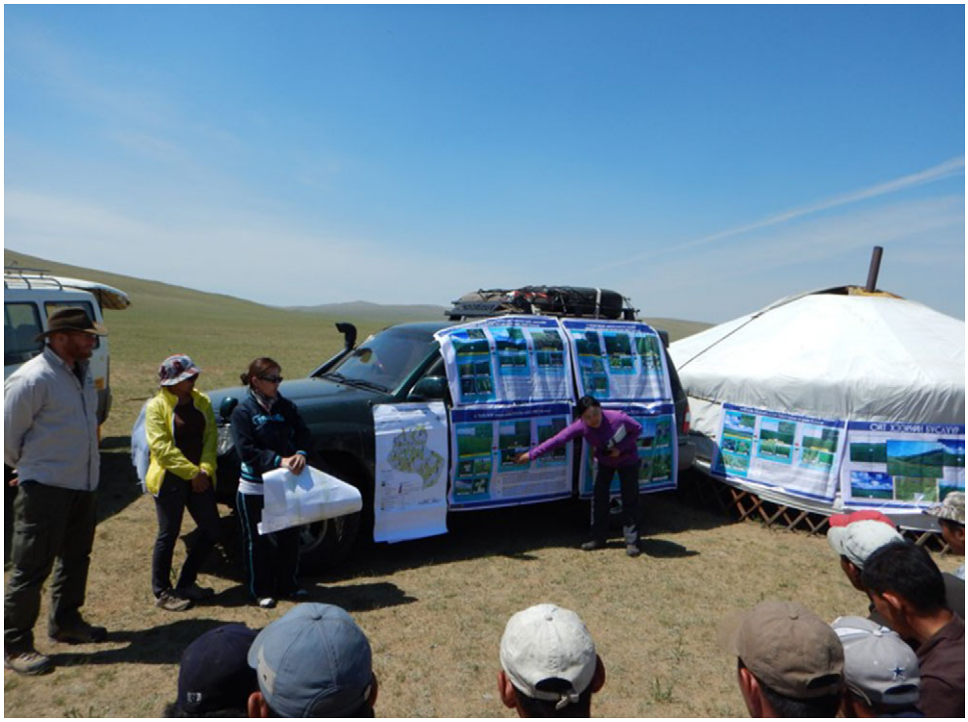

Figure 3. Sumjidmaa Sainnemekh, a technical expert working with the National Agency for Meteorology and Environmental Monitoring and the Mongolian National Federation of Pasture User's Groups discusses monitoring results with Mongolian pastoralists in 2015 based on the approach described in this article.

indicators (e.g., land cover and NPP), rather than surrogate indicators (e.g., soil erosion).

2. ***More accurately define when the land has become degraded or restored: yes, usually.*** Allowing states, and the relationship between states, to be defined based on scientific data and local ecological knowledge should increase the accuracy of these determinations. The approach described here allows for the development of consensus among stakeholders using different indicators of degradation, or reference benchmarks.
3. ***Possible to apply at any scale: yes***. Examples from many locations around the world illustrate how the system can be uniquely applied to individual soils or agroecosystem types within the same landscape or region. However, there can be challenges to consistency in reporting across scales. The decision of whether to adopt a hierarchical system or one that is flexible and adaptable to different landscapes and regions will determine *how* it is applied at multiple scales.
4. ***Intuitive: yes.*** In our experience working with practitioners and land managers throughout the United States and internationally, we have found that this approach is quite intuitive because it uses the observed or measured *state* of the land, based on indicators that best reflect the degradation of that particular type of land, rather than attempting to universally apply an indicator to all types of land. Surrogate indicators (such as soil erosion or NPP) may help define the state, but the selected indicators are typically those that reflect local understanding. States may be defined by one or many correlated indicators and functions. They allow for locally important indicators to discriminate land conditions. The key is to ensure that states are distinguished consistently based on simple observable indicators, such as vegetation cover or obvious soil surface properties, and these simpler indicators are related consistently to more complex processes and indicators defining degradation. It is also intuitive because local inhabitants typically evaluate land degradation via the classification and contrast of discrete types of land.
5. ***Simple, allowing it to be implemented by virtually any land manager, consultant or policymaker with basic geospatial skills: a qualified yes***. The system can be relatively simple to implement at the landscape scale, based on our and our collaborators' experiences over the past several decades. We acknowledge that it can become increasingly complex to manage at the national level where there is a desire to maintain a hierarchical structure at coarser scales, while noting that this complexity will not be visible to land managers working at the landscape scale.

Conclusion, final thoughts and an invitation

Our suggestion to use states and transitions as a basis for monitoring global land degradation and LDN warrants robust discussion of the opportunities that this approach may provide, and whether and how it might be implemented to support individuals, organisations and nations pursuing land degradation neutrality. Based on our experiences and an extensive global literature, there is substantial evidence that the use of states and transitions will be more effective than current approaches. Recently developed concepts and tools can be used to provide a globally consistent but locally tailored approach to the use of state-transition concepts.

The authors of this article humbly recognise that while it draws from the global literature, and we were born and educated in three different countries, we are all currently based in the western United States where state and transition-based monitoring approaches are well-developed. We would welcome a discussion of the potential value of this approach and how it could be practically implemented at landscape to global scales. Implementation of this approach will

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require some type of quality control, particularly in the definition of comparable classifications. There will necessarily be tradeoffs between deference to local knowledge and understanding and a set of more universal guidelines, perhaps focusing on the decision-making process itself. For example, if soil organic matter is identified as the most relevant indicator of a change in state for a particular combination of soil, topography and climate, the process could include consideration of both modelled levels in the undegraded state, as well as measurements from undegraded states (e.g., under native vegetation). These locations should be carefully selected to ensure that they have similar potential. This could also allow soil organic matter to be integrated into a state-based system such as that described above for Mongolia.

Finally, we recognise that no monitoring system is value-neutral. The flexibility that the proposed approach provides to take regional to landscape-scale variability into account reduces the impact of global biases (e.g., the relative value of some land cover types over others, or of prioritising soil carbon sequestration over other ecosystem services) on land degradation determinations. At the same time, however, it opens the door to debates about what the reference should be, particularly in systems where restoration is biophysically, or at least economically, impossible, or land cover has been completely transformed by a change in land use for decades, centuries or more.

We believe that this challenge may be mitigated by two considerations. The first is that a future monitoring system based on the approach described here can continue to use a particular point in time as the baseline, rather than the natural potential of a particular piece of land. The second, which we have successfully applied in many debates in the United States, is to agree to transparently include in the evaluation matrix what is biophysically *possible* (e.g., reconversion of cropland to a diverse perennial grassland), while also including states that can be *realistically* achieved (e.g., a crop production system resulting in minimal erosion and increased soil carbon content and biodiversity). This, in fact, maybe the greatest benefit of the approach: it should lead to the development of local to global monitoring systems that can be used to create positive incentives for good land use practices, even if they are not the best. Future refinements of this approach could follow the approach taken by some certification systems and reflect the magnitude of improvement at the risk of making the system too complex.

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