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Identifying ecosystem service hotspots for targeting land degradation neutrality investments in south-eastern Africa

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ABSTRACT

Land degradation response actions need motivated stakeholders and investments to improve land management. In this study we present methods to prioritise locations for degradation mitigation investments based on stakeholder preferences for ecosystem services. We combine participatory and spatial modelling approaches and apply these for Zambia, South Africa, and Tanzania to: i) prioritise ecosystem services in each country; ii) to map the supply of these ecosystem services in each country, and; iii) prioritise areas important for investment for the continuous delivery of these ecosystem services based on their vulnerability to land degradation. We interviewed 31 stakeholders from governmental and non-governmental organizations to select the most important ecosystem services per county. Stakeholders were also asked to indicate on national maps the hotspots of these ecosystem services and locations with a high degradation risk. We then assessed the supply of the stakeholder-selected ecosystem services and land degradation risk using GIS-based spatial models. We found that for each country the spatial extent and magnitude of ecosystem services supply and land degradation based on GIS data coincides with stakeholder knowledge in some locations. In the context of supporting national level policy to achieve land degradation neutrality as proposed by the United Nations Convention to Combat Desertification we argue that the correct representation, the level of acceptance, and use of modelled outputs to support decisions will be greater when model outputs are corroborated by stakeholder knowledge. Ecosystem services that are identified as "important" by diverse stakeholder groups have a broader level of awareness and could therefore drive motivations, commitments, and actions towards improved land management, contributing to land degradation neutrality.

1. Introduction

Land degradation is a major threat to ecological functioning, food production and livelihood development across the world (Barbier, 2000; MA, 2005; Bindraban et al., 2012). It affects the biological and economic productivity of land due to processes such as soil erosion, salinization, soil crusting, loss of soil fertility, and depletion of seed banks and vegetation cover (Kairis et al., 2014). According to the Millennium Ecosystem Assessment about 10–20 percent of all drylands, which include arid, semi-arid and dry sub-humid areas, are degraded across the world (MA, 2005). A large portion of the world's drylands are located in sub Saharan Africa, where local people's livelihoods are very closely linked to accessible natural resources and ecosystem services (Barbier, 2000). With land degradation, the supply of these resources and services to humans decreases.

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Several policy measures have been put in place to halt and reverse land degradation for continued food production and livelihood development (Stringer and Dougill, 2013). With the establishment of the United Nations Convention to Combat Desertification (UNCCD) in 1994 a large international response to address land degradation issues in drylands was initiated. Through National Action Programmes (NAPs), country Parties to the UNCCD aim to improve the conditions of people and ecosystems affected by land degradation by maintaining and restoring land and soil productivity, and mitigating the effects of drought (UNCCD, 2016). These country-level NAPs set targets and define actions to halt and reverse land degradation in an integrated way. Many of the actions of the NAPs also contribute to the United Nations global Sustainable Development Goals that aim for a land degradation-neutral world by 2030 (Target 15.3) and the restoration and conservation targets of the international Convention on Biological Diversity (Aichi Target 15).

The UNCCD considers the goal of no-net-increase of degraded land at national and global levels as their central remit, whereby the condition of land resources to support ecosystem services and enhance food security is maintained or improved through sustainable use and management of soil, water and biodiversity, i.e. achieving Land Degradation Neutrality (LDN) (Orr et al., 2017). Achieving LDN requires significant investment in improved land rehabilitation, degraded ecosystem restoration, and land stewardship. To promote and manage investments in sustainable land management and land rehabilitation efforts, the UNCCD spearheaded the development of an LDN Fund (Maillard and Cheung, 2016). Robust science is needed to ensure investments are targeted to the locations which will achieve the greatest monetary and non-monetary returns with low risks (Crossman and Bryan, 2009).

A key challenge for assessing the diverse returns on LDN investments is the integration of social-economic and environmental data and values (Winslow et al., 2011). The concept of ecosystem services -human benefits from nature- offers a framework for incorporating diverse processes linking ecological data to social and/or economic values (Díaz et al., 2015). The benefits humans obtain from ecosystems are a function of ecological functioning and human inputs (Willemen et al., 2008; Maes and Jacobs, 2015). Quantitative assessments of a wide range of ecosystem services helps to make explicit the many benefits, avoided costs, and trade-offs of improved land management (Naidoo and Ricketts, 2006; Hauck et al., 2013; Clec'h et al., 2016), and provide important baselines for measuring returns on investment in land rehabilitation, restoration and sustainable land management (ELD Initiative, 2015; Schröter et al., 2015). The visualization of key ecosystem services through mapping can be an effective vehicle for motivating people to engage in sustainable land management, conservation and restoration (Pettit et al., 2011; Darvill and Lindo, 2015; Klein et al., 2015).

There are many ways to map ecosystem services (Gomez-Baggethun et al., 2010; Martínez-Harms and Balvanera, 2012; Crossman et al., 2013). These include spatial, GIS-based models to provide detailed estimates of ecosystem services supply and value using location-based data. In addition, participatory approaches that use knowledge and expertise from people in the study area are increasingly applied to map ecosystem services, especially in attempts to better match science with societal needs (Brown and Fagerholm, 2015). A general point of concern for all mapping approaches is the unknown or poorly presented level of accuracy and representation of the ecosystem service maps (Schulp et al., 2014; Willemen et al., 2015a). This shortcoming impedes the uptake of science to support decision making (Walsh et al., 2015). The large investments required to achieve LDN, and the need to ensure funds are spent in locations where they can deliver the greatest benefits, demands approaches that robustly quantify ecosystem services most important to the decision makers and land managers who will take the investment risks. Approaches that integrate methods, data, and stakeholder views result in comprehensive and less biased information for decision support, compared to single-method approaches (Voinov et al., 2014; Law et al., 2015; van Oort et al., 2015).

In this study we combine participatory and spatial modelling approaches in three countries in Africa affected by land degradation, South Africa, Tanzania and Zambia, to: i) prioritise ecosystem services based on their importance in the country; ii) to map the supply of these ecosystem services, and; iii) prioritise areas that are most likely important for investment for the continuous delivery of these ecosystem services based on their vulnerability to land degradation. We identify locations where, if land degradation is halted, could provide best returns on investments. The priority areas we identify are locations that are particularly rich in key ecosystem services, but are also at high risk from degrading pressures according to both spatial model outcomes and stakeholder's perceptions.

2. Methods

2.1. Study area

Our study focuses on Zambia, South Africa, and Tanzania that for large parts are classified as drylands (Fig. 1). These countries are not only signatories to UNCCD but have ratified the convention with the commitment to undertake considerable efforts in tackling land degradation. However, they have also encountered barriers to implementation due to insufficient resources, weak institutional capacity, and/or inadequate legal support, as indicated in their national reports on UNCCD implementation (http://www.unccd.int).

Land-locked Zambia covers around 753,000 km^2 with a population of about 14.5 million. Average annual rainfall ranges from about 600 mm in the south-west of the country, to over 1200 mm in the north-east (Environmental Council of Zambia, 2008). The seasonality of the rainfall causes rainfall deficits in some parts of the country. Agriculture and copper mining are the two most important components of the Zambian economy (Central Statistics Office, 2014). Agriculture is predominantly rain fed, with less than 10% irrigated (Environmental Council of Zambia, 2008). Small-scale farmers account for over 80% of farmers with central Zambia being the agricultural centre of the country. In the north-west of the country, close to the border with the Democratic Republic of Congo, a 'new copper belt' is emerging. In this area, new mining sites are opened, rapid deforestation rates are observed, and the growing population causes an increasing demand for firewood. Zambia's national programme for combating desertification and mitigating effects of drought has identified the main drivers of land degradation as deforestation for agricultural purposes, soil erosion, high demand for fuelwood and charcoal use, overgrazing, institutional, policy and legal issues, and large scale developmental projects (Kalaba, 2016).

South Africa covers approximately 1.22 million km^2 with a population of about 53 million. Average annual precipitation varies from less than 50 to 3000 mm (Egoh et al., 2008). The country's arid climate, combined with the predominance of shallow soils with limited irrigation potential, and relatively high population of rural subsistence farmers, places much of the country at risk of land degradation. Agriculture contributes to about 10% of employment and only about 13% of the country can be used for crop production due to aridity (van Heerden et al.,

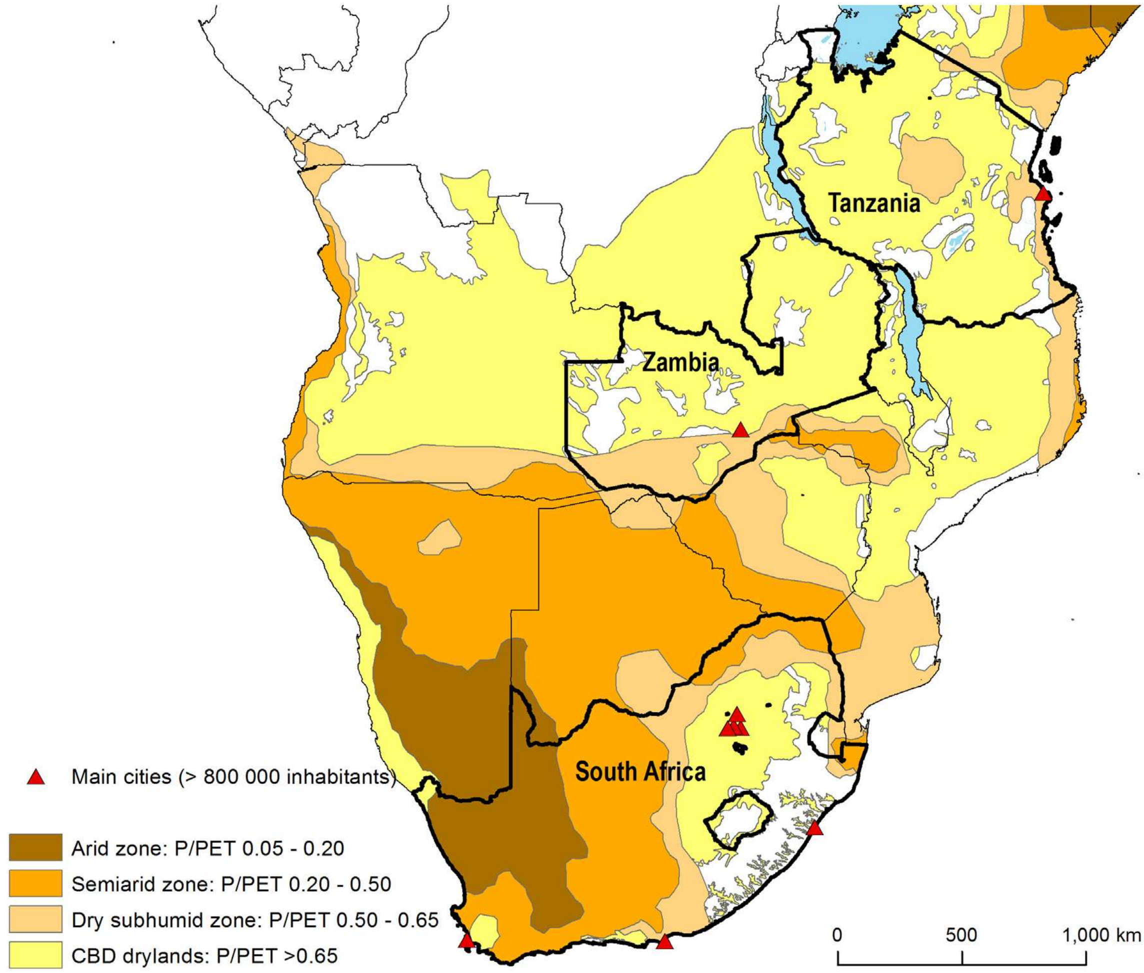

Fig. 1. Location of the three case study countries and aridity zones by Sorensen (2007).

2008). There are 320 dams in South Africa, with about 50% of total water consumed going to irrigating crops (Scholes and Biggs, 2004). Degradation and associated habitat loss is a significant threat to South Africa's biodiversity, with an estimated 18% of the country's native habitat lost due to agriculture, mining, forestry and urban development.

Tanzania covers approximately 945,000 km^2 and is located just south of the equator. In 2013 the population of Tanzania was about 49 million. About 60% of Tanzania is classified as dryland and 90% of the land is covered by savannah vegetation (Vice President's Office, 2014). Agriculture accounts for about 25% of GDP, and provides employment for about 80% of Tanzanians (Byers et al., 2012). The Southern Agricultural Growth Corridor of Tanzania (SAGCOT) is a part of Tanzania's Kilimo Kwanza (Agriculture First) policy aiming to increase the productivity and value of agriculture for economic development and rural poverty alleviation (Milder et al., 2012). Through irrigation infrastructure development an estimated 350,000 ha of land is planned to be brought into intensive agricultural production in the coming years. Tourism is also important to the economy, contributing about 13% to GDP. Major causes of land degradation in Tanzania are overgrazing, poor cultivation practices (including fire mismanagement) and deforestation, exacerbated by rapid population growth, rural poverty, climate change, an unclear land tenure system and conflicting government policies that at times exacerbate land degradation (Vice President's Office, 2014).

2.2. Participatory data collection on ecosystem services and land degradation

Information on degradation risks and ecosystem services that are most important in each country was collected by consulting a range of national level stakeholders. In any participatory approach the selection of stakeholders is a key driver of the results (Brown and Kyttä, 2014; García-Nieto et al., 2015). In this study stakeholders were selected by national scientists in the research team and came from four types of organizations: i) government agencies (e.g. departments of water, agriculture and conservation); ii) national non-governmental organization (NGOs), iii) private companies, and iv) international organizations. The selected organizations all operate on a national-level in land and water management, restoration, and/or conservation practices. The consulted government departments are responsible for implementing the UNCCD NAPs. Stakeholders were consulted to identify and locate ecosystem services of main relevance to their respective country. Stakeholders were also asked to share their knowledge on degradation status and trends, and about prospective land conservation and restoration actions to mitigate degradation. We interviewed stakeholders in teams, with each team consisting of national and international researchers and a UNCCD representative. Each interview lasted 1.5–2 h. Thirty-one individuals were interviewed during 20 meetings (9 in Zambia; 5 in South Africa, 6 in Tanzania). The Supplementary Material lists the professional

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affiliations of the interviewees.

Each stakeholder interview started with a short presentation to define the scope of the research project, and to outline the items on which we want to receive the stakeholder's perspective. These items were:

1. The most important ecosystem services in the country of interest;
2. The approximate location of those services;
3. Suggestions on spatial data for mapping and valuing those ecosystem services;
4. Locations within the country at risk of degradation impacting the supply of ecosystem services;
5. The most important direct (e.g. erosion, flood, overgrazing) and indirect (e.g. population pressures, climate change) land degradation threats to each ecosystem service, and;
6 Their view on promising actions to halt or reduce degradation in the country

We used a semi-structured interview to discuss the six items. For the first item we presented each interviewee with a preliminary list of selected key ecosystem services for their country and asked them to comment, add, or replace the listed ecosystem services as needed. We provided interviewees with the full list of ecosystem services from The Economics of Ecosystems and Biodiversity (TEEB, 2010) as a reference for adjusting the preliminary list. We asked interviewees to draw the locations of key ecosystem services and locations of current degradation processes on a topographic map of their country (Item 2 and 4). The maps supported discussion about specific locations and reasons why certain ecosystem service or degradation trends were occurring in those locations. The maps were also used to collect interviewees' knowledge on ecosystem services and degradation hotspots to compare with our spatial modelling outputs. Interviewees were given a topographic A3 colour country map, colour markers, and arrow stick-on notes. Fig. 2 shows an example of a map produced during an interview in Zambia.

The topographic maps completed by the interviewees were redrawn by hand in ArcGIS 10.3 (ESRI, 2015). We used a small 1.5 cm diameter circle (the size of a fingertip) to indicate the approximate locations indicated by arrow sticky-notes (Fig. 2). For text written on the map we draw polygons around the text. Ecosystem services and land degradation risks were redrawn in separate layers. In some cases there was ambiguity about whether a hand drawn item during the interview should be labelled as an ecosystem service or land degradation threat. We labelled crop production, fishing and grazing as ecosystem service supply areas if they were mentioned in a neutral way. The location was labelled as a land degradation threat if the interviewee explicitly indicated that the location was subject to overgrazing, overfishing or agricultural practices with high negative environmental impact. In the digitising process we renamed some mapped services to clarify their benefit. For example, 'water' drawn on a map to identify an above or below ground water body was renamed 'water supply', whereas 'water' drawn on top of a land area was renamed 'water regulation'. Overlapping polygons were mapped, counted, and rasterized to a relatively coarse 0.5° resolution (around 55 km at the equator) which we assumed was the maximum accuracy at which interviewees could draw on a national-scale map.

To define the priority of an ecosystem service in each country, we counted how often interviewees listed an ecosystem service as important during the interview (Item 1) and drew them on the map (Item 2). This frequency is assumed to represent the importance of ecosystem service for LDN decision making. The data suggestions (Item 3) were used in the development of the spatial models. The perspectives of the interviewees on land degradation drivers and

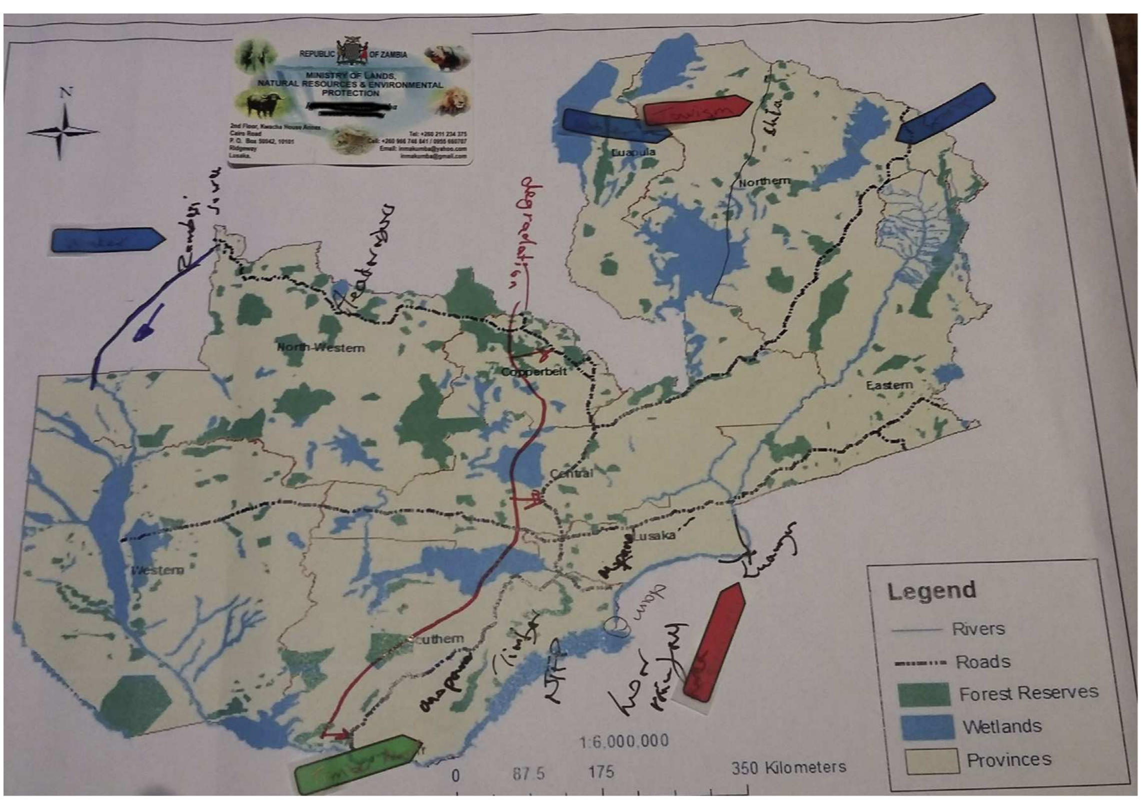

Fig. 2. Example of the use of topographic maps during the stakeholder consultations.

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solutions (Item 5 and 6) were listed to improve the interpretation of the land degradation map and to reflect on land degradation neutrality options.

2.3. Spatial modelling of ecosystem service supply and land degradation hotspots

We first used GIS-based spatial models to map locations rich in ecosystem services supply and to map areas of high risk of degradation. To identify priority locations for LDN investments we then overlaid the maps of ecosystem service supply and land degradation risk. Input data for the ecosystem service supply and land degradation risk maps were acquired from ongoing projects of numerous research organizations, universities and governments in each of the countries. These input spatial data were recommended by interviewees and were acquired during in-person visits to relevant organizations in-country, or in case unavailable, retrieved from open access GIS data platforms. Ecosystem service supply was quantified in biophysical terms depending on the country specific definitions of an ecosystem service and available data. Our ecosystem service quantification methods were mostly existing proxy or process based methods (see Table 1). Other than the country-specific ecosystem service methods, we used one single method for all three countries to assess land degradation risks. We quantified locations under risk of (further) land degradation by combining information on global aridity estimates (Trabucco and Zomer, 2009) with estimates of the level of human influence (WCS and CIESIN, 2005). The Supplementary Materials contains descriptions of data sources and specific methods to quantify ecosystem service supply and land degradation, and shows in which cases we used existing national level maps of ecosystem services.

To sum ecosystem service supply layers with different biophysical units (for example, m^3 of timber/ha/yr or livestock units/ha) to identify hotspot of key ecosystem service supply, all ecosystem service supply layers were linearly rescaled to 1 to 5 (minimum to maximum supply) using the equation (Crossman and Bryan, 2009):

$$x' = \frac{(x - x\ \min)*4}{(x\ \max - x\ \min)} + 1$$

where x' is the transformed value, x is the original value of the ecosystem service, and x max and x min are the maximum and minimum values, respectively, across the range of values for the ecosystem service. Land degradation risk was linearly rescaled the same way, with 1 being lowest risk and 5 highest risk. The rescaling of ecosystem service and land degradation risk scores was based on within country minimum and maximum supply values. Therefore, the rescaled values cannot be used to make comparisons between countries.

Hotspots for targeting land degradation risk mitigation measures at locations rich in key ecosystem services, but at high risk from degrading pressures, were quantified by multiplying the rescaled land degradation risk with the ecosystem services maps, and rescaled to 1 to 5 again. A value of five in the resulting map indicates areas with the highest total ecosystem services supply (number and supply) while being under the highest risk of degradation.

To also allow for a comparison, the stakeholder-based ecosystem service and land degradation hotspot maps were multiplied and also rescaled to 1 to 5. Stakeholder-indicated hotspots of land degradation risk and ecosystem service supply were visually compared with the hotspot maps resulting from the spatial modelling work. Locations that show up as a combined hotspot, the investment priority areas, in both assessments can be considered areas where high ecosystem services supply under risk of degradation is most likely. We put these priority locations for land

Table 1
Ecosystem service quantification methods and data sources per country. ZM = Zambia, SA = South Africa, TZ = Tanzania.

Ecosystem services (Country definition)	Mapped ecosystem service indicators	Used data sources
Fodder provisioning (ZM, SA)	Livestock units (LU) per square kilometre	HarvestChoice (2015) (ZM), National Department of Agriculture (2006) (SA)
Fodder provisioning (TZ)	NDVI as value for greenness, as the assumed proxy for quality, of the grasslands. The index ranges from −1 to 1, with the 1 being the highest supply.	Land cover: grassland cover (IRA, n.d.), NDVI Sept 2010 (SPOT/VGT)
Water supply (ZM, TZ)	Index based on river density and inverse distance to lakes. The index ranges from 1 to 5, with the 5 being the highest supply.	Rivers (RCMRD, 2014a) Lakes (VMAP, 2014)
Water supply (SA)	Runoff in mm per year	Nel et al. (2013)
Fuelwood and charcoal (ZM)	Sustainable timber extraction levels in m^3 per hectare per year	Turpie et al. (2015)
Fuelwood and charcoal (TZ)	Accessible woody biomass (Mg/ha) (Willemen et al., 2013).	Roads (RCMRD, 2014b) AGB Map (Saatchi et al., 2011)
Crop production (TZ)	Cultivated land LC2010 combined with AEZ-based crops suitability data. All Non-suitable classes are left out.	LC2010 (IRA, n.d.), AEZ Crop suitability (SUA, n.d.)
Erosion control (ZM)	Estimates of the quantities of sediment that were prevented from reaching dams in tonnes per hectare Tallis et al. (2013)	Turpie et al. (2015)
Erosion control (SA)	Estimated sediment is being retained due to the direct effect of land-cover in tonnes per hectare	O'Farrell (2014)
Erosion control (TZ)	Erosion prevention index based on soil and land use attributes which are at risk of erosion. The index ranges from 1 to 5, with the 5 being the highest supply.	LC2010 (IRA, n.d.), Soils (De Pauw, 1984)
Carbon storage (ZM)	The current carbon stocks in above ground vegetation and soil in tonnes of C per hectare	Turpie et al. (2015)
Water purification (SA)	An estimate of the quantity of nutrients (nitrogen and phosphorous) retained by ecosystems in hectare per year	O'Farrell (2014)
Water flow regulation (ZM, SA, TZ)	Water flow regulation index based on slope, wetland distance, river distance and land cover. The index ranges from 1 to 5, with the 5 being the highest supply.	DEM (SRTM30), Country land cover, rivers, and lakes
Flood protection (TZ)	Flood protection index based on land uses and their ability to reduce flood risk. The index ranges from 1 to 5, with the 5 being the highest supply.	LC2010 (IRA, n.d.)
Habitat for attractive tourism species (ZM, TZ)	Species Attractiveness Index of accessible Protected Areas. The index ranges from 0 to 1, with the 1 being the highest supply.	Willemen et al. (2015b), Major Roads (RCMRD, 2014b)

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degradation responses within the context of the current locations of land with a protected status (IUCN and UNEP-WCMC, 2014).

3. Results

3.1. Key ecosystem services identified by stakeholders

As shown in Fig. 3, the ecosystem services most frequently identified as important by the stakeholders in all three countries were those with a market value (e.g. timber, charcoal, tourism), a direct contribution human wellbeing (e.g. food, fuelwood), or have an important contribution to economic activities such as agriculture (e.g. water, fodder, erosion prevention). The top three ecosystem services, either mentioned or drawn on the map during the interviews, in Zambia were food supply through agriculture and fishery, water supply, and water regulation and tourism (both identified nine times). Similar services were also identified as important in South Africa (water regulation, water supply, food production and erosion control) and Tanzania (water regulation, water supply, and fodder production).

In all three countries stakeholders identified about an equal number of key provisioning and regulating services. The key ecosystem services identified by both national government organizations and other stakeholder organizations could have the broadest level of awareness and could be an important motivator for improved land management in locations where those ecosystem services are supplied. Fig. 3 therefore presents how often a type of stakeholder mentioned a certain ecosystem service as important. We were only able to consult stakeholders from four different types of organization in Zambia. Food supply and water regulation services were mentioned by all four of them. We mostly consulted government officials for the selection of priority ecosystem services in South-Africa and Tanzania.

Stakeholders had in some cases very different perceptions of ecosystem service priorities and degradation threats. For example, water supply in the Southern Agricultural Growth Corridor of Tanzania was considered both 'scarce' and 'plentiful' by different stakeholders in the country. There were also opposing views of natured-based tourism among stakeholders. Statements about tourism in the three countries ranged from "an ecosystem service of national importance", to "tourism at game farms is a land degradation threat", or "contribution of tourism to land degradation is low, it leads more to cultural degradation". Despite wide attention in international decision making, the 'climate change regulation' ecosystem service was only included in Zambia as an ecosystem service of national importance. In South Africa this ecosystem service was removed from the preliminary list because of the perceived limited capacity of vegetation types in the country to capture and store carbon. Some stakeholders in Tanzania wanted to rephrase this regulation service to 'the capacity to adapt to climate change', emphasizing their focus on climate change adaption rather than on mitigation.

A number of other benefits from nature identified by the stakeholders are not included in the TEEB ecosystem service classification. For example, water for navigation in Zambia, game farms and non-food products from agriculture (e.g. vineyards) in South Africa were identified and mapped by stakeholders as important but are not in the TEEB classification. In these cases we decided to label navigation as a provisioning service as it relates to the water volumes, game farms as recreation, and wine production as a food. For the listing of ecosystem services, we could not reclassify the stakeholder identified 'NTFP' (non-timber forest products), which can refer to food and non-food provisioning services. The final list of selected ecosystem services is shown in Table 2, which includes the priority services identified by the stakeholders and takes into account the project objective and feasibility of quantifying each service. The high reliance on forest foods in Zambia is due to high poverty levels (Kalaba et al., 2013). This ecosystem service was omitted in a later phase because there was no adequate species distribution data to quantify it. We also omitted the Zambian cultural heritage service because of a lack appropriate data and models.

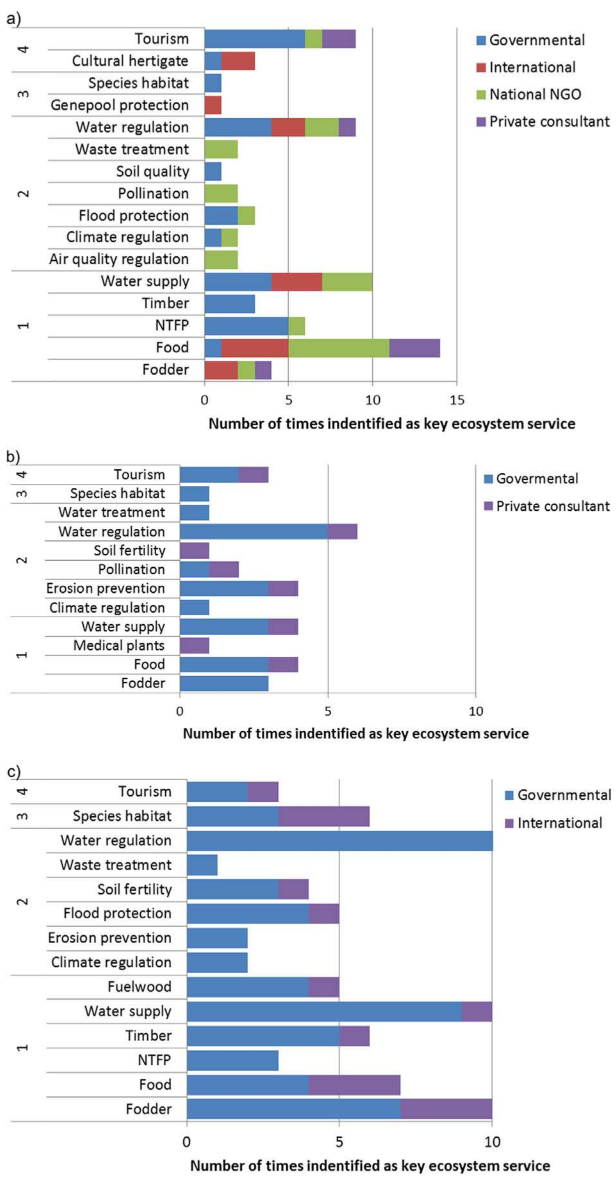

Fig. 3. Priority ecosystem services indicated by stakeholders in a) Zambia (n = 68, of which 34 from the maps); b) South Africa (n = 31, of which 7 from maps); Tanzania (n = 73, of which 38 from the maps). NTFP: Non-timber forest products. 1 = Provisioning; 2 = Regulating; 3 = Habitat; 4 = Cultural ecosystem services.

3.2. Hotspots of ecosystem services and land degradation risk

The selected priority ecosystem services (Table 2) and land degradation risks were spatially quantified using GIS-based models. In Zambia ecosystem services hotspots are located across the country, but mostly along rivers and in protected areas. Land degradation risk hotspots in Zambia are mostly found in the south. In South Africa hotspot of ecosystem services are clustered in the more humid south east, while areas with a high degradation risk

Table 2
Selected key ES for each country after stakeholder consultation. Ecosystem services added to preliminary list by interviewees are in bold. Ecosystem services removed from the preliminary list and not included in this study are in light grey. The omitted services due to data limitations are indicated with an X.

ES category	Zambia	South Africa	Tanzania
Provisioning	• **Fodder provisioning** • Water supply • Fuelwood and charcoal provisioning • **Forest foods supply-X** • Timber supply	• Fodder provisioning • Water supply	• **Fodder provisioning** • Water supply • Fuelwood and charcoal provisioning • **Crop production** • Timber
Regulating	• **Water flow regulation** • Erosion prevention • Climate regulation • • Flood protection • Soil fertility	• Water flow regulation • Erosion prevention Climate regulation • Water purification	• Water flow regulation • Erosion prevention • Flood protection • Soil fertility
Habitat	• Biodiversity and species habit		• Biodiversity and species habitat
Cultural	• **Tourism** • **Cultural heritage (wetlands)-X**	• Tourism	• Tourism

are mostly found around the main cities in the central and west of the country. The locations of ecosystem service supply hotspots are shown in green in Fig. 4. Areas of highest land degradation risk are shown in red in Fig. 4. The Supplementary Materials include the 20 ecosystem service supply maps separately. In addition to the modelled maps, the hotpots based on the digitized locations of key ecosystem services and land degradation threats identified by stakeholders are shown in Fig. 5. For Tanzania the spatially modelled and stakeholder estimates of ecosystem service hotspots and land degradation risk show a similar pattern (Figs. 4 and 5). Both mapping approaches show highest land degradation risks in the semi-arid central parts of the country, while the ecosystem service hotspots form a diagonal crossing the country from northwest to the south-east. For the other two countries the visually observed patterns show less spatial congruence between the spatially modelled and stakeholder drawn maps.

3.3. Investment priority areas and options

The stakeholder-based and modelled ecosystem service hotspots and land degradation risk assessments were combined to quantify and identify hotspots (Fig. 6) for targeting land degradation mitigation measures and attracting investments by interested entities, such as the emerging LDN Fund. As stakeholders were asked to only draw important ecosystem service and land degradation areas, a value of 1 on the stakeholder map (Fig. 5) should be interpreted as a hotspot for targeting mitigation measures. Hotspots for targeting interventions that appear in both mapping approaches reflect locations where model outputs are corroborated by stakeholder knowledge. During the stakeholder consultations, a variety of promising actions to safeguard ecosystem service flows to society were mentioned (see Supplementary Materials for full list). These include sustainable land management practices but also legal and regulatory measures to create an enabling environment for land degradation reduction. To visualize areas where conservation practices are already taking place, we included protected area boundaries on the priority map (ranging from IUCN's strict protection to sustainable use designations) in Fig. 6. Here we highlight some interventions in relation to the hotpot target areas in Fig. 6.

In Zambia, target areas that show up in both the stakeholder-based and modelled assessments include some of the catchment areas for Zambia's main rivers. Expansion of protected forest reserve areas in the catchment of the Zambezi in the west, and the Kafue River in the central area of the county was one action suggested by stakeholders. Forest areas in Zambia appear as ecosystem service hotpots while facing degradation. Stakeholders recommended that mining and timber companies, as drivers of land degradation, invest in sustainable land and forest management in the areas where they are active. Forest areas around large densely populated cities in Zambia are also under pressure from firewood and charcoal collection. Alternative energy resources were suggested to reduce this pressure. Protected areas with a high supply of key ecosystem services but under pressure of degradation can be found in the south of Zambia (modelled results) and the north-west of the country (stakeholder results).

In South Africa areas identified as high in ecosystem services with high risk of degradation by both mapping approaches are located around big cities such as Johannesburg in Gauteng, Durban in KwaZulu-Natal and around Cape Town in the Western Cape. Actions identified by interviewees included clearing of invasive species, natural regeneration, planting of trees and grasses, and better regulation of the mining industry. The grasslands and forested areas in the KwaZulu-Natal and Gauteng provinces in the east are identified as ecosystem service hotspots in South Africa but are found in areas with high degradation potential where loss of vegetation cover could lead to ecosystem service loss. High priority areas without a protected status are mostly found in the south-eastern part of South Africa. Earlier work showed that grasslands are underrepresented in the country's protected areas (Rouget et al., 2004) and are therefore vulnerable to unsustainable land uses.

In Tanzania, priority areas for investments where both ecosystem service supply and human pressures are high include dry central parts of the country, and areas near the Ruaha National Park and the Usambara Mountains in the north east. The priority locations largely overlap with protected areas. To reduce the risk of degradation and maintain the supply of key ecosystem services, stakeholders indicated a need for investing in law enforcement and actions to support alternatives for fuelwood collection such as climate smart agriculture that includes tree species.

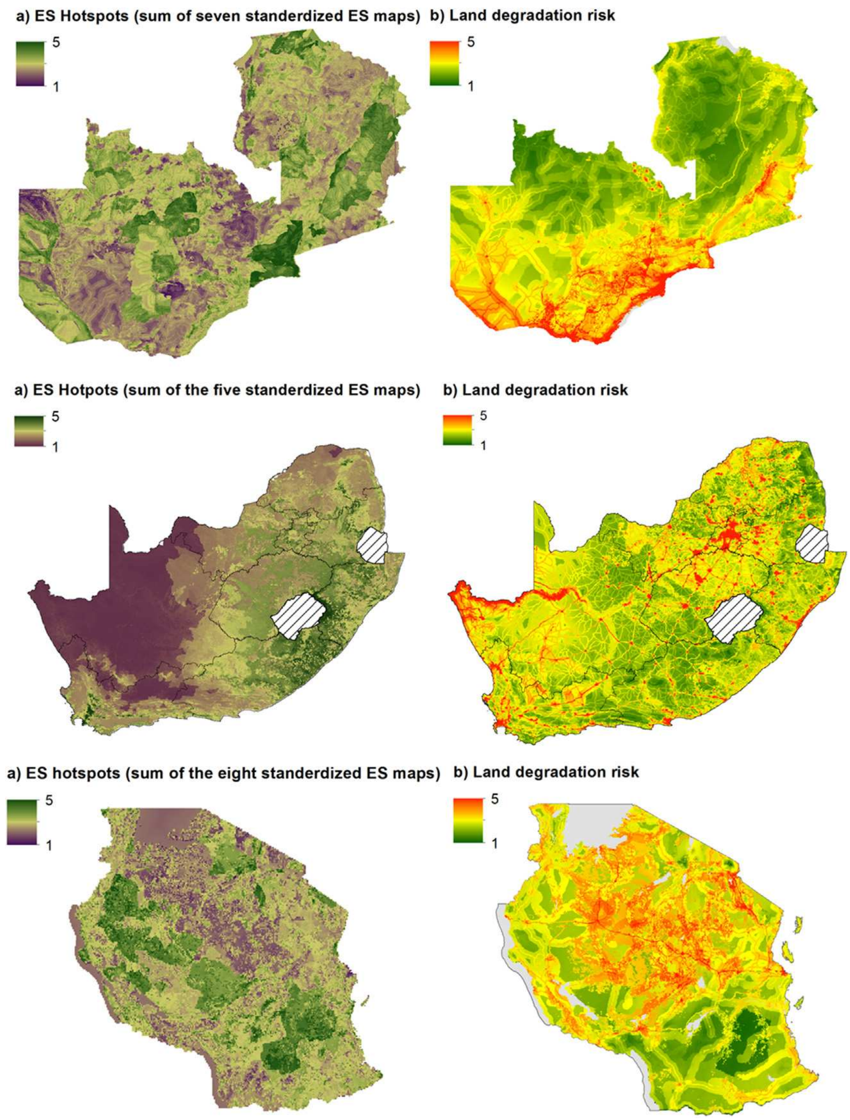

Fig. 4. From top to bottom the Zambia, South Africa, and Tanzania spatial model results: a) ecosystem service supply hotspots, based in the ecosystem services included in this study; b) land degradation risk index. A score of 5 indicates the highest supply or high degradation risk in the country.

4. Discussion

In this study we used integrated mapping approaches to visualize key ecosystem service supply areas in relation to land degradation risk for three African countries with considerable dryland areas; Zambia, South-Africa, and Tanzania. This new approach to promote and target investments in the prevention of degraded land that yields the greatest benefits in term of ecosystem services has some important implications, requirements, and challenges which we discuss below.

4.1. Country level findings and implications

To define priority locations for land degradation mitigation investment we used the concept of ecosystem services for a systematic discussion on environmental benefits with stakeholders in the three countries. We found that all interviewees, based at a wide range of institutions, were all familiar with the ecosystem service concept. There appeared to be an advanced awareness of the term as stated by Guerry et al. (2015). However we also found some difficulties using ecosystems services terminology. The term “regulating services” (as ecosystem service category) was confusing to some. Some stakeholders interpreted this term as regulatory measures for e.g. water purification (prescriptive policy-based). We also found that the ecosystem service framework did not capture the full breadth of land degradation problems that could be addressed though sustainable land management and reduced land degradation risk in the three countries. For example, interviewees in Zambia highlighted the impact of mining on land degradation and deforestation, which also include indirect processes such as mining trucks that facilitate illegal charcoal trade. Interviewees in South Africa also mentioned mining as a key process impacting benefits from ecosystems. For example, many coal fields are located beneath the best quality agricultural lands, limiting their use for food production. Other ecosystem service beneficiary and access problems were highlighted by interviewees in Tanzania with the example that the distribution and access to the many fresh water sources is limited for many people due to limited infrastructure.

The national level maps resulting from this study show general spatial patterns of key ecosystem service supply and land

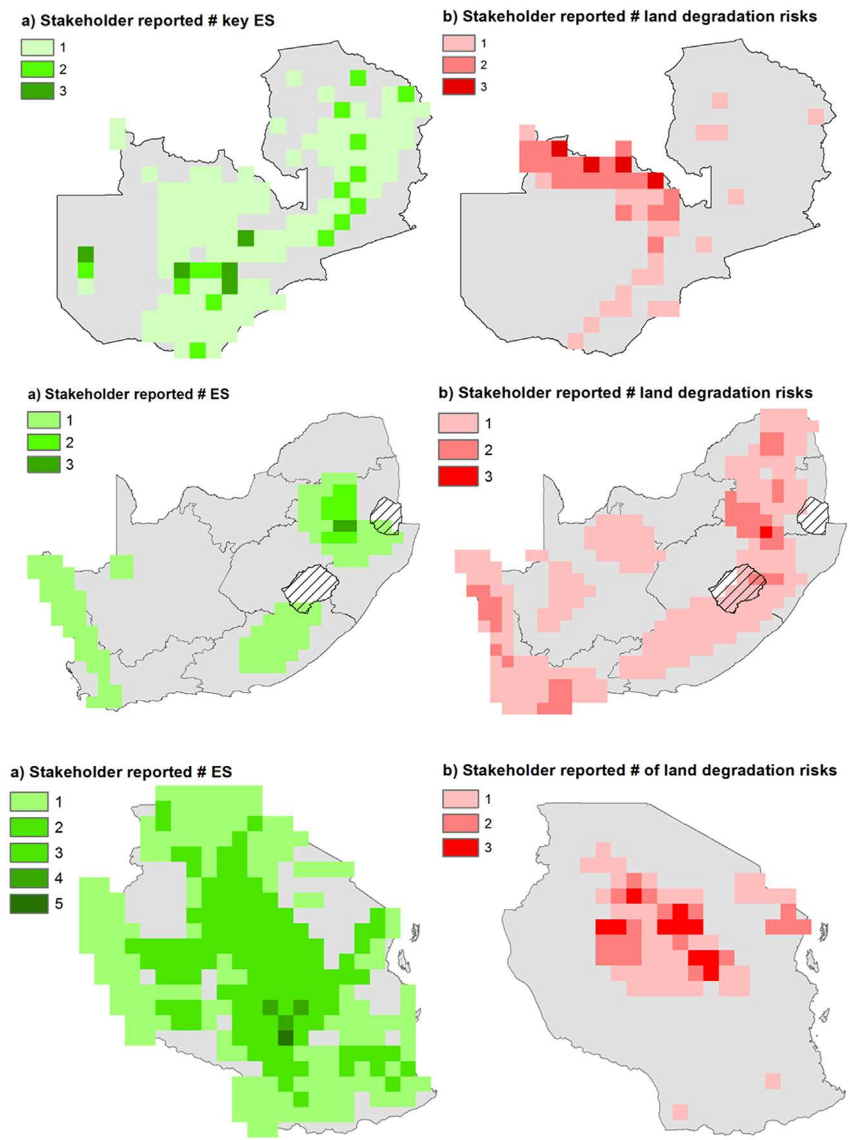

Fig. 5. From top to bottom the Zambia, South Africa, and Tanzania digitized participatory maps a) number of ecosystem services mentioned; b) number of land degradation risks mentioned. The Zambia participatory maps include information from eight interviews and the Tanzania maps are based on six interviews. The South Africa stakeholder maps are only based on two group interviews (no maps were drawn during the other two).

degradation risks. The maps resulting from the stakeholder interviews and spatial models do not readily allow for detailed interpretations because they are based on a wide variety of data sources and assumptions. For example, degradation risk was mapped assuming only spatial data on climate and human pressure would capture the main degradation risk factors (therefore excluding factors such as soil type and topography; these were represented indirectly through land use). The absence of location-specific drivers could explain the large difference in land degradation risk between the expert-derived and modelled outputs (See stakeholder identified list in Supplementary Materials). The absence of mining data in the modelled land degradation risk assessment underestimates the degradation risk especially in the north-west of Zambia. In South Africa our modelled land degradation risk assessment omits three important drivers of degradation that were flagged by the interviewees: invasive species, soil erodibility, and mining sites. Adding these components to the land degradation risk assessment would improve the credibility and reliability of the risk assessment.

For the three countries the target maps for investment can be used to select areas for further and more detailed assessment and exploration of land degradation intervention strategies and subsequent trade-offs across beneficiaries. Each alternative land management in each priority location will come with several trade-offs, peculiar to the social, economic and ecological characteristics of the surrounding landscapes. A detailed trade-off analysis between beneficiaries from alternative land management is not included in this study but should be included in small scale studies (e.g. at project site level), where the complexity of local and regional systems and specific investment plans can be assessed. The target areas for interventions in our study did not include information on the dependence or demand for ecosystem services locally. For example, the western part of South Africa has a high water demand due to low rainfall and desertification but a does not fully appear as target location due to its overall low ecosystem service supply. Including spatial explicit assessments on local demands would better capture the welfare implications associated with interventions decisions (O'Farrell et al., 2010).

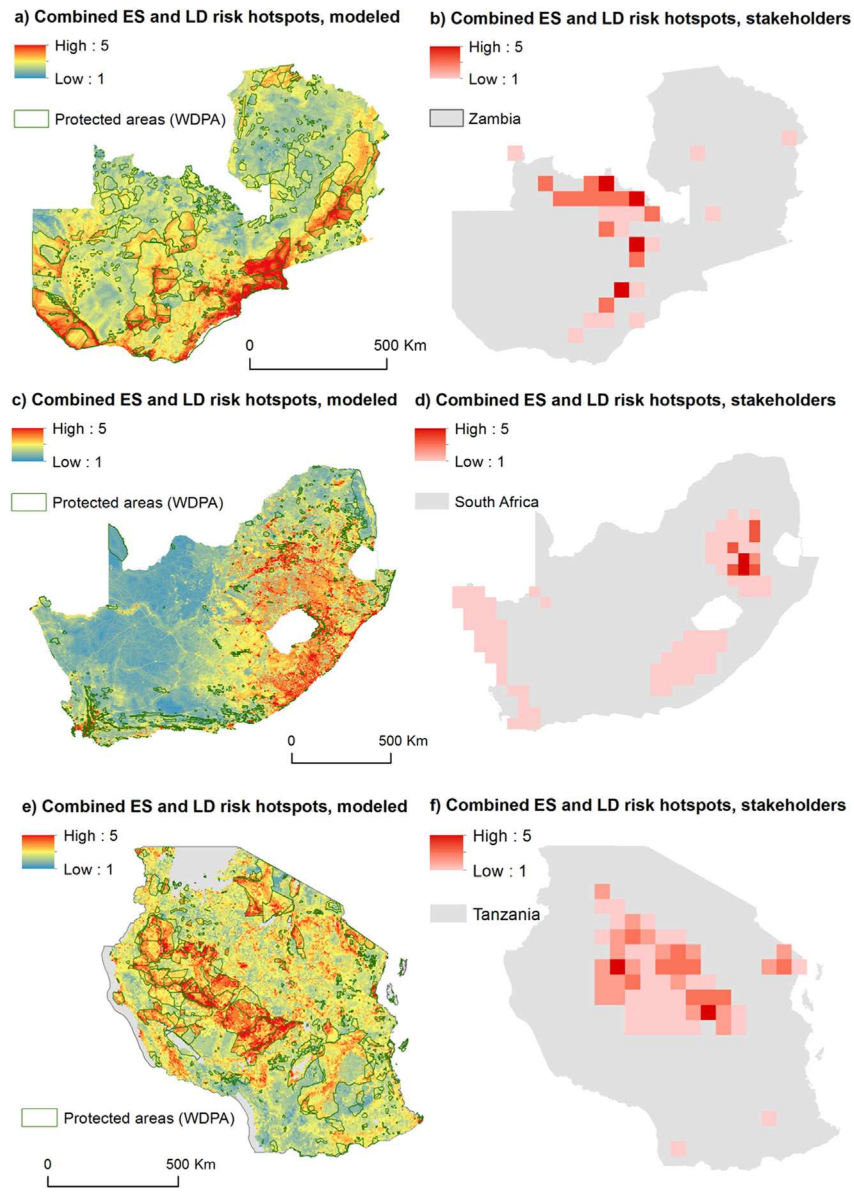

Fig. 6. Combined ecosystem service hotspots and land degradation risks for Zambia, South Africa and Tanzania. Red indicates areas of high degradation risk and high supply of ecosystem services. The green boundaries show the protected areas in the three countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Opportunities and challenges of integrated knowledge mapping

Stakeholder relevant, robust, and transparent spatial information are essential criteria for supporting decision making (Willemen et al., 2015a). We addressed these three criteria by combining participatory approaches with GIS modelling. LDN decision making depends on and affects different stakeholder groups, which all have a different perception of which ecosystem services are "most relevant" to preserve. Ecosystem services repeatedly identified by the diverse stakeholder organizations could be seen as those with the broadest level of awareness and could therefore drive motivation, commitment, and action towards improved land management in locations where those ecosystem services are supplied. Our study reveals that the water supply service could be a powerful motivator. Our results show that water related ecosystem services are prioritized in the three countries. This is not surprising as these are water stressed countries where degradation related water scarcity will have large implications for economic activities such as food production and tourism (Gössling et al., 2012; McIntyre et al., 2016). Stakeholder-driven policy and incentives for change towards ecosystem service protection and LDN are more likely to succeed when there is good awareness of the magnitude of ecosystem service supply and degradation risk. Participatory approaches to addresses a common problem, like land degradation impacts, can create mutual interest and awareness of processes influencing ecosystem service supply (Sitas et al., 2013). Therefore, co-production of knowledge through participatory mapping approaches typically lead to a higher engagement, better match between science and practice, and a higher uptake of the produced maps.

The advantage of using multiple mapping approaches is that it leads to complementary types of insights and detail that are needed for balanced and informed decision-making (Voinov et al., 2014; Law et al., 2015; van Oort et al., 2015). Measures of quality (i.e.

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results from sensitivity and accuracy analyses) of the used GIS data were not available for our study. However locations that show up as hotspots of ecosystem services, land degradation risk, and target sites with both mapping approaches are likely a priority site for LDN action. Due to the known, but unquantified, errors in our maps, the priority areas were not tallied but only compared visually. With ecosystem service maps now an important input for decision making, the reporting, quantifying and visualizing of uncertainty in ecosystem service maps is a key research challenge.

4.3. *Decision making and investments in land degradation neutrality*

LDN relates to decision making at multiple levels, from international to national and to local, through UNCCD commitments, National Action Programmes, and on the ground interventions. This multi-level aspect needs to be considered: i) selection of investment priorities; ii) data accuracy of decision support information, and; iii) financing strategies.

First, in our study we focused on national level priority ecosystem services to define locations to target LDN investment. Internationally or locally these priorities can be different. The selection of project sites and objectives could clash with local priorities or local perceptions of key ecosystem services, hampering the uptake of LDN actions. Second, different levels of accuracy are needed at the different decision making levels. Our national level maps are not necessarily suitable for local level decision making. However, they can inform UNCCD or LDN decision making processes by, for example, facilitating the identification of priority issues and locations in the UNCCD signatory countries. Lastly, LDN investment strategies reflect financial and investment opportunities at different levels. The emerging international LDN Fund is designed as a public-private platform to mobilize blended finance for land degradation neutrality actions, and is expected to open up opportunities for sustainable land management and land rehabilitation worldwide (Mirova and UNCCD Global Mechanism, 2016). At the national level, investment plans are under development. For example, in a recent report by the ProEcoSer project (UNEP, 2015) strategies to mainstream ecosystem services into policies and practices of public and private actors in South Africa include plans for building public-private partnerships for consolidated on-the-ground ecosystem management, for example within the national Working for Water (W*f*W) or Working for Wetlands (W*f*Wet) programmes.

5. Conclusions

Combining spatially explicit and quantitative information on ecosystem services supply with land degradation maps gives a new comprehensive view on the locations where investments in mitigating degradation could be targeted. Our study resulted in country maps for Zambia, South Africa and Tanzania showing areas where LDN investments in reducing land degradation can generate the highest net positive results in terms of ecosystem service supply. We combined the use of spatial modelling and participatory mapping approaches which resulted in complementary insights on ecosystem service supply and degradation risks. For some areas, the spatial model and stakeholder-based maps show similar patterns in ecosystem service hotspots and land degradation risks. In the context of supporting national level policy to achieve land degradation neutrality we argue that these overlapping locations are of great interest. When model-based maps are corroborated by stakeholder knowledge they score likely better in correct representation and in acceptance of the map to support decisions. Besides investment locations, we also investigated which ecosystem services were considered of national importance according to different national level stakeholder groups. Ecosystem services that are frequently mentioned ad identified as important by both national governmental bodies and other stakeholder organizations are likely to have a higher level awareness and agreed importance. These ecosystem services could motivate governments and others to support and invest in halting and reserving land degradation. Our study reveals that the water supply service could be a powerful motivator for Zambia, South African and Tanzania.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2017.05.009.

References

Barbier, E.B., 2000. The economic linkages between rural poverty and land degradation: some evidence from Africa. Agriculture, Ecosyst. Environ. 82, 355–370.
Bindraban, P.S., van der Velde, M., Ye, L., van den Berg, M., Materechera, S., Kiba, D.I., Tamene, L., Ragnarsdóttir, K.V., Jongschaap, R., Hoogmoed, M., Hoogmoed, W., van Beek, C., van Lynden, G., 2012. Assessing the impact of soil degradation on food production. Curr. Opin. Environ. Sustain. 4, 478–488.
Brown, G., Fagerholm, N., 2015. Empirical PPGIS/PGIS mapping of ecosystem services: a review and evaluation. Ecosyst. Serv. 13, 119–133.
Brown, G., Kyttä, M., 2014. Key issues and research priorities for public participation GIS (PPGIS): a synthesis based on empirical research. Appl. Geogr. 46, 122–136.
Byers, B., Aloyce, Z., Munishi, P., Rhoades, C., 2012. Tanzania Environmental Threats and Opportunities Assessment. USAID-Tanzania, Tanzania.
Central Statistics Office, 2014. Gross Domestic Product 2010 Benchmark Estimates. Government of Zambia, Lusaka.
Clec'h, S.L., Oszwald, J., Decaens, T., Desjardins, T., Dufour, S., Grimaldi, M., Jegou, N., Lavelle, P., 2016. Mapping multiple ecosystem services indicators: toward an objective-oriented approach. Ecol. Indic. 69, 508–521.
Crossman, N.D., Bryan, B.A., 2009. Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. Ecol. Econ. 68, 654–668.
Crossman, N.D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E.G., Martín-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M.B., Maes, J., 2013. A blueprint for mapping and modelling ecosystem services. Ecosyst. Serv. 4, 4–14.
Darvill, R., Lindo, Z., 2015. Quantifying and mapping ecosystem service use across stakeholder groups: implications for conservation with priorities for cultural values. Ecosyst. Serv. 13, 153–161.
De Pauw, E., 1984. Soils, Physiography and Agro-Ecological Zones of Tanzania. Crop Monitoring and Early Warning Systems Project, FAO. GCPS/URT/047/NET. Ministry of Agriculture, Dar es Salaam.
Díaz, S., Demissew, S., Joly, C., Lonsdale, W.M., Larigauderie, A., 2015. A rosetta stone for Nature's benefits to people. PLoS Biol. 13, e1002040.
Egoh, B., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C., van Jaarsveld, A.S., 2008. Mapping ecosystem services for planning and management. Agric. Ecosyst. Environ. 127, 135–140.
ELD Initiative, 2015. The Value of Land: Prosperous Lands and Positive Rewards through Sustainable Land Management. Available from: www.eld-initiative.org (Bonn, Germany).
Environmental Council of Zambia, 2008. Zambia Environment Outlook 3. Environmental Council of Zambia, Lusaka, Zambia.
ESRI, 2015. ArcGIS 10.4. Environmental Systems Research Institute, Inc., Redlands, California.
García-Nieto, A.P., Quintas-Soriano, C., García-Llorente, M., Palomo, I., Montes, C., Martín-López, B., 2015. Collaborative mapping of ecosystem services: the role of stakeholders' profiles. Ecosyst. Serv. 13, 141–152.

Gomez-Baggethun, E., de Groot, R., Lomas, P.L., Montes, C., 2010. The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. Ecol. Econ. 69, 1209–1218.
Gössling, S., Peeters, P., Hall, C.M., Ceron, J.-P., Dubois, G., Lehmann, L.V., Scott, D., 2012. Tourism and water use: supply, demand, and security. An international review. Tour. Manag. 33, 1–15.
Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M.W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Ricketts, T.H., Rockström, J., Tallis, H., Vira, B., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proc. Natl. Acad. Sci. 112, 7348–7355.
HarvestChoice, 2015. Livestock Density (LU/sq. km, 2005) by the International Food Policy Research Institute, Washington. DC and University of Minnesota, St. Paul, MN.
Hauck, J., Görg, C., Varjopuro, R., Ratamäki, O., Maes, J., Wittmer, H., Jax, K., 2013. "Maps have an air of authority": potential benefits and challenges of ecosystem service maps at different levels of decision making. Ecosyst. Serv. 4, 25–32.
IRA (Institute for Resource Assessment), n.d., Tanzania Land cover map 2010.
IUCN, and UNEP-WCMC, 2014. The World Database on Protected Areas (WDPA). UNEP- WCMC, Cambridge, UK. Available at: www.protectedplanet.net.
Kairis, O., Kosmas, C., Karavitis, C., Ritsema, C., Salvati, L., Acikalin, S., Alcalá, M., Alfama, P., Atlhopheng, J., Barrera, J., Belgacem, A., Solé-Benet, A., Brito, J., Chaker, M., Chanda, R., Coelho, C., Darkoh, M., Diamantis, I., Ermolaeva, O., Fassouli, V., Fei, W., Feng, J., Fernandez, F., Ferreira, A., Gokceoglu, C., Gonzalez, D., Gungor, H., Hessel, R., Juying, J., Khatteli, H., Khitrov, N., Kounalaki, A., Laouina, A., Lollino, P., Lopes, M., Magole, L., Medina, L., Mendoza, M., Morais, P., Mulale, K., Ocakoglu, F., Ouessar, M., Ovalle, C., Perez, C., Perkins, J., Pliakas, F., Polemio, M., Pozo, A., Prat, C., Qinke, Y., Ramos, A., Ramos, J., Riquelme, J., Romanenkov, V., Rui, L., Santaloia, F., Sebego, R., Sghaier, M., Silva, N., Sizemskaya, M., Soares, J., Sonmez, H., Taamallah, H., Tezcan, L., Torri, D., Ungaro, F., Valente, S., de Vente, J., Zagal, E., Zeiliguer, A., Zhonging, W., Ziogas, A., 2014. Evaluation and selection of indicators for land degradation and desertification monitoring: types of degradation, causes, and implications for management. Environ. Manag. 54, 971–982.
Kalaba, F.K., 2016. Barriers to policy implementation and implications for Zambia's forest ecosystems. For. Policy Econ. 69, 40–44.
Kalaba, F.K., Quinn, C.H., Dougill, A.J., 2013. The role of forest provisioning ecosystem services in coping with household stresses and shocks in Miombo woodlands, Zambia. Ecosyst. Serv. 5, 143–148.
Klein, T.M., Celio, E., Grêt-Regamey, A., 2015. Ecosystem services visualization and communication: a demand analysis approach for designing information and conceptualizing decision support systems. Ecosyst. Serv. 13, 173–183.
Law, E.A., Bryan, B.A., Torabi, N., Bekessy, S.A., McAlpine, C.A., Wilson, K.A., 2015. Measurement matters in managing landscape carbon. Ecosyst. Serv. 13, 6–15.
MA, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.
Maes, J., Jacobs, S., 2015. Nature-based Solutions for Europe's Sustainable Development (Conservation Letters).
Maillard, S., Cheung, R., 2016. Unlocking the Market for Land Degradation Neutrality (Paris, France).
Martínez-Harms, M.J., Balvanera, P., 2012. Methods for mapping ecosystem service supply: a review. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 8, 17–25.
McIntyre, N., Bulovic, N., Cane, I., McKenna, P., 2016. A multi-disciplinary approach to understanding the impacts of mines on traditional uses of water in Northern Mongolia. Sci. Total Environ. 557–558, 404–414.
Milder, J.C., Buck, L.E., Hart, A.K., Scherr, S.J., 2012. The SAGCOT Greenprint" a Green Growth Investment Framework for the Southern Agricultural Growth Corridor of Tanzania. EcoAgriculture Partners, Ithica, USA.
Mirova, and UNCCD Global Mechanism, 2016. Land Degradation Neutrality Fund Project: White Paper. Global Landscapes Forum London.
Naidoo, R., Ricketts, T.H., 2006. Mapping the economic costs and benefits of conservation. PLoS Biol. 4, e360.
National Department of Agriculture, 2006. Grazing Potential South Africa. CSIR and the Institute for Soil Climate and Water.
Nel, J., Colvin, C., David, L.M., Smith, J., Haines, I., 2013. South Africa's Strategic Water Source Areas. Report for WWF-South Africa.CSIR Report No: CSIR/NRE/ECOS/ER/2013/0031/A.
O'Farrell, P., 2014. Benefit Flows and Recommendations Relating to Modeling Approaches for Deriving Sediment and Nutrient Retention Values at a National Level. CSIR, South Africa.
O'Farrell, P.J., Reyers, B., Le Maitre, D.C., Milton, S.J., Egoh, B., Maherry, A., Colvin, C., Atkinson, D., De Lange, W., Blignaut, J.N., Cowling, R.M., 2010. Multi-functional landscapes in semi arid environments: implications for biodiversity and ecosystem services. Landsc. Ecol. 25, 1231–1246.
Orr, B.J., Cowie, A.L., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G.I., Minelli, S., Tengberg, A.E., Walter, S., Welton, S., 2017. Scientific Conceptual Framework for Land Degradation Neutrality. A Report of the Science-Policy Interface. UNCCD, Bonn, Germany.
Pettit, C.J., Raymond, C.M., Bryan, B.A., Lewis, H., 2011. Identifying strengths and weaknesses of landscape visualisation for effective communication of future alternatives. Landsc. Urban Plan. 100, 231–241.
RCMRD, 2014a. Tanzania Rivers vector map. Accessed July 2015: http://servirportal.rcmrd.org/.
RCMRD, 2014b. Tanzania Roads vector map. Accessed July 2015: http://servirportal.rcmrd.org/.
Rouget, M., Reyers, B., Jonas, Z., Desmet, P., Driver, A., Maze, K., Egoh, B., Cowling, R.M., 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. In: Terrestrial Component, vol. 1. South African National Biodiversity Institute, Pretoria.
Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M., Morel, A., 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. Proc. Natl. Acad. Sci. 108 (24), 9899–9904.
Scholes, R.J., Biggs, R. (Eds.), 2004. Ecosystem Services in Southern Africa: a Regional Assessment. Council for Scientific and Industrial Research, Pretoria, South Africa.
Schröter, M., Remme, R.P., Sumarga, E., Barton, D.N., Hein, L., 2015. Lessons learned for spatial modelling of ecosystem services in support of ecosystem accounting. Ecosyst. Serv. 13, 64–69.
Schulp, C.J.E., Burkhard, B., Maes, J., Van Vliet, J., Verburg, P.H., 2014. Uncertainties in ecosystem service maps: a comparison on the European scale. PLoS One 9, e109643.
Sitas, N., Prozesky, H., Esler, K., Reyers, B., 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. Landsc. Ecol. 1–17.
Sorensen, L., 2007. A Spatial Analysis Approach to the Global Delineation of Dryland Areas of Relevance to the CBD Programme of Work on Dry and Subhumid Lands. UNEP-WCMC, Cambridge.
Stringer, L.C., Dougill, A.J., 2013. Channelling science into policy: enabling best practices from research on land degradation and sustainable land management in dryland Africa. J. Environ. Manag. 114, 328–335.
SUA (Sokoine University of Agriculture), n.d., Crop Suitability per Agroecological Zone, Tanzania.
Tallis, H.T., Ricketts, T., Guerry, A., Wood, S.A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., 2013. InVEST 2.5.3 User's Guide. The Natural Capital Project, Stanford, CA.
TEEB, 2010. In: Kumar, Pushpam (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington.
Trabucco, A., Zomer, R.J., 2009. Global Potential Evapo-transpiration (Global-PET) and Global Aridity Index (Global-aridity) Geo-database. Available online from the CGIAR-CSI GeoPortal at: http://www.csi.cgiar.org (in C. C. f. S. Information., editor).
Turpie, J., Warr, B., Ingram, J.C., 2015. Benefits of Forest Ecosystem in Zambia and the Role of REDD+ in a Green Economy Transformation (United Nations Environment Programme, Nairobi, Kenya).
UNCCD, 2016. Benefits and Responsibilities of Parties to the Convention.
UNEP, 2015. Success Stories in Mainstreaming Ecosystem Services into Macroeconomic Policy and Land Use Planning: Evidence from Chile, Trinidad and Tobago, South Africa and Viet Nam. The United Nations Environment Programme (Nairobi, Kenya).
van Heerden, J.H., Blignaut, J., Horridge, M., 2008. Integrated water and economic modelling of the impacts of water market instruments on the South African economy. Ecol. Econ. 66, 105–116.
van Oort, B., Bhatta, L.D., Baral, H., Rai, R.K., Dhakal, M., Rucevska, I., Adhikari, R., 2015. Assessing community values to support mapping of ecosystem services in the Koshi river basin. Nepal. Ecosyst. Serv. 13, 70–80.
Vice President's Office, 2014. Status of Land Degradation on Tanzania.
VMAP, 2014. VMap0 GIS data. Accessed July 2015 through: http://gis-lab.info/qa/vmap0-eng.html.
Voinov, A., Seppelt, R., Reis, S., Nabel, J.E.M.S., Shokravi, S., 2014. Values in socio-environmental modelling: persuasion for action or excuse for inaction. Environ. Model. Softw. 53, 207–212.
Walsh, J.C., Dicks, L.V., Sutherland, W.J., 2015. The effect of scientific evidence on conservation practitioners' management decisions. Conserv. Biol. 29, 88–98.
WCS, and CIESIN, 2005. In: Wildlife Conservation Society - WCS and Center for International Earth Science Information Network - CIESIN - Columbia University (Ed.), Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Influence Index (HII) Dataset (Geographic). NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY.
Willemen, L., Burkhard, B., Crossman, N., Drakou, E.G., Palomo, I., 2015a. Editorial: best practices for mapping ecosystem services. Ecosyst. Serv. 13, 1–5.
Willemen, L., Cottam, A.J., Drakou, E.G., Burgess, N.D., 2015b. Using social media to measure the contribution of red list species to the nature-based tourism potential of African protected areas. PLoS One 10, e0129785.
Willemen, L., Drakou, E.G., Dunbar, M.B., Mayaux, P., Egoh, B.N., 2013. Safeguarding ecosystem services and livelihoods: understanding the impact of conservation strategies on benefit flows to society. Ecosyst. Serv. 4, 95–103.
Willemen, L., Verburg, P.H., Hein, L., Van Mensvoort, M.E.F., 2008. Spatial characterization of landscape functions. Landsc. Urban Plan. 88, 34–43.
Winslow, M.D., Vogt, J.V., Thomas, R.J., Sommer, S., Martius, C., Akhtar-Schuster, M., 2011. Science for improving the monitoring and assessment of dryland degradation. Land Degrad. Dev. 22, 145–149.

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