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Land degradation assessment through an ecosystem services lens: Integrating knowledge and methods in pastoral semi-arid systems

D. Tarrasón [a, *], F. Ravera [a, b], M.S. Reed [c], A.J. Dougill [d], L. Gonzalez [e]

[a] CREAF, Cerdanyola del Vallès 08193, Catalonia, Spain
[b] Social-ecological Systems Laboratory, Department of Ecology, Universidad Autónoma de Madrid, c/9 Darwin 2, 28049 Madrid, Spain
[c] Faculty of Computing, Engineering and The Built Environment, Birmingham City University, City Centre Campus, Millennium Point, Curzon Street, Birmingham, B4 7XG, UK
[d] Sustainability Research Institute, School of Earth & Environment, University of Leeds, Leeds, West Yorkshire LS2 9JT, UK
[e] CII-ASDENIC (Centro de Investigación e Innovación- Asociación de Desarrollo Social de Nicaragua), Estelí, Nicaragua

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ABSTRACT

This paper develops and applies an integrated and participatory methodological framework to assess land degradation in pastoral systems through an ecosystem services (ES) lens in a semi-arid region of northern Nicaragua. We initially integrated local and scientific knowledge to assess ecological changes and understand the links with ecosystem services supplied by the local grazing system. Hence, we discuss land degradation features and test a state-and-transition ecological model, that is, we developed jointly with local farmers the hypotheses to understand transitions between ecological states and these hypotheses were then evaluated through an inventory of vegetation and an assessment of soil properties and seed bank composition. The assessment reveals that shifts in ecological state do not cause permanent soil properties changes, but that at a landscape scale they can limit production, affecting local livelihoods. The framework proposed provided local farmers with relevant information and facilitated communication with researchers, enabling them to use the co-constructed knowledge to implement adaptive management strategies to improve local productive systems.

1. Introduction

With increasing concern over global food supplies, there is growing interest in maintaining food production in arid and semi-arid regions. These areas support some of the world's poorest people (Millennium Ecosystem Assessment, 2005), who are often most vulnerable to land degradation (UNEP, 1993; IAASTD, 2008) and sensitive to climate change (IPCC, 2007). Land degradation debates in these regions have begun to reflect more interpretative and post-modern epistemologies, recognising that a reduction in the potential resource of the land can only be defined in relation to the uses people have for it (Warren, 2002). As such, it is increasingly recognised that for land degradation assessment to be accurate and reliable, it must use multiple methods at a range of scales, and incorporate the perspectives of those who use and manage the land (Reed et al., 2008). How such integrated land degradation monitoring and assessment approaches are developed and applied, remains the subject of much academic and policy debate (e.g. Turner et al., 2007; Reed and Dougill, 2010).

According to United Nations conventions on climate change, biodiversity and, specifically, the UN Convention to Combat Desertification, unsustainable land use is driving land degradation, with long term losses in ecosystem functions, which limit unaided recovery. The Millennium Ecosystem Assessment (2005, p 5) defined land degradation as "a persistent reduction of biological and economic productivity" and reported data from around the world that for arid and semi-arid lands link the transition of grasslands to shrublands to the increased surface runoff, topsoil erosion, and exposure to rocky surfaces. Eventually, the degradation due to overstocking and range mismanagement led also to a decline on fodder availability (Millennium Ecosystem Assessment, 2005). Ecosystem services are defined as functions of and processes supplied by ecosystems valued by humans (Millennium Ecosystem Assessment, 2005), thus land degradation is mainly approachable through the lens of a reduction of ecosystem services. Literature that links land degradation and ecosystem services

* Corresponding author.
E-mail address: d.tarrason@creaf.uab.cat (D. Tarrasón).

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provision mainly focuses on biophysical approaches of assessment (Bai et al., 2013; Lal et al., 2013). However, there are a growing number of attempts to develop land degradation assessment methods that may capture a more complex understanding of human–environment interactions (e.g. Milton et al., 1994; Thomas and Twyman, 2004; Reed et al., 2006; Reed and Dougill, 2010). These approaches, combine local (often tacit) knowledge and scientific information (Stringer and Reed, 2007; Turner et al., 2007) allowing researchers to investigate uncertainties and assumptions, developing a more rigorous understanding of land degradation processes (Johnson et al., 2004) and, thus, informing environmental decision-making (Reed, 2008). They can also empower local communities to monitor and manage land degradation easily and accurately (e.g. Turner et al., 2007; Ingram, 2008). Methods are emerging that attempt to integrate local and scientific knowledge about land degradation severity and extent and co-develop adaptations that are scientifically robust, yet familiar to land users who can then apply them easily and cost-effectively (e.g. Stocking and Murnaghan, 2001; Joubert et al., 2008; Reed et al., 2008). The goal of this paper, therefore, is to develop and apply an integrated approach for land degradation assessment in pastoral systems through an ecosystem service framework. Specifically, the paper aims to: i) explore hypotheses to explain the relationship between multidimensional driving forces and vegetation shifts at territorial scale; ii) test the state-and-transition model suggested by local farmers looking at changes in vegetation cover, soil properties and seed banks composition. It does so through the development of a participatory process which combines local knowledge (qualitative) and scientific information (quantitative) to identify jointly with local farmers the main features of land degradation in a context-specific case study, through an exploration of ecological changes that lead to a permanent decrease in key ecosystem services.

2. Methods

2.1. Study area

The case study is located in northern Nicaragua (13°09′N-86°14′W) in the semi-arid plateau of Miraflor-Moropotente Terrestrial Protected Landscape. This case provides empirical data on Central American dryland environments that have been largely unexplored, despite 25% of Central American people living in arid and semi-arid areas (Reynolds et al., 2005) and a quarter of these agro-pastoral areas being classed as seriously degraded (Scherr, 1999).

The semi-arid climate of the studied area (Group B, according to Köppen classification is influenced by the North America Monsoon System which connects the Atlantic-Caribbean and the Pacific Oceans). Annual mean temperature is 23.5 °C and total rainfall amount 773 ± 195 mm. Rainfall occurs mainly between May and October, followed by a marked dry season (Source: summary for INETER from 1957 to 2005). The region is also exposed to frequent droughts and floods related to the El Niño-Southern Oscillation (ENSO) phenomenon (Ravera et al., 2011).

The semi-arid plateau was documented in the 18th century as a tropical savannah but today is made up of a complex patchwork of natural grasslands with dominance of *Paspalum notatum* Fluggé, cultivated fields (mainly grain crops, but also cash crop such as potatoes) and seasonally dry forest remnants (Tarrasón et al. 2010). The transformation came about as a result of major socio-political and institutional changes that have occurred in the last decades. Despite these changes, livestock production with double goal (i.e. Holstein and Brahman livestock races for calves and milk production) in medium and small scale farming is still the most important component of the local livelihoods' subsistence and source of employment, and it contributes significantly to national dairy-milk production (Ravera et al. 2011). Within this relatively small region, a variety of pastoral management practices is found that respond to multiple environmental rationalities (Ravera et al., 2014). New regulation rules in management practices of grasslands were introduced at the beginning of the 1990s when the area was declared "Terrestrial Protected Landscape", such as the restriction in the use of fire (MARENA, 2004).

The soils in the semi-arid plateau are classified as *Entic Udic Haplusterts* and *Typic Haplustults* (SSS, 2006). Table 1 summarises general soil characteristics of vertisol, the major soil type in the studied area. The soil development is influenced by a strongly contrasted seasonal climate. During the wet winter season, the soil remains in saturated conditions and becomes completely dry and desiccated throughout the soil profile in the summer season. Expandable smectite clay minerals (montmorillonites) are responsible for the repetitive expansion and shrinkage accompanying flood/drought cycles and generate deep cracks and gilgai micro-relief. Note should be taken of the high amount of organic carbon in the soil surface (3.1%). The high Cation-Exchange Capacity (CEC)/clay ratio (1.7) indicates that smectite is the major contributor to the elevated CEC values (39.7 meq 100 g^{-1}). This result shows that soils in the studied area have high fertility, but only if they have been managed adequately (IUSS Working Group WRB., 2006).

2.2. Research design and methods

In this study we designed a four-step methodological framework, adopted from Reed et al. (2006) and further developed by Reed et al. (2011) to integrate local and scientific knowledge within a participatory assessment of land degradation in a pastoral system (Fig. 1). Below we present methods and tools used in each step.

2.2.1. Step 1. Identifying features of land degradation and linkages with ecosystem services provision

A first series of informal field visits and in–depth interviews with key informants (n = 12) made it possible to gain insights into people's concerns over key land degradation-related problems in the area. Information from a literature review on soil functions and services provided for semi-arid pastoral systems was also collected. The Ecosystem Services are classified in three types: provisioning, regulating and cultural Two expert meetings with the participation of European research staff (two soil ecologists, one ecological economist, one biologist) and local research staff (one agricultural economist, two students in environmental science) enabled discussions on the link between ecological processes, key ecosystem functions and services provided by soils in semi-arid grazing systems, and how losses are characteristic of land degradation.

2.2.2. Step 2. Integrating scientific and local knowledge to conceptually design a model that links drivers of change and ecological processes

A second series of semi-structured interviews with local farmers (n = 40) made possible to explore the local perceptions about ecological changes over time, main drivers of change and their likely impacts on the maintenance of ecosystem services, *i.e.*, land degradation features. This information validated by a focus group discussion with key informants and scientific information (step 1) allowed for a state-and-transition conceptual model to be drafted, incorporating the diversity of knowledge (Ravera et al. 2011). The state and transition model was adapted from Dougill et al. (1999) and Joubert et al. (2008). Transitions between different vegetation states were explored through the use of pictures illustrating