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Assessing rangeland condition in the Kalahari Duneveld through local ecological knowledge of livestock farmers and remotely sensed data

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ABSTRACT

Monitoring of land degradation in remote rangelands, such as the Kalahari Duneveld, presents significant logistical challenges because of the need for systematic measurements of rangeland condition over time and space. The distinct vegetation dynamics and manifestation of degradation on dunes and interdunes in the Kalahari Duneveld, and their edaphic characteristics augment the difficulty with rangeland assessment. This study examined the effectiveness of using the local ecological knowledge (LEK) of livestock farmers in Mier and remotely sensed data to assess rangeland condition relative to field-measured vegetation and ground cover with step-point walking transects. We used Landsat-7 ETM+ imagery to calculate the Normalized Differential Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and tasseled cap greenness to characterize vegetation cover. The multivariate analysis of variance and analysis of variance showed that the farmers' assessment of rangeland condition explained the significant difference in the field-measured grass, shrub and bare ground cover. NDVI, SAVI and tasseled cap greenness all correlated poorly to the field-measured vegetation cover because of the excess spectral noise from the high iron oxide content in the soil. The farmers' LEK has potential to contribute toward monitoring of remote Kalahari Duneveld.

1. Introduction

The United Nations Convention to Combat Desertification (UNCCD) is the international agreement established to address the global environmental problem of desertification, or land degradation in drylands. Land degradation refers to a persistent reduction or loss in the provision of all services that land otherwise provides (Lal et al., 2012). Drylands are arid, semi-arid and dry sub-humid areas. Member nations of the UNCCD pledged to improve the condition of affected areas as one of the strategic objectives and agreed on provisional impact indicators to measure their progress toward this goal in the 10-Year Strategy (2008–2018) of the Convention (UNCCD, 2009). To measure progress requires systematic assessment of total area affected by desertification and land condition over time. The remoteness and large spatial extent of some rangelands make such monitoring very difficult and costly (Sommer et al., 2011).

Local ecological knowledge (LEK) and remotely sensing observations have advantages that can potentially address the difficulty and expense in monitoring remote and extensive rangelands. We define LEK as knowledge that is integrally linked with the activities of people, and produced in dynamic interactions among humans and between humans and nature (Agrawal, 1995). Local resource users can contribute with their knowledge and experiences gained from frequent interaction with the target natural resources, which are sometimes difficult to access for researchers (e.g., Danielsen et al., 2009; Fernandez-Gimenez et al., 2006). For example, Zambian fishermen in Bangweulu Swamps could access hard to reach locations and collected large quantities of reliable fish length-frequency data inexpensively (Ticheler et al., 1998). Remotely sensed earth observations such as the Landsat data series have the strengths of extensive spatial and temporal coverage, enabling researchers to assess large landscape and monitor for changes over a

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long temporal scale (e.g., Dube and Pickup, 2001; Pickup and Chewings, 1994).

The Landsat data series, begun in 1972, is the longest continuous record of changes in Earth's surface as captured by a satellite system. The Landsat satellites measure how light from the visible and infrared portions of the electromagnetic spectrum reflects off Earth's surfaces. Different surface materials reflect different wavelengths in the electromagnetic spectrum at different intensities. Reflectance data can be used to derive information about vegetation attributes, which are common metrics for rangeland condition because vegetation is integral to many terrestrial ecosystem functions and processes. Vegetation indices (e.g., Huete et al., 1997) and the tasseled cap transformation (Crist and Cicone, 1984; Kauth and Thomas, 1976) are two techniques that have been used to assess vegetation attributes based on reflectance data.

The theoretical basis for remote-sensing derived vegetation indices rests on the physical characteristics of photosynthetically active leaves and their typical spectral reflectance signatures. The chlorophyll pigments in the palisade mesophyll cells absorb blue and red light, so the prevalence of chlorophyll pigments in healthy foliage results in low blue and red reflectance. The internal scattering of the near-infrared (NIR) radiant energy at inter-cellular air spaces composing the spongy mesophyll cells in a green leaf explains the high NIR reflectance. Vegetation indices such as the Normalized Differential Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) are ratios of the difference between red and NIR reflectance, where higher ratios correspond to more vegetation (Huete, 1988; Tucker, 1979). SAVI expands on NDVI to incorporate a soil adjustment factor to remove much of the canopy background noise associated with soil brightness variations that make sparse vegetation analysis more difficult (Huete, 1988). The tasseled cap transformation is a linear transformation that compresses multiple spectral bands into three composite dimensions (i.e., brightness, greenness, and wetness) to optimize data viewing for vegetation studies (Crist and Cicone, 1984; Kauth and Thomas, 1976). The greenness dimension has been shown to correlate with percent canopy cover, leaf area index, and fresh biomass (Bauer et al., 1980).

Despite the advances made in remote sensing studies of vegetation, detecting degradation in arid and semi-arid areas remains challenging, because plant cover is generally sparse, and it is often difficult to distinguish naturally sparse vegetation patterns from degradation (Pickup and Chewings, 1994; Thompson et al., 2009). Specific soil characteristics including moisture, color and reflectivity can also influence the spectral signal received by the sensor (Kammerud, 1996). Our ability to leverage the advantages of remotely sensed data depends on our understanding of how sensitive and distinguishable spectral reflectance are to the complex combination of vegetation, soil, and landform influences relative to land degradation. Although research showed that integration of LEK with remotely sensed data improved the accuracy of environmental assessments (e.g., Pitt et al., 2012; Sirén and Brondizio, 2009), such an integrative approach is rare in rangeland assessment.

This study aimed at exploring the potential for integrating LEK with Landsat-7 ETM+ data to assess rangeland condition in the Kalahari Duneveld bioregion ("duneveld") in Mier, South Africa (Rutherford et al., 2006). Assessing vegetation condition in the remote duneveld is complicated by the physiographic pattern formed by two distinct components, dunes and interdunes, with different vegetation dynamics and manifestation for degradation. Interdunes are swales between two parallel dunes (Bullard et al. 1995). Previous vegetation studies that used NDVI to map vegetation and degradation had varying degrees of success and difficulty (Palmer and van Rooyen, 1998; van Rooyen, 2000). Palmer and van Rooyen (1998) found that bare ground on dunes and dense shrub in interdunes both had high NDVI values and NIR reflectance because of the mineral composition of the Kalahari red sand. van Rooyen (2000) later found that herbaceous cover correlated negatively with NDVI, which is contrary to conventional results. Both studies elucidated the challenging nature of assessing the rangeland condition in the duneveld through remote sensing, and presented an unexplored opportunity to examine the potential of integrating remote sensing with LEK. We conducted this study with the duneveld livestock farmers to answer the following questions:

- How does the farmers' assessment of veld condition relate to field-measured vegetation and ground cover?
- How do the vegetation metrics NDVI, SAVI, and tasseled cap greenness calculated from remotely sensed images relate to the field-measured vegetation and ground cover?
- How does the farmers' assessment of veld condition relate to NDVI, SAVI, and the tasseled cap greenness?

Veld is a common term for grasslands, savannas and semi-arid shrublands in South Africa, and veld condition is generally understood as being synonymous with vegetation condition.

2. Material and methods

2.1. Study area

The study area comprises the Kalahari Duneveld, located in the Mier municipality of the Northern Cape province in South Africa, extending from 26° to 27° 40′ South, and 20°–21° East (Fig. 1). Its elevation ranges from 900 to 1200 m a.s.l. (van Rooyen, 2000). Mier is in the savanna biome (Rutherford et al. 2006). It has a mean annual precipitation of 197 mm and a 54% coefficient of variation, based on the climate data from 1969 to 2012 collected in five local weather stations showed in Fig. 1 (Fig. 2). Seventy percent of the rain falls during the summer months (January to April).

The physiography of the duneveld is characterized by stable, relic northwest-to-southeast trending parallel linear sand dunes, with an average height of 2–20 m and an average wavelength (i.e., distance from dune crest to crest) of 136–225 m (Bhattachan et al., 2012; Bullard et al., 1995). The characteristic red color in the relatively infertile sandy soils is attributed to the dominance of iron oxide coated quartz grains in the soil composition (van Rooyen, 1984). The soils on the dune crests have coarse and loose sands, while the interdune soils are sometimes associated with pink to white compact sands due to a high calcrete content (van Rooyen, 2000).

These stable, relic dunes are covered with vegetation classified as Gordonia duneveld (71%), Auob duneveld (27%), and Gordonia plains shrubland (2%) (Rutherford et al., 2006) (Fig. 1). Gordonia duneveld is an open shrubland with ridges of grassland dominated by dune grass (Poaceae *Stipagrostis amabilis* (Schweick.) De Winter) on the dune crests, false camel thorn (Leguminosae *Acacia haematoxylon* Willd.) on the dune slopes, camel thorn (Leguminosae *Acacia erioloba* E.Mey.) on lower slopes, and three thorn (Bignoniaceae *Rhigozum trichotomum* Burch.) in interdunes (Rutherford et al., 2006). Auob duneveld is open shrubland with a shrub layer dominated by *A. haematoxylon*, black thorn (Leguminosae *Acacia mellifera* Benth.) and *R. trichotomum*, and trees such as *A. erioloba* and shepherd tree (Capparaceae *Boscia albitrunca* Gilg & Gilg-Ben.) are widely scattered on a scanty grass layer (Rutherford et al., 2006). We excluded Gordonia plains shrubland, pans, outcrops, and dry riverbeds from the study area, because the vegetation dynamics and physiography in these areas are different from those

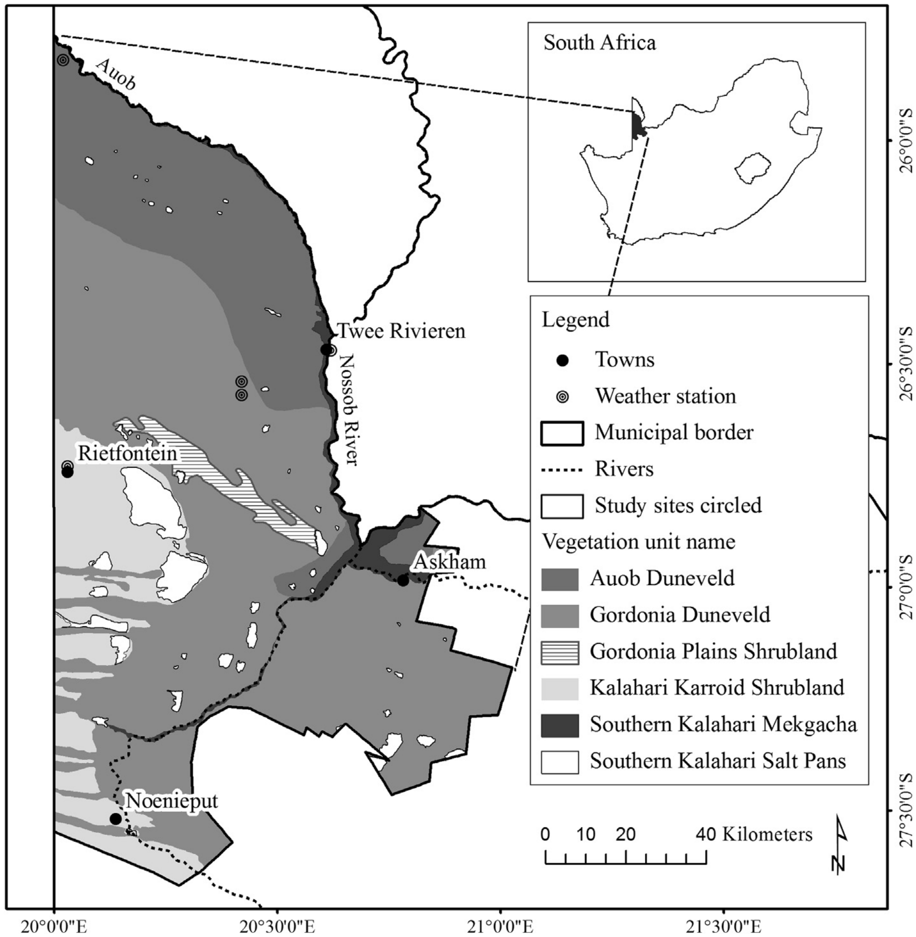

Fig. 1. Study sites as contained in the Auob and Gordonia Duneveld in the Mier municipality, Northern Cape, South Africa. The Kalahari Duneveld bioregion encompasses Auob Duneveld, Gordonia Duneveld and Gordonia Plains Shrubland (*sensu* Rutherford et al., 2006).

in the Auob and Gordonia Dunevelds (Rutherford et al., 2006; van Rooyen, 2001).

Vegetation degradation manifests differently on dunes and in interdunes. Degraded dunes are devoid of almost any vegetation, while degraded interdunes are covered with *R. trichotomum*, and sour grass (Poaceae *Schmidtia kalahariensis* Stent). These two species of shrub (*R. trichotomum*) and annual grass (*S. kalahariensis*) are indicators of the veld condition in the duneveld because they are strongly associated with degraded interdunes (Rutherford and Powrie, 2010; van Rooyen, 2000).

Mier was assessed to have severe vegetation degradation in the late 1990s (Hoffman and Ashwell, 2001). The cause for vegetation degradation in Mier was attributed to over-grazing by livestock and poor land management (van Rooyen, 2000). Such degradation has serious economic implications because the savanna vegetation is the most important source of forage for extensive livestock farming (mostly a mixture of sheep, goats and cattle) and game ranching, which are two dominant land uses in Mier (van Rooyen, 2000). Vegetation cover is also the most important factor determining dune mobility (Rutherford and Powrie, 2010).

2.2. Participant recruitment and photo elicitation

Thirteen participants were recruited through a chained-referral, a purposive and opportunistic sampling method (Bernard, 2006) in September 2010 as part of an international research project that aimed at engaging local stakeholders to evaluate their land management (Bautista and Orr, 2011). The participants were predominantly older and experienced semi-commercial farmers raising a mixture of sheep, goats and cattle on their private farms which were between 1721 ha and 3608 ha in size (Table 1). The protocol for this research was approved by the Institutional Review Board for the Protection of Human Subjects of the University of Arizona (IRB project number: 10-0631-02).

The lead author conducted photo elicitation with 10 of the 13 participants individually through a native-speaker translator. Photo elicitation is a qualitative research method that gives participants the power to document their observations through the photographs that they produce and through subsequent elicitations about the meaning of the photographs (Collier 1957, 1967; Oliffe and Bottorff, 2007). We lent a digital camera (Canon A490) to each participant for one-half to three days, and asked them to photograph veld condition and land management. We revisited the participants individually to load the photographs taken onto a laptop computer, and let each participant choose the photographs to guide a discussion (60–90 min) about what was depicted in the photographs. The elicitations were audio recorded, and later translated and summarized in English.

2.3. Participatory mapping and field evaluation

The 13 participants were revisited individually in September 2012. We prepared color printout maps of their farms that were made from the most recent Google Earth images, with scale, north-

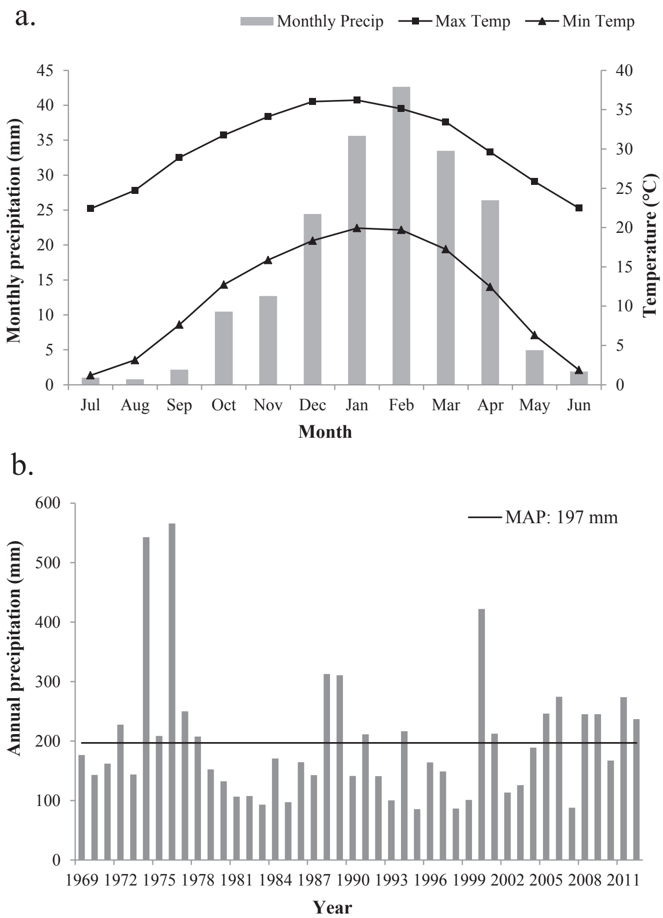

Fig. 2. (a) Mean monthly precipitation, maximum and minimum temperature based on the record from 1969 to 2012. (b) Annual precipitation, total from July to June, from 1969 to 2012.

arrow and landmark such as farm border, road and homestead drawn to help orient the participants. Each participant was asked to delineate areas on the maps that he/she considered being in good, fair and poor veld condition (30–45 min).

Table 1
Participant demographics and attributes about their farms and land management.

Participant	Age class	Gender	Farm size (ha)	Duneveld on farm (%)[b]	Year moved to farm	Livestock type[c]
1	50's	Male	2341	100	1984	Mixed
2	40's	Female[a]	2488	100	1989	Mixed
3	60+	Couple	2221	100	1986	Cattle
4	60+	Male	3012	100	1971	Mixed
5	60+	Male	3290	100	1977	Mixed
6	60+	Male	2602	100	1984	Sheep
7	30's	Male	2257	100	1992/1993	Mixed
8	40's	Male	2756	100	1992	Mixed
9	50's	Male	1758	63	1985	Mixed
10	50's	Male	3608	64	1978	Mixed
11	40's	Male	1878	79	1971	Sheep
12	30's	Male[a]	21,551	85	1988	Mixed
13	50's	Female	1721	88	1980s	Mixed

[a] These were couple participants but only one spouse actively participated. The gender of the active participant was indicated in each case.
[b] In cases where the percentages of Duneveld on farms do not equal to 100, the remaining percentages of vegetation type on farms are Gordonia Plains Shrubland, Kalahari Karroid Shrubland, Southern Kalahari Mekgacha and Southern Kalahari Salt Pans (classification per Rutherford et al., 2006).
[c] Mixed livestock type means a mixture of sheep, goats and cattle, as well as a small proportion of game animals in some cases.

Nine participants agreed to drive with us after the discussion to show us two to four areas with different veld conditions that they had indicated on the maps (60–120 min). Participants confirmed their assessments of the veld condition on dunes and in interdunes separately at each chosen location, where we conducted step-point transects of which the starting points were randomly selected. Where possible, we included one transect on a dune crest ("dune" hereafter) and one near the mid-line of an interdune at each location. For each step-point transect, the lead author walked 100 paces (~50 m) along an imaginary transect that pointed toward a prominent distant landmark. Additionally at every other step, the author lowered a sampling pin – guided by a pre-defined notch on her right boot – to the ground to record the first hit of vegetation or ground cover (Evans and Love, 1957). The first hits were recorded as one of the five vegetation and ground cover categories – grass, shrub, forb, litter and bare ground. Grass, shrub and forb were recorded as canopy cover, which is the vertical projection of the outermost perimeter of the natural spread of foliage of plants (Elzinga et al., 2008). Shrub included both shrubs and trees. Shrub density was visually estimated in a 50×2 m^2 belt transect that was visually drawn at each transect (Elzinga et al., 2008), and recorded as one of the six categories (unit = shrubs/ha): <500, <1000, <1500, <2000, <2500, and >2500. Eighty-six transects were sampled: 37 on dunes and 49 on interdunes.

2.4. Image processing

We obtained the 4 October 2012, 30-m resolution Landsat-7 ETM+ scenes (path 175, rows 78 and 79) from the U.S. Geological Survey (USGS) Earth Resources Observation Systems (EROS) Data Center because that image acquisition date was closest in time to when the field sampling was conducted. The downloaded scenes were Level 1T products so they had already been geometrically rectified and referenced to Universal Transverse Mercator (UTM) system (WGS84 ellipsoid zone 34S projection, and WGS84 datum). The calibrated digital number (DN) was converted to at-sensor spectral radiance [W/(m^2 sr μm)] using the formula defined by Chander et al. (2009). The at-sensor spectral radiance was converted to surface reflectance using a 6SV radiative transfer model (Vermote et al., 2006) by submitting the at-sensor spectral radiance to the L'Observatory de Physique du Globe website (http://6s.ltdri.org). We used the mid-latitude winter atmospheric profile, continental aerosol model and homogeneous ground reflectance type without directional effect as parameters for the radiative transfer model.

The downloaded Landsat-7 scenes had what is known as a "line drop" problem (lines with missing data) due to a malfunction of the Scan Line Corrector (SLC) on the sensor; the malfunction has occurred in Landsat-7 scenes captured since May 2003. A USGS assessment reported that the post-anomaly data maintain expected radiometric and geometric fidelity (USGS, 2003). We used only pixels with data for all six bands in our remote-sensing analysis so the sample size of the step-point transects for the remote-sensing analysis was reduced to 74 transects (31 dune and 43 interdune).

Two vector files were acquired from the VEGMAP project and the Chief Directorate: Surveys and Mapping (CDSM) to delineate the farm borders and Gordonia and Auob Duneveld.

2.5. Qualitative and quantitative data analysis

Qualitative analysis software, NVivo 10 (QSR International Pty Ltd, Australia), was used to code the photo elicitation summaries into three themes: good, fair and poor veld condition. The three themes encompassed any content pertaining to participants' observations and perception of good, intermediate and degraded veld condition, respectively. Each participant determines his/her own criteria to assess the veld condition. The qualitative analysis is used to help us understand what they perceived as good, fair and poor veld condition.

The two preprocessed Landsat-7 scenes were mosaicked into one ("processed image"). Tasseled cap (TC) transformation was performed on the processed image (Crist and Cicone, 1984; Crist and Kauth, 1986; Kauth and Thomas, 1976), and three raster files (i.e., brightness [band 1], greenness [band 2], and wetness [band 3]) were created with ERDAS IMAGINE 11 (Intergraph Corporation, Georgia). NDVI and SAVI were calculated per-pixel as follows (Huete, 1988; Tucker, 1979) in ERDAS IMAGINE 11:

$$\mathrm{NDVI} = \rho\mathrm{nir} - \rho\mathrm{red}/\rho\mathrm{nir} + \rho\mathrm{red} \quad (1)$$

where:

ρnir = Reflectance values for near infrared (band 4)
ρred = Reflectance values for red (band 3)

$$\mathrm{SAVI} = [(1 + L) \times (\rho\mathrm{nir} - \rho\mathrm{red})]/(\rho\mathrm{nir} + \rho\mathrm{red} + L) \quad (2)$$

where:

$L = 0.5$.

ArcMap 10 (Esri, California) was used to extract the NDVI, SAVI, TC brightness, greenness, and wetness values in the pixels containing the step-point transects, which were digitized on the screen using the track file record by the GPS (Garmin GPSMap 60). Average NDVI, SAVI, TC brightness, greenness, and wetness values were calculated for each transect from all the pixels containing that transect, weighted by the relative length in each pixel.

Grass, shrub, forb, litter, and bare ground cover were calculated as percentages that add to 100% for each transect by dividing the number of hits for each cover type by 50, which was the number of hits per transect. Participants' assessment of the veld condition for each transect was recorded as an ordinal variable, "condition", of three levels: good, fair, and poor.

A multivariate analysis of variance (MANOVA) with Wilks' Lambda distribution was performed with the grass, shrub, forb, litter, and bare ground cover as dependent variables, and condition as an explanatory variable for dune and interdune transects separately on SPSS Statistics (IMB Corporation, New York). This is to test if the five mean cover values were significantly different under different condition levels. Analyses of variance (ANOVA) was done subsequently to test for significant difference in the mean for each cover type as explained by condition. ANOVA on NDVI, SAVI, and TC greenness were done individually with condition as the explanatory variable to test for significant differences in the three metrics under different condition levels. Tukey's honestly significant difference (HSD) tests was done post hoc to identify the specific pair of condition levels that had significantly different cover, NDVI, SAVI, and TC greenness. We checked that the assumptions of (M)ANOVA had been met.

We further created a new variable, "condition-interdune", to reclassify all the poor-condition interdune transects into poor-shrubby (shrubs predominated) and poor-bare (litter and bare ground predominated) based on the estimated shrub density. Poor-condition interdunes with less than 500 shrubs/ha were reclassified as poor-bare and the other poor-condition interdunes as poor-shrubby. MANOVA and ANOVA were re-done with the same dependent variables against condition-interdune as the explanatory variable. Two outlier transects were excluded in these new analyses because the participant who assessed the veld condition of these two transects held opposite views regarding the relation between shrub cover and veld condition relative to the other participants. ANOVA was done on *R. trichotomum* and *S. kalahariensis* canopy cover to test for significant difference in the canopy cover percentages for the different condition-interdune. Tukey's HSD tests were done post hoc to identify the specific pairs of condition-interdune levels that were significantly different.

Linear regression models were done to examine the correlation between "plant cover" (i.e., total canopy cover of grass, shrub and forb) and NDVI, SAVI, and TC greenness. To examine the potential utility of other spectral bands besides the two used in NDVI and SAVI, we ran linear regressions for all six bands individually against plant cover.

3. Results

3.1. Participants' perception and mapping of veld condition

Participants generally perceived an abundance of perennial grass or presence of large tufts as an indication of good veld condition (Fig. 3a). They explained the importance of having a lot of common dune grass (*S. amabilis*) on dunes because their extensive roots stabilize the dunes against wind erosion. Perennial grasses such as gha grass (Poaceae *Centropodia glauca* (Nees) Cope), tall bushman grass (Poaceae *Stipagrostis obtusa* Nees) and short bushman grass (Poaceae *Stipagrostis ciliata* (Desf.) De Winter) were perceived as desirable forage grass by most participants. Some participants also mentioned plant diversity as an indicator for good veld condition, noting the value of having a variety of grass, forb (e.g., Chenopodiaceae *Salsola* spp.) and shrub (e.g., *A. erioloba*, *B. albitrunca* and *A. haematoxylon*) species on their farms. Diversity also encompassed the presence of a mixture of plant species preferred by different types of livestock (i.e., browsers and grazers), and/or available during different seasons (wet and dry season species). The benefits of diversity are valuable to the participants, because most of them have a mixture of grazer and browser livestock, and the participants mainly rely on the rangeland to minimize the amount of fodder that they have to buy during the dry season.

All but one participant perceived the thickening of *R. trichotomum* (a shrub) and an abundance of *S. kalahariensis* (an annual grass) as indicators for poor veld condition (Fig. 3d and b, respectively). Participants explained that *R. trichotomum* suppresses perennial grass so only bare ground and *S. kalahariensis* occupy the interstitial space. They further explained that this annual grass is not palatable to livestock when it is green because it is acidic, and that their livestock only graze on sour grass when it is very young or after it has senesced. The participant who perceived *S. kalahariensis* differently indicated that he has a lot of *R. trichotomum* throughout his farm so having *S. kalahariensis* between the encroaching shrub is better than bare ground, which would provide no forage at all. Two participants also reported *A. mellifera* encroachment on their farms. When participants photographed and spoke about poor veld condition on the dunes, they described bare dunes (Fig. 3c), which they explained to be prone to wind erosion.

The participants were less clear about the boundary between fair veld condition and the two contrasting condition categories: good and poor. Good to fair and fair to poor veld condition seemed to be a continuum with gradually less of the favorable attributes such as abundance of perennial grass, particularly palatable species, and more of unfavorable attributes such as increase in bare ground, *R. trichotomum* and *S. kalahariensis*.

All participants could show the general location of areas of different veld conditions on their farms during participatory

a. Good condition interdune. "...This photo shows good grazing veld due to the presence of a lot of gha-grass (*Centropodia glauca*)." Participant 1

b. Poor condition interdune. "This is how it should not look. It is only sour grass (*S. kalahariensis*). Here and there a perennial tuft. It is a poor area." Participant 11

c. Poor condition dune. "This photo is desert. Although it is disturbed, it has aesthetic value for tourists visiting the Kalahari." Participant 6

d. Poor condition interdune. "This photo just shows again that there is...only bare sand in the area where the three-thorn (*R. trichotomum*) are found." Participant 1

Fig. 3. Photographs taken by participants to illustrate different veld conditions on dunes and interdunes.

mapping, but they could not precisely show the spatial extent of these areas. The participants that have multiple water points and camps on their farms were more comfortable with drawing polygons on their maps to delineate the boundaries of different veld conditions. Some participants simply used points instead of polygons to draw on their maps because they could not be sure of the exact shape and size to draw the polygons. We did not incorporate their efforts to capture spatial extent because of the uncertainty they expressed and the lack of consistency in the degree of precision.

3.2. Participants' assessment vs. field measurements

Of the 86 step-point transects, 33 were assessed as good, 22 as fair, and 31 as poor condition by the participants. The measured vegetation and ground cover differed significantly among different conditions as perceived by the participants ($p < 0.000$ for dunes; $p < 0.001$ for interdunes). Grass, shrub and bare ground cover were significantly different on dunes of different conditions, while only grass and shrub cover were significantly different on good, fair and poor interdunes (Table 2). Grass cover explained the most variance among dunes and interdunes of different conditions (Partial Eta2 = 0.574 and 0.400, respectively) (Table 2). Good dunes had significantly more grass cover than fair and poor condition dunes (Fig. 4a), while both good and fair interdunes had significantly more grass cover than poor interdunes (Fig. 4b). Good and fair dunes had significantly less shrub cover and bare ground than poor dunes (Fig. 4a). Shrub cover was not discriminable in good and poor interdunes; both had significantly more shrub than fair interdune transects (Fig. 4b).

3.3. Poor-bare vs. poor-shrubby interdunes

When the poor-condition interdune transects were split into poor-bare and poor-shrubby and the two outlier transects were excluded, forb and litter cover were also significantly different ($p = 0.031$ and 0.020, respectively) in addition to grass and shrub

Table 2
ANOVA results for the vegetation cover in dunes and interdunes in relation to the veld condition classification.

Cover	Land form	Type III sum of squares	df	Mean square	*F*	*p*	Partial Eta squared	Observed power
Grass	Dune	0.546	2	0.273	22.90	0.000	0.574	1.000
Shrub	Dune	0.040	2	0.020	3.82	0.032	0.184	0.655
Forb	Dune	0.000	2	0.000	0.10	0.901	0.006	0.065
Litter	Dune	0.038	2	0.019	1.30	0.286	0.071	0.262
Bare	Dune	0.456	2	0.228	8.13	0.001	0.323	0.942
Grass	Interdune	0.713	2	0.357	15.33	0.000	0.400	0.999
Shrub	Interdune	0.079	2	0.040	3.35	0.044	0.127	0.604
Forb	Interdune	0.004	2	0.002	0.41	0.669	0.017	0.112
Litter	Interdune	0.199	2	0.100	2.76	0.073	0.107	0.519
Bare	Interdune	0.022	2	0.011	0.44	0.650	0.190	0.117

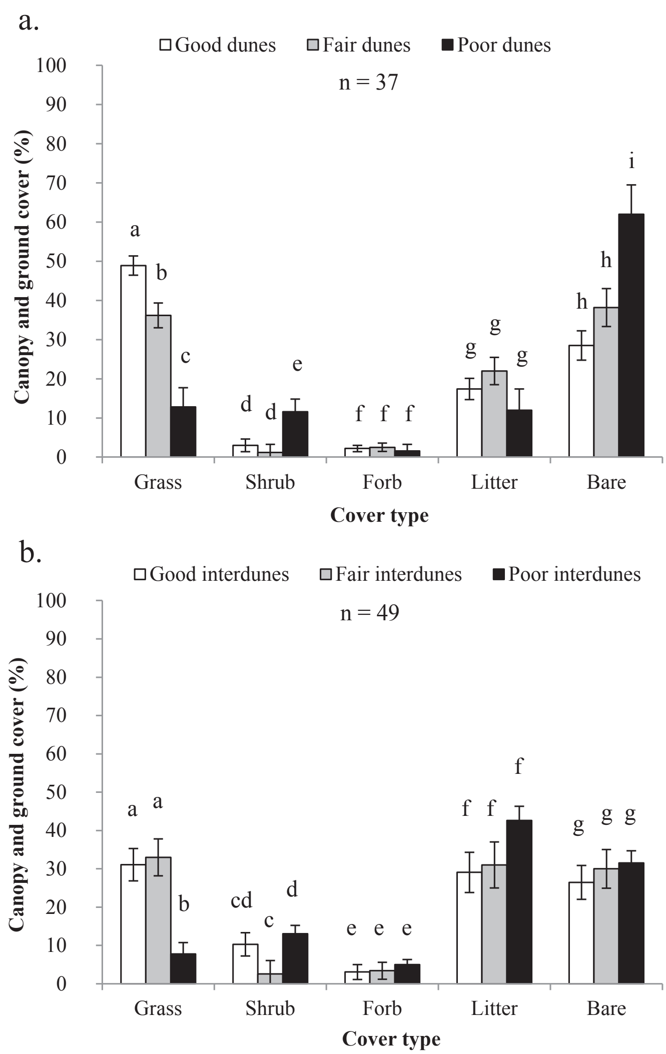

Fig. 4. (a) Mean canopy cover for grass, shrub and forb, and mean litter and bare ground cover in good-, fair- and bad-condition dunes. (b) Mean canopy cover for grass, shrub and forb, and mean litter and bare ground cover in good-, fair- and bad-condition interdunes. The error bars are standard error. The letters denote means that are significantly different at $p < 0.05$ with post hoc Tukey's HSD tests.

cover (Table 3). Poor-shrubby interdunes had significantly more shrubs, while poor-bare interdunes had a significantly greater cover of forbs than all other conditions (Fig. 5). Poor-bare interdunes also had more litter than good interdunes (Fig. 5).

3.4. Remotely-sensed data vs. field measurements

NDVI, SAVI, and TC greenness correlated very poorly with field-measured plant cover (i.e., total canopy of grass, shrub and forb; $R^2 = 0.201$, 0.045 and 0.246, respectively) (Fig. 6c), and the best-fit linear regression lines had nearly zero slopes (Fig. 6c). SAVI had the worst performance, but it had the highest coefficient of determination when plotted against bare ground cover (Fig. 6d). In general, plant cover correlated poorly with the green, red and NIR bands (Fig. 6a), which are most often associated with vegetation. Bare ground however was three to 14 times more correlated with these three bands than plant cover was, albeit the coefficients of determination were still low (Fig. 6a,b). Blue and shortwave infrared (SWIR) bands also correlated poorly with plant cover. The TC composites (i.e., TC brightness and TC wetness) that are normally

Table 3
ANOVA results for the vegetation cover in interdunes with poor-bare and poor-shrubby condition as separate categories in relation to the veld condition classification.

Cover	Type III sum of squares	df	Mean square	*F*	*p*	Partial Eta squared	Observed power
Grass	0.867	3	0.289	14.78	0.000	0.508	1.000
Shrub	0.255	3	0.085	13.94	0.000	0.493	1.000
Forb	0.041	3	0.014	3.25	0.031	0.185	0.705
Litter	0.355	3	0.118	3.63	0.020	0.202	0.758
Bare	0.004	3	0.001	0.06	0.983	0.004	0.059

associated with soils also correlated poorly with bare ground cover (Fig. 6d).

3.5. Participants' assessment vs. remotely-sensed data

Good, fair and poor dunes, as assessed by the participants, did not have significantly different NDVI, SAVI, and TC greenness values, while different condition interdunes had significantly different TC greenness and NDVI values (Table 4).

4. Discussion

There was a considerable overlap between participants' perception of veld condition and scientific knowledge about degradation and vegetation in the Kalahari. For example, many scientists view shrub encroachment as degradation because it reduces forage production for livestock (e.g., Moleele and Chanda, 2003; Perkins and Thomas, 1993). This perspective was shared by all but one participant. The four perennial grass species named by the participants as desirable and indicators for good veld are classified either as highly or medium palatable in a reference book for grass identification in southern Africa (van Oudtshoorn, 2002). This finding concurred with another study's results, which also showed that farmers' judgment of grass value corresponded well with the scientific valuation for four of the seven species evaluated in Namibia (Klintenberg et al., 2007). Furthermore, participants' description of degraded dunes as bare and interdunes as

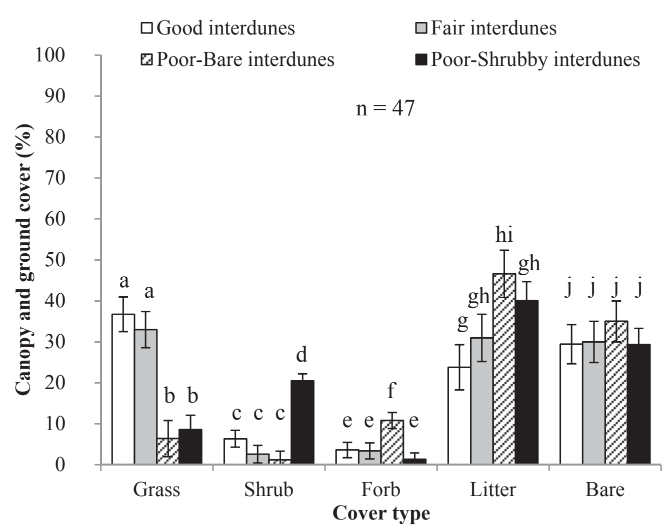

Fig. 5. Mean cover for grass, shrub and forb, and mean litter and bare ground cover in good-, fair-, poor-bare- and poor-shrubby-condition interdunes. The error bars are standard error. The letters denote means that are significantly different at $p < 0.05$ with post hoc Tukey's HSD tests.

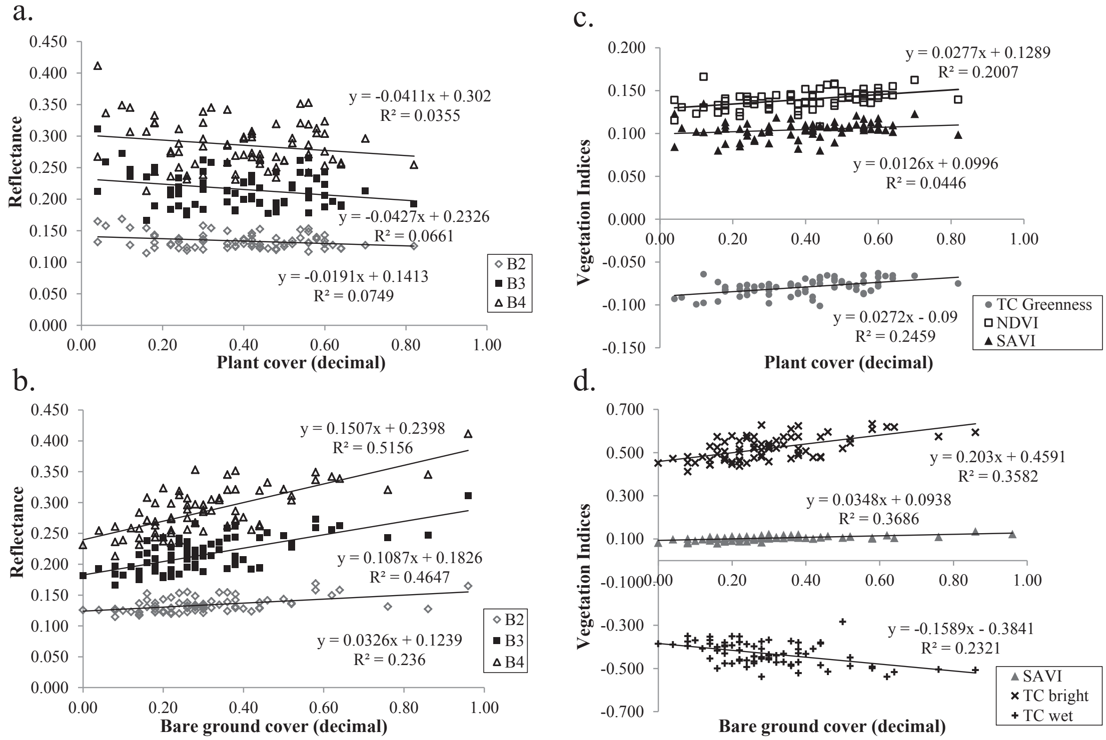

Fig. 6. (a) Linear regression of plant cover (= grass + shrub + forb) against band 2, 3 and 4 reflectances. (b) Linear regression of bare ground against band 2, 3 and 4 reflectances. (c) Linear regression of plant cover against TC greenness, NDVI and SAVI. (d) Linear regression of bare ground cover against TC greenness, NDVI and SAVI. The best-fitted lines, linear equations, and R^2 are included in each figure.

encroached by *R. trichotomum* overlapped with the description provided by scientific research on duneveld degradation (van Rooyen, 2000). Another study on the degradation indicators used by farmers in Botswana and Swaziland also noted a significant overlap between scientific and local knowledge (Stringer and Reed, 2007).

While LEK provided insight into the general location of good, fair and poor veld, the participatory mapping method that we used was not effective in capturing information about the spatial extent of these areas. The duneveld in Mier is an expansive rangeland of undulating dunes that are relatively uniform in height, and that are intersected by a sparse distribution of unpaved roads and homesteads. Limited prominent landmarks on the duneveld and the small scale of our printed maps might be why the farmers struggled to use polygons to delineate areas of different veld conditions. We also observed that the participants described their observations about the vegetation more readily when they accompanied us on the step-point transects than when drawing on the maps. Oudwater and Martin (2003) faced similar challenges with using participatory mapping to obtain local farmers' soil classification. The farmers were able to delineate only four categories on their soil map, but they were able to produce more detailed and precise classification in subsequent transect walks. They hypothesized that farmers' soil knowledge was linked to visual observations, which are readily accessible on transect walks.

The different veld conditions as assessed by the participants reflected distinct vegetation and ground covers that correspond well with scientists' descriptions. For example, dunes assessed as good condition by the participants had significantly more grass cover, and less shrub cover and bare ground. Grasses consisted of only perennial species because annual grasses such as *S. kalahariensis* had senesced and turned to litter at the time of the field sampling. This matches with the vegetation descriptions for Gordonia Duneveld (Rutherford et al., 2006) and for dune crest habitats (van Rooyen, 2001). Dunes assessed as poor-condition by the participants had a dominance of bare ground and significantly more shrub cover; this pattern of cover matched with van Rooyen's (2000) description for degraded dunes. Similarly, when poor-condition interdunes were separated into poor-bare and poor-shrubby, the vegetation cover pattern of less perennial grass and greater shrub cover in poor-shrubby interdunes matched with scientists' description for degraded interdunes in Duneveld (Rutherford and Powrie, 2010; van Rooyen, 2000).

Table 4
ANOVA results for NDVI, SAVI and tasseled cap greenness in relation to the veld condition classification.

Cover	Land form	Type III sum of squares	df	Mean square	*F*	*p*	Partial Eta squared	Observed power
NDVI	Dune	0.000	2	0.000	0.96	0.396	0.064	0.199
SAVI	Dune	0.000	2	0.000	0.68	0.513	0.047	0.154
TC Greenness	Dune	0.000	2	0.000	2.36	0.114	0.149	0.436
NDVI	Interdune	0.001	2	0.000	5.35	0.009	0.211	0.812
SAVI	Interdune	0.000	2	0.000	1.36	0.269	0.064	0.276
TC Greenness	Interdune	0.001	2	0.000	6.52	0.004	0.246	0.885

An NDVI, SAVI or TC greenness value would reveal less information about the vegetation cover than a veld condition category – good, fair or poor – assessed by the participants would. This because the three vegetation metrics calculated from the Landsat-7 images correlated very poorly with the field-measured plant cover, while participants' assessment of veld condition reflected distinct vegetation and ground covers. This corresponds with the expectation that on-site observations of local knowledgeable individuals will be more accurate than remotely sensed observations. We would also expect that the partial Eta square to be higher for the grass, shrub and bare ground cover (except for interdune transects) in the ANOVA because these three cover types were most mentioned in participants' description of the good and poor veld condition. This study is in agreement with other LEK research that found strong correlation between local land users' assessment and field-based measurements, including farmers' assessment of soil fertility and vegetation change (Karltun et al., 2013; Roba and Oba, 2008). Our results show that local participants such as the livestock farmers can contribute to rangeland assessment by distinguishing veld condition accurately over an extensive area relatively quickly based on their experience and observations gained from regular interaction with the environment. There are scientists who question the accuracy and precision of assessment made by local participants, and this is a valid concern. The accuracy and precision of environmental assessment based on LEK should be investigated case by case.

The participants' assessment also revealed an interesting nuance about poor-condition interdunes. Their assessment showed that poor interdunes could either be encroached by shrubs as in the poor-shrubby interdunes, or not as in the poor-bare interdunes. It seems that degraded interdunes can manifest as having more forb, litter, and bare ground cover in place of grass without shrub encroachment in a stable or transition state.

We had hypothesized that the measured plant cover and farmers' assessment of veld condition would correlate strongly with at least one of the three vegetation metrics calculated from the Landsat-7 processed image. Both field-measured plant cover and farmers' assessment correlated poorly with all three metrics. As a result, we expected mostly a lack of significant difference in TC greenness, NDVI and SAVI among the different veld conditions. As mentioned above, two prior remote sensing studies elucidated the issue of excessive background noise caused by the high iron oxide content in the Kalahari sand (Palmer and van Rooyen, 1998; van Rooyen, 2000). This is because iron rich soils, particularly those with sandy soil texture, tend to have high red and NIR reflectance (Richter et al., 2009). We found the spectral profiles of bare ground to be similar to those of well-vegetated areas; the profiles all showed high red and very high NIR reflectance. Since both NDVI and SAVI rely on the difference between the red and NIR reflectance to predict the amount of vegetation, they were unable to distinguish vegetation from the Kalahari sand. TC greenness did not perform well either because the transformation coefficients put the most weight on the NIR reflectance. Our results concurred with previous studies that found vegetation studies in semi-arid and arid environments using remotely sensed data alone to be difficult (Pickup and Chewings, 1994; van Rooyen, 2000).

Another major challenge in using remote sensing to assess veld condition in the duneveld is that degradation on dunes and in interdunes is reflected differently in terms of vegetation cover so more plant cover does not always equate good veld condition. For example, high shrub and litter cover in interdunes means encroachment by *R. trichotomum* and *S. kalahariensis*, which is perceived as degradation by the participants and many scientists (Kong, 2013; Palmer and van Rooyen, 1998; van Rooyen, 2000). It is therefore necessary to be able to distinguish the dunes and interdunes when assessing veld condition in the duneveld. The size of the two physiographic features has bearing on the spatial resolution requirement for remote sensing images because the minimum spatial resolution needs to be less than half the dimension of the smallest landscape feature to be captured. The dune wavelength (distance from the top of a dune to another) in Mier duneveld ranges from 90 m to 1050 m (Bullard et al., 1995). Assuming that dunes and interdunes have the same width and that dune wavelength is at the lower end of the range aforementioned, the minimum spatial resolution requirement would be 22.5 m. This is slightly finer than the 30 m resolution of Landsat-7 scenes so the spatial resolution of our data could be another reason contributing to the unsatisfactory results.

5. Conclusions

The LEK of the rural livestock farmers in Mier have much potential to contribute to the monitoring of land degradation in the duneveld because their assessment of the veld condition corresponded well with the field measurements and did much better than the three vegetation metrics determined from remotely sensed data. Despite the advances in remote sensing, there is still not an effective technique to evaluate vegetation in every type of ecosystems. This research suggests that enhancing the potential of remotely sensed data to assess the veld condition in the duneveld will require techniques that can distinguish the spectral profile of bare ground with high iron oxide from a grass-dominant or shrub-dominant vegetated area. Future studies of veld assessment in the duneveld may explore the use of textural measures from microwave to delineate smooth bare dunes vs. different textural roughness of vegetated surface.

While the UNCCD strategic plan encourages extensive public participation, local involvement in monitoring and evaluation of land degradation is still limited. Perhaps this is because national assessments of land degradation historically have mostly taken a top-down approach. If future monitoring and evaluation efforts are to be more inclusive of LEK, there is a need for a greater understanding of how assessments by local land users can be integrated with existing national assessments. Local participation in monitoring and evaluation may create a platform for developing more locally relevant management strategies to combat land degradation. The aspect of how monitoring information will be provided back to local communities should be included in the planning for such participation to enable the communities to benefit from their participation. In this research, the lead author shared the results with the translator for the participatory mapping because he is a well-respected farmer in Mier. More could have been done to involve the community in sharing the research results with better planning and more resource.

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