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Multi-Criteria Decision Analysis to identify dryland ecosystem service trade-offs under different rangeland land uses

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ABSTRACT

Land degradation undermines ecosystem service provision, limiting economic returns from semi-arid rangelands. We apply a Multi-Criteria Decision Analysis (MCDA) to assess the value of ecosystem services, using monetary and non-monetary techniques in semi-arid rangelands in Kgalagadi District, southern Botswana. In doing so, we provide an empirical understanding of the linkages between policy, land use and the provision of ecosystem services based on the perspectives of local stakeholders identified through interviews and a workshop consultation. Findings suggest communal grazing provides the widest range of monetary and non-monetary values linked to ecosystem service delivery. Current economic incentives and policy initiatives supporting the livestock sector, linked to fencing and borehole drilling, create perverse incentives that over-emphasise commercial food production at the expense of other services. We identify a need for policy reforms to support livelihood diversification through the provision of a wider range of ecosystem services, and for further research to explore market opportunities for veld products and carbon trading. We show that MCDA offers a useful holistic assessment framework that could be applied more widely to semi-arid rangelands globally.

1. Introduction

Land degradation is driven by a variety of socio-economic, political and environmental factors, and undermines a range of ecosystem services (ES) for billions of people who depend on the natural resource base for their livelihoods and subsistence (Foley et al., 2005). The United Nations Convention to Combat Desertification (UNCCD) provides an important international policy framework for countries to tackle land degradation. At the national level, parties to the UNCCD develop National Action Programmes (NAPs) to outline the national status of land degradation, and provide a Sustainable Land Management (SLM) strategy to address the problem (Stringer et al., 2007). SLM refers to practices through which land users can meet their needs and derive socio-economic benefits from the land, while simultaneously ensuring long-term productive potential and maintenance of the land's environmental functions (WOCAT, 2010). In addition to NAPs, countries develop sector-specific policies that treat land degradation as a cross-cutting issue. This cross-cutting nature demands the integrated assessment of different kinds of land uses and management, and information that can help policy makers to prioritise actions to enhance ES delivery (and/or avoid ES losses), and promote SLM within decision making (Akhtar-Schuster et al., 2011). In turn, this requires integrated, holistic methodologies that bring together socio-economic, environmental and policy dimensions (Bateman et al., 2013; Costanza et al., 2014).

Various analytical frameworks can quantify and value ES, providing useful information for the public and policymakers (e.g. TEEB, 2010). For example, the monetary value of ES can be conceptualised as the way in which they contribute to different elements of the 'Total Economic Value'. ES may increase an individual's welfare through direct provision of goods (e.g., food or recreational use), or indirectly through e.g. the regulation of water and carbon cycles (TEEB, 2010). People also value ES for their non-use (also termed "passive-use") benefits. However, these conventional monetary

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valuation approaches do not capture shared values, which people hold for others and the communities and society in which they live (Kenter et al., 2014). This presents the need to integrate these various dimensions through mixed-method approaches that combine deliberative-based techniques, where varied stakeholders' perspectives are brought together. Fish et al. (2011) identify Multi-Criteria Decision Analysis (MCDA) as an effective decision making tool to evaluate the non-monetary and monetary costs and benefits of different management options. MCDA offers a useful integrative approach that also allows cultural and shared values related to ES to be assessed in a systematic way based on key socio-economic, policy and environmental priorities (Kenter et al., 2014).

Following the de Groot et al. (2010) ES classification, in this paper we present an analytical framework using MCDA to identify the multiple monetary and non-monetary dimensions of land use and management in southern Kgalagadi District, Botswana. We identify, value and score ES benefits from four types of land management: (i) private (fenced) cattle ranching, (ii) (unfenced) communal livestock grazing, (iii) (private) game farming and (iv) Wildlife Management Areas (WMAs). We then discuss the costs and trade-offs associated with ES delivery under each of these options. Our approach provides decision makers with a valuable analytical example that can be used to better understand ES provision across semi-arid rangelands, while findings can be used to inform measures that could reduce degradation of particular ES and advance SLM.

2. Materials and methods

2.1. Study area

Data were collected during 2013–2014 along an east–west transect of the southern part of Kgalagadi District, Botswana (Fig. 1), incorporating a total area of *c.* 66,000 km^2 (Government of Botswana (GoB), 2003) and an estimated human population of 30,000 (GoB, 2012a). Rangeland degradation has led to extensive bush encroachment (Thomas and Twyman, 2004); reducing good quality grazing and increasing rural poverty levels (Chanda et al., 2003). Land uses include communal grazing areas (unfenced cattle posts) (*c.* 14,800 km^2), privately owned (fenced) cattle ranches (*c.* 8,900 km^2), private game ranches (*c.* 800 km^2) and Wildlife Management Areas (WMAs) (*c.* 14,800 km^2) designated as protected conservation areas around the National Parks (Kgalagadi Transfrontier Park, *c.* 26,700 km^2).

2.2. Methods

We use MCDA as a framework that allows monetary-based techniques to be integrated with non-monetary ecological and shared values (de Groot et al., 2010; Kenter et al., 2014). This allows us to rank alternative options by quantifying, scoring and weighting a range of quantitative and qualitative criteria (Fontana et al., 2013). Scoring was undertaken by the project team (composed of national and international researchers with expertise in land policy, livelihoods, ES valuation, land degradation assessment, range ecology, geomorphology and environmental economics). Weighting was undertaken in consultation with stakeholders from the government and NGOs.

2.2.1. Problem definition

The research problem was defined as: "Which land uses and land management strategies are best placed to generate the widest range of economic and non-economic values linked to specific ES delivered in Kalahari rangelands in southern Kgalagadi District, Botswana?".

2.2.2. Identification of options, criteria definition and assessment

Four land uses which include all the key land uses in the study area were defined as MCDA options: (i) communal livestock grazing; (ii) private cattle ranches; (iii) private game ranches; (iv) WMAs. Performance of the options was measured by their

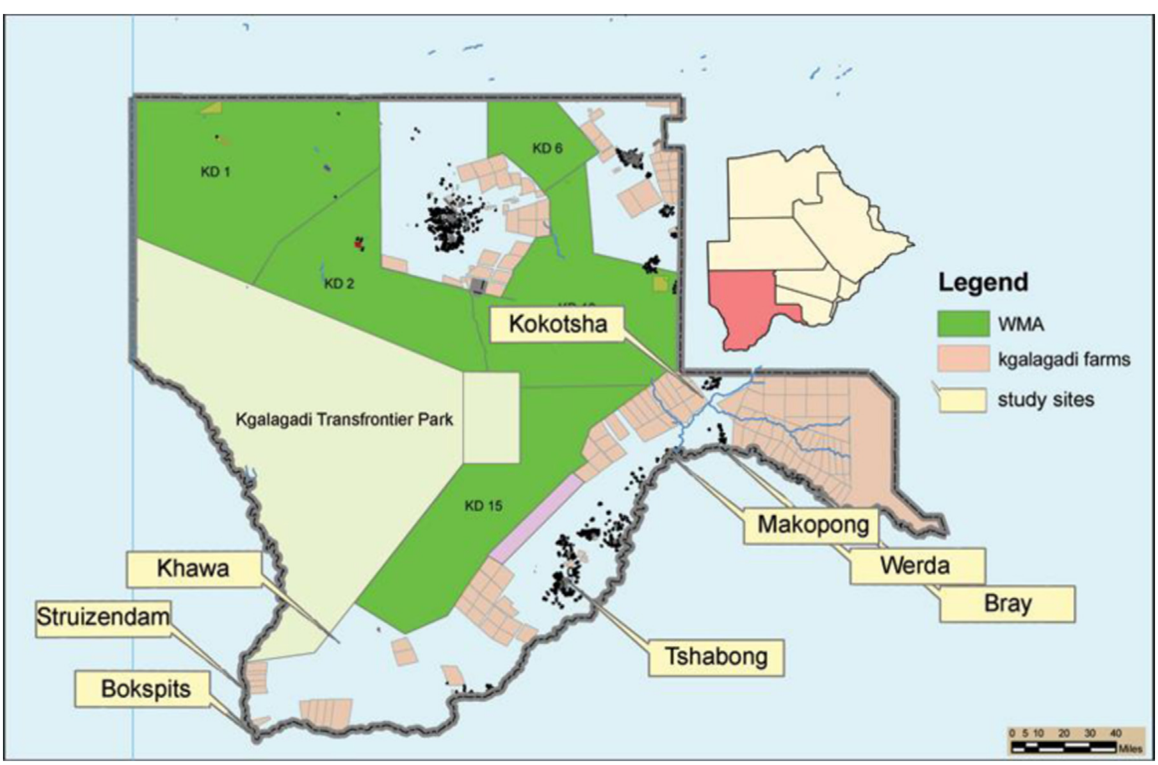


Fig. 1. Land use of Kgalagadi District, southern Botswana and study sites *Source*: adapted from KGLB (2013).

Table 1
Criteria and indicators used to assess capacity to deliver ecosystem services in Kgalagadi District, southern Botswana, as assessed through MCDA.

Criterion (ecosystem service)	Indicator	Type of measurement
Food (commercial)	• Net profit of meat production (US$/ha/yr) • Stocking level (Ha/Livestock Unit)	Quantitative-monetary and Quantitative-non-monetary
Food (wild)	• Gathering of veld products • Subsistence hunting	Qualitative
Fuel	• Firewood collection	Qualitative
Construction material	• Collection of thatching grass and poles for fencing	Qualitative
Groundwater	• Value of water extracted (US$/ha/yr)	Quantitative-monetary
Plant and livestock diversity	• Species and genetic diversity between forage species • Genetic diversity between livestock breeds	Qualitative
Climate regulation	• Value of carbon sequestration (US$/ha/yr)	Quantitative-monetary
Recreation	• Revenues from Community Based Natural Resource Management, trophy hunting & photographic safari (US$/ha/yr) • Ecotourism potential • Wild animal diversity	Quantitative-monetary and qualitative
Cultural/Spiritual benefits	• Presence of landscape features or species with cultural/spiritual value	Qualitative

capacity to deliver the identified ES in the year 2013. Nine criteria were identified, supported by 14 indicators (Table 1).

In order to understand stakeholder values for the indicators, we conducted 37 semi-structured interviews (see S1) across 8 study sites. Respondents were selected based on relevant expertise (for government officers and village development committees) and ownership of cattle and/or game. The sample comprised: communal livestock farmers ($n=20$), private cattle ranchers ($n=10$), private game ranchers ($n=3$), government officers ($n=3$) and village development committee leaders ($n=1$). Quantitative data were collected to investigate the monetary costs and gains from land use activities noted in interviews and included examination of financial statements where available. Qualitative interview data also covered the different land management strategies adopted and their main implications for land degradation and ES provision. Policy analysis identified priorities in different sectors and the economic mechanisms currently used to advance their implementation. 12 ecological assessments were also undertaken to verify assumptions made on land use and patterns of ecological change / degradation (Dougill et al., 2014). The following subsections detail the methods and data used to assess each criterion.

Criterion 1: Food (commercial). Mean net profit of the meat production indicator was derived by subtracting annual operating expenses under each land use option from the total operating revenues. Values provided by private cattle and game farms through financial statements[1] were measured for different fiscal years during 2010–2013 and compared after being deflated to 2013 prices using the Botswana Consumer Price Index (CPI). Private operating expenses included feed and medicines, motor vehicles and transport, fuel and oil, electricity, repairs and maintenance, and salaries and wages used for bush removal. In communal grazing areas, revenues and expenses were calculated based on interview data integrated with literature values (GoB, 2007). Revenues included the average livestock herd size owned (cattle and smallstock; assessed through interview data) multiplied by the mean off-take rate (identified in GoB, 2007) and valued according to the 2013 market price. Expenditure from interview data included the mean cost of borehole drilling (with a 10-year depreciation period), borehole equipment and maintenance, kraals (enclosures for livestock), feed and medicines, fuel and labour. Minimum and maximum expected profit values were estimated by calculating a 95% confidence interval of the standard deviation of the profit mean with uncertainty expressed by the standard error. The stocking level non-monetary indicator provided the mean stocking values, assessed through interviews and analysis of secondary data contained in GoB (2007).

Criterion 2 (Food, wild), Criterion 3 (Fuel) and *Criterion 4 (Construction material).* The indicators 'gathering of veld products', 'subsistence hunting', 'firewood collection' and 'collection of thatching grass and poles for fencing' were qualitatively assessed using a 5-point scale (1 very low, 5 very high) according to information gained through interviews and from previous studies in this area that focused explicitly on community use of wild (veld) products, fuel and construction material (e.g. Thusano Lefatsheng Trust, 2005; Twyman, 2000).

Criterion 5: Groundwater. The economic value of the groundwater extracted was estimated using interview data. The average number of boreholes used per ha under each land use was calculated and multiplied by the borehole's extraction capacity (L/hr). Total L/ha/yr of water extracted was derived by multiplying the latter value by 365 days and assuming a daily pumping time of 16 h (from interview data). The result was valued according to the 2006 market price of non-potable (raw) water (GoB, 2006) deflated to the real 2013 price. A 95% confidence interval was calculated to provide minimum and maximum expected values, together with its standard error.

Criterion 6: Plant and livestock diversity. This criterion classifies biodiversity (the variability among living organisms including genetic diversity) as a final ES (de Groot et al., 2010; Mace et al., 2012). The two indicators of biodiversity (forage species and livestock breeds) indicate the capacity to ensure resilient food production against future climate change and or diseases. These indicators were assessed using a 5-point scale (1 very low, 5 very high) according to findings from the ecological assessments at each study site (Dougill et al., 2014) and interviews data quantifying the livestock breeds present at each site.

Criterion 7: Climate regulation. The monetary value of net carbon (C) sequestration was assessed through the benefit transfer method (Richardson et al., 2014). Above-ground biomass (vegetation) C storage estimates were based on the ecological studies (Dougill et al., 2014). Previous Kalahari soil analyses found that soil C gains through photosynthesis in lightly grazed WMAs are close to being balanced by C losses (Dougill and Thomas, 2004). Net amounts of total soil C sequestered per annum were estimated using recent studies in southern Botswana (Thomas, 2012). Three scenarios were used: (i) intense grazing (communal livestock grazing and private cattle ranches) where net gains were identified as 0.25 t C/ha/yr, (ii) light grazing (game ranches) where net gains are 0.20 t C/ha/yr and (iii) very light grazing (WMAs) where gains are 0.05 t C/ha/yr, with the higher C storage at intensively grazed sites resulting from bush encroachment leading to higher above-ground biomass C storage. These figures were multiplied by

[1] 2013 Exchange rate applied: Pula/US$=0.11.

the total land surface under each use and valued according to the 2013 C price set in the European Union Emissions Trading Scheme (EU ETS) (US $6.7/t).

Criterion 8: Recreation. Revenues from Community-Based Natural Resource Management (CBNRM) gained through trophy hunting and/or photographic safaris for the controlled hunting area in the WMA were assessed by examining the 2006 hunting agreement provided by the Khawa Kopanelo Development Trust. These values validate the CBNRM estimates from another study based in southern Botswana (Madzwamuse et al., 2007). Real 2013 prices were calculated using the Botswana CPI. The ecotourism potential indicator was assessed using a 5-point scale in interviews, and the WMA land use management plan and a local development plan designed by a private safari operator. Wild animal diversity was assessed using a 5-point scale developed by using the 2012 Aerial Census of Animals in Botswana (GoB, 2012b) that maps the spatial distribution of the main 26 wild animal species.

Criterion 9. Cultural/Spiritual benefits. The same qualitative methods for assessing the indicator 'presence of landscape features or species with spiritual value' were used as for criteria 2, 3 and 4 using previous studies from Arntzen et al. (2010) and Madzwamuse et al. (2007).

2.2.3. Criteria weighting

Each criterion was weighted to reflect its relative importance to society for the final ranking. Weights were assigned using a direct weighting system based on the ranking technique (Hokkanen and Salminen, 1994; Hokkanen et al., 1995), with scores obtained in a national policy workshop held in 2014. Attendees at this workshop were secured via 28 invitations sent to national and regional experts on land degradation. Fifteen stakeholders attended, and their individual ranking for the criteria weights was gathered through a questionnaire, yielding a similar number of responses to those in other studies (e.g. Fontana et al., 2013; Hajkowicz et al., 2000). Stakeholders were from several sectors affected by land degradation, including agriculture and water ($n=6$), wildlife and forestry (n=6), as well as the cross-cutting sectors of statistics ($n=2$) and energy ($n=1$). Rankings were obtained on a 9-point scale ranging from most important (9) to least important (1) criteria. The ordinal information was used to derive cardinal weights needed for the MCDA using the rank sum method (Barron and Barret 1996). The geometric mean was used to aggregate the individual priorities of each stakeholder into a single representative weight for the entire group (Fontana et al., 2013). Although ordinal ranking does not necessarily reflect the exact importance of criteria for stakeholders (Hokkanen et al., 1995), time and resource constraints motivated our decision to use direct ranking rather than the commonly used pair-wise comparisons. Indeed, direct ranking allows a simpler representation of the relative importance of the criteria involved (Rogers and Bruen, 1998) and is often preferred by decision makers (Hajkowicz et al., 2000). Additionally, Hokkanen and Salminen (1994) tested an alternative method which weighted the criteria according to stakeholders' perceptions of how many times each criterion was more important than others, finding discrepancies between the two approaches to be minimal. Our approach is therefore robust, something which we tested through sensitivity analysis (see Section 3).

2.2.4. Derivation of overall preference scores for each land use option

Quantitative and qualitative criteria were scored on a homogeneous 100-point scale. A score of 0 represented the worst level of performance encountered, and 100 the best (as per UK Government (GoUK), 2009). End points were established based on the criteria assessment. A linear value function translated the 100-point performance scale of each criterion (j) into a MCDA criterion score (0-100). For each land use option (i), each criterion score (s_{ij}) was multiplied by the criterion's weight (w_j). The land use options' overall preference score (S_i) was derived by summing these products for all the criteria (n) under each land use option (Eq. 1).

$$Si=\sum_{j=1}^{n} wjsij \tag{1}$$

3. Results

Table 2 shows the performance of each criterion under the different land use options, alongside the type of valuation and data collection method(s) used to inform the MCDA.

Table 3 details the weights attributed to each criterion. Normalised values indicate groundwater ranks highest, followed by commercial food production, plant and livestock diversity, wild food, fuel and construction material. Climate regulation, recreation and spiritual inspiration were ranked lowest.

Final scores (quantitative and qualitative criteria ranked on a 100-point scale) are outlined in Table 4. Weighted values (single land use options' scores multiplied by normalised criterion weight) are in brackets.

Performance of each land use regarding its capacity to deliver the range of ES under consideration is summarised in Fig. 2. Communal livestock grazing provides the greatest benefit to society, achieving the highest MCDA score, followed by private cattle ranches, WMAs and private game ranches. High scores for communal grazing areas are mainly linked to their use for commercial food production, with management practices allowing wild food production, fuelwood collection, construction material provision, climate regulation and cultural/spiritual non-use values to be retained.

We recognise that our results have been derived from a single set of scoring and weighting of the criteria. It is therefore plausible that a different set of scores/weights would have led us to other conclusions. To increase confidence in our results, a deterministic sensitivity analysis was carried out. Through several iterations, different weightings and scores were applied to assess possible deviations in the final MCDA ranking against results in Fig. 2 (Broekhuizen et al., 2015). Iterations included doubling the weighting of one or multiple criteria at the same time under different scenarios, and also doubling or halving the MCDA score of multiple options (i.e. commercial food, wild food, construction material, climate regulation, recreation and cultural/spiritual benefits) (Fig. 3). This approach is intuitive and easily applicable to both uncertainty in performance scores and criteria weights (Broekhuizen et al., 2015).

Results indicated insensitivity of the highest and lowest results in the ranking (i.e. communal grazing was always ranked first and the private game ranch option last). Rankings of private cattle ranches and WMAs changed position when some of the different weights were tested (Figs. 3.b,.c, .e and .f). When scoring of different options was tested (Fig. 3.f), the intermediate MCDA ranking did change. This suggests that if a broader panel of individuals was interviewed the main results would not change, but changes in the intermediate options may occur. The same sensitivity tests were carried out on an alternative set of weighted scores, where the criteria weights were elicited through policy and discourse analysis rather than stakeholder ranking (see S2). By testing possible changes in the results when an alternative set of stakeholders' preferences is used, similar results were obtained.

4. Discussion

The MCDA shows that Kalahari communal rangelands are important for a broader range of ES than simply commercial food

Table 2
Criteria performance for four land use types in Kgalagadi District, southern Botswana, as assessed through the MCDA.

Criterion (ecosystem service)	Indicator / ES category (de Groot et al., 2010)	Communal livestock grazing	Private cattle ranches	Private game ranches	WMAs	Valuation/collection methods used to inform the MCDA
	Provisioning services					
Food (commercial)	Net profit of meat production (US $/ha/yr)	Mean: 0.64 (−0.56; 1.95)[a] (0.64)[b]	Mean: 1.21 (0.66; 1.75)[a] (0.16)[b]	Mean: −2.07 (−7.89; 3.75)[a] (1.33)[b]	0 (0.0)[b]	Interviews & market prices
	Stocking level (Ha/LSU)	Mean: 11 (9; 13)	Mean: 14 (8; 20)	Mean: 9.5 (7; 12)	Mean: 160 (120; 200)	Interviews & literature
Food (wild)	Gathering of veld products	High	Low	Low	Medium	Interviews & literature
	Subsistence hunting	High	Very low	Very low	Very high	Interviews & literature
Fuel	Firewood collection	Very high	Medium	Medium	High	Interviews & literature
Construction material	Collection of thatching grass and poles for fencing	Very high	Medium	Low	High	Interviews & literature
Groundwater	Value of water extracted (US$/ha/yr)	Mean: 0.84 (0.63; 1.05)[a] (0.21)[b]	Mean: 0.97 (0.22; 1.71)[a] (0.37)[b]	0.15 (0)[b]	0 (0)[b]	Interviews & market prices
Plant and livestock diversity	Species and genetic diversity between forage species	Low	Medium	High	Very high	Ecological assessments
	Genetic diversity between livestock breeds	Low	High	Very low	Low	Interviews
	Regulating services					
Climate regulation	Value of carbon sequestration (US $/ha/yr)	1.7	1.7	1.3	0.3	Benefit transfer & market prices
	Cultural services					
Recreation	Revenues from CBNRM trophy hunting and photographic safari (US $/ha/yr)	0	0	0	0.04	Interviews
	Ecotourism potential	Low	Very low	High	Very high	Interviews
	Wild animals diversity	Medium	Very low	Very high	Very high	Literature
Cultural/Spiritual benefits	Presence of landscape features or species with cultural/spiritual benefits	Very high	Very low	Medium	Very high	Interviews

[a] 95% confidence interval of the standard deviation of the mean.
[b] Standard error.

production, but that the value of these other ES is currently underestimated. When non-marketed ES are weighted according to their relative importance to other ES, communal grazing areas rank as the land use that generates the highest value (both in provisioning and cultural terms), followed by WMAs. This indicates that the value of a land use is not only linked to the availability of an ES, but also to its relative importance to society. The relative importance of ES assessed might vary for different social groups, and as shown by the sensitivity analysis, this can change the ranking of intermediate MCDA land use options. Our approach produces robust results (see sensitivity analysis, Section 3) that allow for a meaningful discussion of the impacts on ES trade-offs of different land management strategies through a simplified representation of the stakeholders' preferences on the importance of the different criteria (see Section 2.2.3).

4.1. Land management strategies and policy drivers: Impacts on ES trade-offs

Livestock production is the major land use, partly due to the strong policy support (TGLP, 1975; NPAD, 1991) and subsidy schemes granted to the livestock sector (e.g. Services to Livestock Owners in Communal Areas (SLOCA), 2002, Livestock Water Development Programme (LWDP), 2002 and the Livestock Management and Infrastructure Development Programme (LIMID), 2007). National policies have promoted fencing and land privatisation for livestock production, assuming that private ranches would adopt more sustainable and profitable land management practices through rotational grazing and reduced stocking levels. The literature suggests that per animal productivity gains on fenced ranches are only slightly better than those on communal grazing areas (Hubbard, 1982); our MCDA

Table 3
Criteria weighting based on the rating technique with inputs from policy stakeholders.

Criteria	Ground water	Food[a]	Plant & livestock diversity	Food (wild)	Fuel	Constr. material[b]	Climate reg.[c]	Recreation	Spiritual[d]	Total
Mean weight (normalised)	0.18	0.17	0.15	0.12	0.11	0.10	0.08	0.06	0.03	1.0
Mean weight (non-normalised)	7.6	7.0	6.2	4.9	4.4	4.1	3.3	2.6	1.4	-
Standard deviation	1.2	1.8	1.3	1.5	1.6	1.4	1.9	1.8	1.8	-

Abbreviations

[a] commercial.
[b] construction material.
[c] climate regulation.
[d] cultural/spiritual benefits.

Table 4
Final scoring of the MCDA (scale 0–100) (weighted values, representing single land use options' scores multiplied by normalised criterion weight, in brackets).

Criterion	Indicator / ES category	Communal livestock grazing	Private cattle ranches	Private game ranches	WMAs
	Provisioning				
Food (commercial)	Net profit of meat production	73 (12)	78 (13)	50 (9)	68 (12)
	Stocking level	98 (17)	96 (16)	99 (17)	20 (3)
Mean		86 (15)	*87* (15)	*75* (13)	*44* (7)
Food (wild)	Gathering of veld products	75 (9)	25 (3)	25 (3)	50 (6)
	Subsistence hunting	75 (9)	0 (0)	0 (0)	75 (9)
Mean		75 (9)	*13* (2)	*13* (2)	*63* (8)
Fuel	Firewood collection	100 (11)	50 (6)	50 (6)	75 (8)
Construction material	Collection of thatching grass and poles for fencing	100 (10)	50 (5)	25 (3)	75 (8)
Groundwater	Value of water extracted	49 (9)	57 (10)	9 (2)	0 (0)
Plant & livestock diversity	Species and genetic diversity between forage species	25 (4)	50 (8)	75 (11)	100 (15)
	Genetic diversity between livestock breeds	25 (4)	75 (11)	0 (0)	25 (4)
Mean		25 (4)	*63* (9)	*38* (6)	*63* (9)
	Regulating				
Climate regulation	Value of carbon sequestration	68 (5)	68 (5)	52 (4)	12 (1)
	Cultural				
Recreation	Revenues from CBNRM trophy hunting and photographic safari	0 (0)	0 (0)	0 (0)	44 (3)
	Ecotourism potential	25 (2)	0 (0)	75 (5)	100 (6)
	Wild animals diversity	50 (3)	0 (0)	100 (6)	100 (6)
Mean		*25* (2)	*0* (0)	*58* (4)	*81* (5)
Cultural/ Spiritual inspiration	Presence of landscape features or species with spiritual value	100 (3)	0 (0)	50 (2)	100 (3)
TOTAL (weighted)		(67)	(52)	(39)	(49)

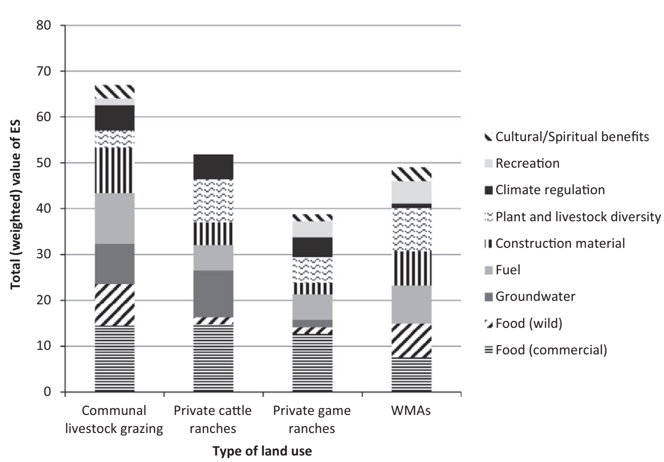


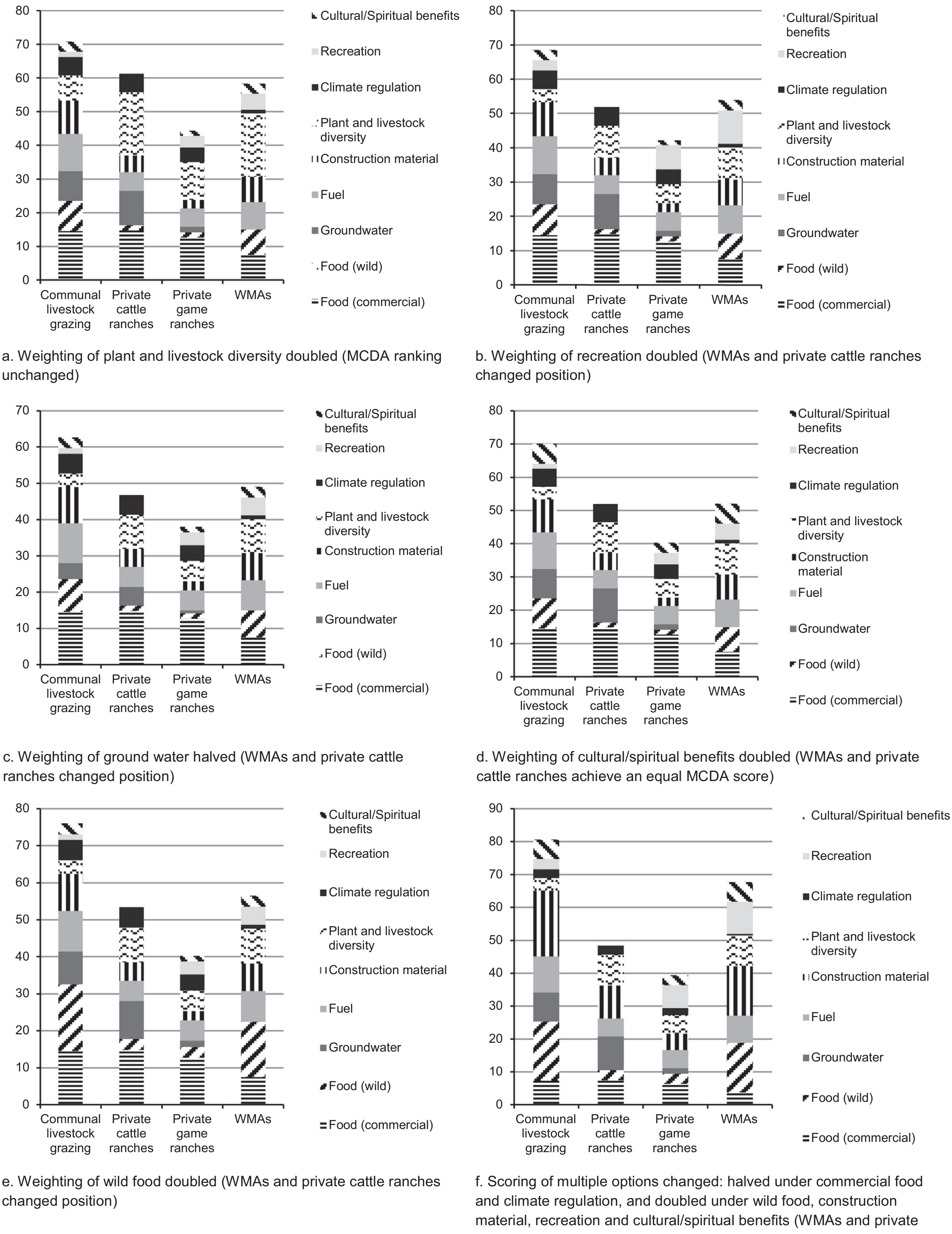
Fig. 2. Weighted performance of ecosystem service delivery under four alternative land uses in Kgalagadi District, southern Botswana, as assessed through the MCDA.

findings support this assertion (Table 2).

Commercial food production is a complementary ES to plant and livestock diversity (Mace et al., 2012). Diversity of forage species (Scherf et al., 2008) and livestock breeds (Notter, 1999) is vital for the nutritional status of cattle and to ensure their resilience, particularly during drought. The highest MCDA scores under the plant and livestock diversity criterion were achieved by private cattle ranches and WMAs as opposed to private game ranches and communal grazing areas. In the WMAs, limited degradation is found and nutritious forage species are preserved (Dougill et al., 2014). Private cattle ranches support SLM by implementing management strategies that aim to conserve grazing resources: "*Since we increased the resting period across paddocks to 90 days, the land condition has drastically improved and we have plenty of grass…new perennial grasses are growing such as Brachiaria nigropedata, Digitaria eriantha and Schmidtia pappophoroides*", (interview data, private cattle ranch, Werda, 2013). Despite these practices, ecological assessments show that privately-owned cattle ranches are just as heavily bush-encroached as communal grazing areas (Dougill et al., 2014).

SLM practices are supported on private ranches by sizeable investments to remove encroaching bushes to increase the grazing surface and enhance grass quality. Costs reach US $22.9/ha through selective hand spraying or US $36.6/ha through aerial spraying. Few farmers can afford such investments, despite encouraging results: "*Some people do not de-bush as they have no money. I am borrowing [the money used for treatment]… removing bushes pays back shortly*" (interview data, private cattle ranch, Werda, 2013). Practices such as bush removal can enhance provisioning ES through improved cattle production resulting from better forage, but this reduces the carbon stored in above-ground biomass. Sizeable investments also allow the management of mixed cattle breeds in private ranches. Mixed breeding is less common in communal areas due to a lack of fences: "*We are not able to keep specific breeds other than Tswana because our cattle are mixed with the ones owned by other farmers*" (interview data, communal farmer, Werda, 2013).

Freshwater is scarce and groundwater extracted through boreholes is often highly saline, so while Table 2 suggests groundwater extraction has the second highest economic value, the figures need to be interpreted cautiously. Extraction through borehole technology is expensive, and drilling investments translate into an economic loss when the water found is unusable, due to excessive salinity or because the quantity is small: "*In 2011 we drilled 5 boreholes, but 2 have too salty water and 3 are empty*" (interview data, communal farmer, Khawa, 2013). Interview data indicate that on average a single private cattle rancher uses 5 boreholes with a mean extraction capacity of 4,400 L/h while a communal farmer uses 2 boreholes (of which 1 commonly belongs to a syndicate) with a mean extraction capacity of 2,500 L/h. Pumping time ranges from 9 h/day to 24 h/day for both communal and private users, despite government recommendations that for adequate groundwater recharge, pumping should not exceed 8 h/day. Water extraction costs for livestock in communal areas have been subsidised through various programmes (e.g. LIMID, LWDP and SLOCA). Subsidies cover up to 60% of the borehole drilling costs (GoB, 2013), allowing a positive MCDA score for this land use.



a. Weighting of plant and livestock diversity doubled (MCDA ranking unchanged)

b. Weighting of recreation doubled (WMAs and private cattle ranches changed position)

c. Weighting of ground water halved (WMAs and private cattle ranches changed position)

d. Weighting of cultural/spiritual benefits doubled (WMAs and private cattle ranches achieve an equal MCDA score)

e. Weighting of wild food doubled (WMAs and private cattle ranches changed position)

f. Scoring of multiple options changed: halved under commercial food and climate regulation, and doubled under wild food, construction material, recreation and cultural/spiritual benefits (WMAs and private cattle ranches changed position)

Fig. 3. Sensitivity analysis of the MCDA ranking of four land uses in Kgalagadi District, southern Botswana, performed by applying varied MCDA scoring and weighting (X Axis 'Type of land use', Y Axis 'Total (weighted) value of ES').

Important trade-offs between commercial food production (including groundwater extraction) and conservation of forage species diversity are observed in the MCDA: a high score for the former is usually associated with a lower score for the latter. Policy-led expansion of boreholes across semi-arid communal rangelands has concentrated cattle around water points and moved away from multi-species production systems and viable CBNRM projects. Fencing for commercial production and the effective private status of individually owned (or syndicate owned) cattleposts, has greatly reduced the amount of communal grazing land (Perkins, 1996). Ecological assessments indicate this produces a noticeable retreat of grass cover as well as bush encroachment up to at least 5 km from water points in communal grazing areas (Dougill et al., 2014).

Apart from livestock production, communal and WMA land uses are important sources of veld products. They provide supplementary (wild) food (and water), particularly in the dry season or during drought, and can also be used as medicines (e.g. *Hoodia gordonii* is used as an appetite suppressant and Devil's Claw (*Harpagophytum procumbens*) is an analgesic, sedative and anti-inflammatory) with commercial value. Trade-offs between cattle farming and veld products are observed in the weighted MCDA scores. The economic value and availability of veld products have declined with the expansion of borehole drilling. Consequently, these products are found increasingly further from communal settlements (Perkins et al., 2002). Villagers' willingness to invest time in veld product collection is limited by the lack of a formal market, hampering generation of financial returns: "*We do not harvest for sale because it is very difficult to sell these products…we only consume them in the household*" (interview data, communal farmer, Khawa, 2013). Similar trade-offs are observed between policy-driven cattle production and use of construction material (thatching grass and poles for fencing) and fuel (firewood). These two ES rank higher under communal grazing and in WMAs, showing their importance in the management strategies adopted under these land uses. The supply of these ES is threatened by degradation and privatisation, as with veld products.

Subsistence hunting plays a significant role in WMAs and the neighbouring communal grazing areas, contributing to the highest values achieved by these land uses under the criterion 'wild food production'. Hunting is regulated by licensing through the Department of Wildlife and National Parks (DWNP). Interviews indicate that strict government control (including a hunting ban applied since January 2014) discourages hunting: "*There are too many rules that constrain hunting*" (interview data, communal farmer, Khawa, 2013).

CBNRM approaches have been developed through the Wildlife Conservation Policy of 1986 since the 1990 s and a CBNRM Policy was adopted in 2007. CBNRM charges local communities adjacent to WMAs with managing wildlife so that resource conservation and financial returns can be simultaneously promoted. Exclusive rights were granted over a wildlife quota. Communities could decide whether to hunt the quota for subsistence use or sell the quota rights to a private operator. CBNRM trophy hunting and photographic safaris have generated tangible benefits to the WMA community of Khawa. Our analysis reveals that these activities generate up to US $31,000 annually: "*Hunting is our only source of revenue. It allows us to sustain our livelihoods*" (interview data, communal farmer, Khawa, 2013). CBNRM approaches offer additional opportunities to generate economic benefits through ecotourism, where tourists are attracted by wildlife diversity and cultural experiences (e.g. guided visits and 4×4 driving).

CBNRM and natural resource use diversification remain constrained by policy and market incentives in the livestock sector. Declining wildlife numbers and diversity are caused by the expansion of livestock production and exacerbated by the promotion of fencing which, together with veterinary cordon fences, have blocked wildlife migration routes (Perkins, 1996). Policy incentives within the livestock sector, alongside recent decisions on hunting, contrast with the WMAs' wildlife conservation objective, limiting the economic viability of CBNRM under this land use: "*Wildlife numbers are declining. The government took key animals-lions and leopards-out of the hunting quota for conservation purposes. Since then, the safari hunting business has not anymore been profitable, neither for the private operators or the community*" (interview data, private safari operator, Werda, 2013).

The hunting ban and climatic constraints constrain CBNRM development. Low rainfall and high inter-annual variability (Mogotsi et al., 2013) exacerbate degradation observed as a result of suboptimal land management strategies: "*The area is vulnerable to drought. When it rains the veld is fine even if we are overgrazed, but during droughts many of our cattle die*" (interview data, communal farmer, Kokotsha, 2013). While climate change requires long-term approaches so that rangeland users can adapt, the MCDA findings show that current policy fails to provide strong support that guides livelihoods away from livestock production into alternative activities.

In addition to the provisioning and cultural services, the Kalahari provides other values through climate regulation. Whether C sequestration can be profitable is questionable, due to low global prices, uncertainty over markets and standards, and poorly developed methodologies, particularly for monitoring, reporting and verification (Stringer et al., 2012). Care needs to be taken that increased woody biomass resulting from land degradation is not encouraged through carbon credit schemes. Other monetary approaches could be used to extract economic benefits from C sequestration and biodiversity enhancement, e.g. through Payments for Ecosystem Services (PES) initiatives. However, little evidence of how these schemes could work is available for rangeland systems (Dougill et al., 2012). Potential markets also may not exist for all ES, e.g. the spiritual value of landscapes is difficult to be valued economically. Future policy interventions will need to be placed within the cultural context of ES values, so that they create incentives for land users to invest in rangeland resources, rather than misusing them (Ostrom et al., 1999).

4.2. Policy change for SLM

Southern Botswana's rangelands pose complex land management challenges when viewed through an ES lens, particularly when some ES are providing current economic benefits whereas others are yet to be tapped. Policy and economic mechanisms are needed so that the values assessed through MCDA can be translated into concrete economic benefits. These might include establishing a functioning market for ES that can generate immediate benefits through local commercialisation (i.e. wild food, construction material and fuel). However, our MCDA indicates that policy measures should not only focus market establishment, but also on promoting management practices that do not reduce access to the broader range of ES.

Declining opportunities for hunting and gathering are linked to reduced wildlife numbers and plant diversity losses resulting from intensive cattle rearing. This, together with limited capability to develop tourism and CBNRM activities, exacerbates poverty for rangeland users and results in higher dependency on government support and drought relief programmes. Well- intentioned poverty alleviation schemes that provided livestock to the poorest in society have increased stocking rates (and degradation) around communal (village) water points, but reduced the biodiversity value of the system.

Key to maintaining wild animal biomass in the south-western Kalahari is to maintain mobility over large areas, with its conservation linked to the development of wildlife-based economic activities such as tourism. Policies that support borehole drilling and fencing conflict with those needs and drought relief interventions address only short-term sector-specific needs. They fail to develop multi-species production systems and to create longer term drought-resistant socio-economic structures (Jacques, 1995). There is an urgent need to promote alternative land management strategies that improve SLM and the community welfare through economic and livelihood diversification. To achieve this requires assessment of how different policies and incentives interact and conflict, such that a more enabling policy context can be developed by promoting synergies. Successful outcomes (both socio-economic and environmental) depend not only on the type of land use promoted by policy, but also on the range of management strategies adopted under each land use, and the interactions between them.

5. Conclusions and ways forward for SLM

This paper applied MCDA to Kalahari rangelands of Botswana's southern Kgalagadi District to assess the linkages between rangeland land uses and the provision of ES. The study provides an empirical contribution to our understanding of which land uses and land management strategies are best placed to generate the widest range of monetary and non-monetary values from specific ES. While private land use enables higher incomes that can be invested in SLM practices, our findings suggest that communal grazing was identified as the most appropriate land use option for ES provision, achieving the highest MCDA score.

Significant government support to the cattle sector through borehole technology for groundwater extraction and through fencing has increased cattle populations and degradation around water points. Veld products, construction material and fuelwood remain undervalued from an economic perspective due to the lack of markets. Creation of a market with commercial potential is needed so that the provisioning values of these ES translate into wider economic benefits to society. However, perverse incentives that encourage overharvesting must be avoided when the commercial market is created.

Livestock production and wildlife areas could be more clearly separated by limiting borehole development within communal grazing land use in areas in proximity to WMAs. This would increase livelihood diversification opportunities for the poorest households by increasing the opportunities derived from provisioning ES, and potentially rewarding cultural ES. Whether such diversification could include revenues from C trading remains unclear and requires further investigation.

By integrating monetary with non-monetary valuation techniques, MCDA provides a mechanism for identifying the values of stakeholders from a range of policy sectors, which in turn support wider dryland populations who depend on ES. Policies that fail to take a holistic approach to valuing such services risk inadvertently exacerbating land degradation, resulting in unforeseen social and economic costs. In promoting SLM practices, future policies should go beyond the profitability of commercial food production and consider the broader livelihood impacts (the social distribution of wealth and diversification), and the ecological implications of all the ES analysed, including non-marketed provisioning services and cultural values. Such an approach better recognises that livelihoods are not just about income generation but also are supported by other social, cultural, environmental and physical assets.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2015.12.005.

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