TREE COVER, TREE HEIGHT AND BARE SOIL COVER DIFFERENCES ALONG A LAND USE DEGRADATION GRADIENT IN SEMI-ARID SAVANNAS, SOUTH AFRICA

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ABSTRACT

High resolution airborne hyperspectral and discrete return LiDAR data were used to assess bare soil and tree cover differences along a land use transect consisting of state-owned, privately-owned conservation areas, and communal areas in South African savannas. The results show that tree cover is higher in conservation areas as compared to communal areas where local people use fuel wood for personal consumption. Low impact communal sites (limited use) tend to have higher tree cover than higher impacted communal sites. Generally communal areas have altered tree height distribution but in diverse way depending on the geology or the level of human utilization. Bare soil cover was generally found to be quite low (< 10%) in all different land uses, suggesting that the degradation level in communal areas might not be as high as generally perceived.

Index Term s— Kruger, tree cover, bare cover, LiDAR

1. INTRODUCTION

Land degradation is one of the most significant environmental problems in savannas of Southern Africa, affecting vegetation structure, cover, and patchiness and resulting in the loss of resources used by human populations and wildlife. The sustainability of these ecosystems is influenced by a complex combination of factors, including rainfall, land management (e.g. fire, herbivore density), soil properties, and topographic effects through slope redistribution of water and nutrients [1]. In South Africa, much of the degraded lands are believed to be located in former "homelands" or Bantustans [2]. These territories, inherited from resettlement policies during the apartheid era, are managed by a communal tenure system and are densely populated by poor rural communities. Communal rangelands are a crucial component of livelihoods of these populations by providing a variety of natural resources (fuel wood, forage for cattle herd, timber, medicinal plants) [3]. The extent to which the communal lands are degraded (both spatially and in term of severity) is unknown and subject to debate [4-6]. Very little data exist, especially in comparison to conserved areas assumed to be in much better condition. This is largely due to the lack of spatial ecosystem state data at the appropriate scale. Traditional remote sensing approaches are of limited use either because they are too coarse (e.g. Landsat TM) in comparison to the heterogeneity and small scale processes characterizing savannas and/or ineffective in assessing structural properties, notably the tree–grass association which is a key component of savanna. Bushbuckridge in the Mpumalanga province is one of such communal area and is located west of one of the largest concentration of conserved lands in South Africa, offering an opportunity to assess and quantify differences of ecosystem states across various land use regimes. In this study we used high resolution airborne hyperspectral and discrete return LiDAR data to assess these differences. We focused on tree canopy cover / height and bare cover as indicator of potential impact of fuel wood collection [7] and grazing intensity [8].

2. MATERIAL AND METHODS

2.1. Study area

The study area is located in the "lowveld" savanna biome in the north-east of South Africa. The land use transect includes moderate use by wildlife in the Kruger National Park (KNP), heavier use by wildlife in adjacent private reserves, Sabie Sabie Game Reserve (SSGR), and low, moderate, and heavy use by people and livestock in the rural areas, Bushbuckridge (Table 1, Figure 1). The latter are widely regarded to be degraded following their historical status as communal lands. Previous studies suggest that communal rangelands exhibit a consistent long-term reduction in vegetation production per unit rainfall [9]. The transect falls along an east-west rainfall gradient from 540 mm/yr on the western boundary of the KNP to 800 mm/yr on the foot hills of the Drakensberg escarpment. Rains are concentrated in summer (October–May) and are generally in the form of convective thunderstorms. Mean annual temperature is 22 degrees C. Main geological substrates are nutrient-poor granite with local intrusions of nutrient-rich gabbro.

2.2. Carnegie Airborne Imagery (CAO)

Hyperspectral imagery and discrete LiDAR data were acquired in April-May 2008 with the Carnegie Airborne Observatory systems for 8 Land Use (LU) sites across the study area (Figure 1, Table 1). The CAO hyperspectral instrument is a high-fidelity CASI-like VNIR instrument, in this study programmed to acquire 72 contiguous bands (9.6 nm bandwidth) at 1 m spatial resolution.

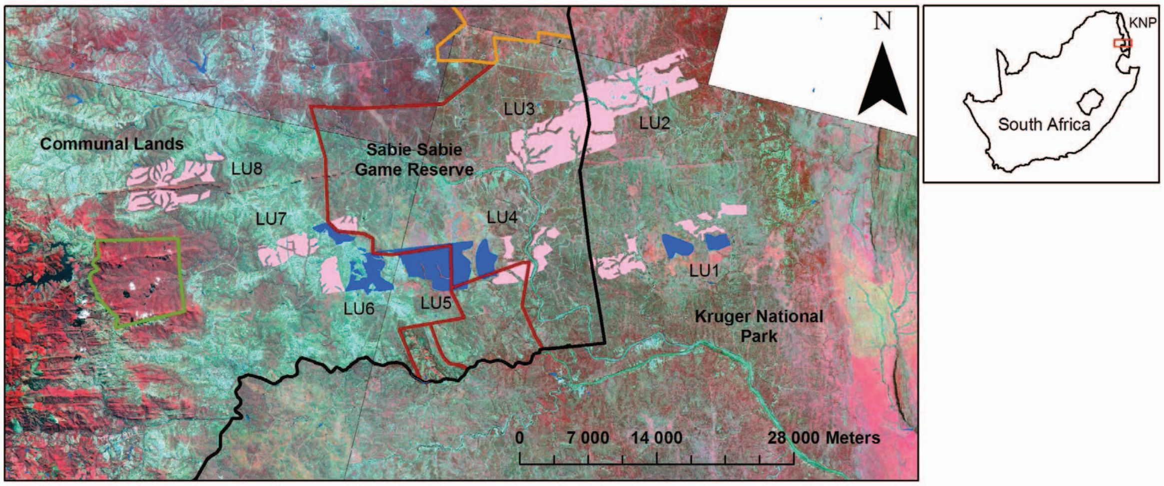


Fig. 1 Study area and land use transect showing the eight land use (LU) sites, Kruger National Park (KNP), Sabie Sabie Game Reserve (SSGR), and communal lands (Com. L.). Gabbro sites are indicated in blue and granite sites in light pink.

Table 1 Land use, geology, and rainfall.

Land use type	Site No.	Use intensity	Geology	Rainfall (mm)
KNP	LU1	-	GR/GA	550
KNP	LU2	-	GR	550
SSGR	LU3	-	GR	560
SSGR	LU4	-	GA/GR	600
Com. L.	LU5	High use	GA	630
Com. L.	LU6	High use	GA/GR	700
Com. L.	LU7	Mod. use	GR	718
Com. L.	LU8	Low use	GR	750

KNP Kruger NP SSGR Sabie Sand Game Reserve Com. L. communal lands GR granite GA gabbro KNP

The LiDAR instrument was operated in discrete-return mode with four ranges and four intensities per laser shot. Both datasets were co-located and orthorectified using attitude/altitude data obtained from a high precision GPS-IMU navigation system and ray tracing models [10]. Hyperspectral data were converted at-apparent-surface reflectance using lab calibration spectra and atmospheric correction models, ACORN 5 LiBatch with MODTRAN routines.

2.3. Data processing and analysis

Prior to data analysis we excluded the riparian areas and the dirt roads from all LU sites. In the communal lands (LU5-LU8) we masked all settlements and subsistence cultivated fields as our aim was to focus on non-transformed areas. LU6 granite was not considered as 95% of the site consists of cultivated fields.

2.3.1. Tree canopy height- LiDAR

LiDAR point clouds were modeled to extract top of canopy, ground height, and tree height. For each site and geology total percentage canopy cover was computed and compared. Vegetation height data were binned into 1 m bins to construct canopy height distributions. Bhattacharyya distance was used to express the dissimilarity of the canopy height distributions of the sites [11].

2.3.2. Bare soil fraction – Hyperspectral

Bare soil cover was extracted for the granite sites using a Brightness Index (BI) calculated from the visible bands. BI is the equivalent to the Euclidian distance in a space of *n* dimension and measures the average reflectance intensity in the visible [12]. BI increases with the fraction of bare cover (Figure 2), because of bright crusts and coarse sandy deposits produced by bare granite soils. Validation (n= 159) yielded an overall mapping accuracy of 89.9% to extract pixels with > than 50% bare cover. The BI was not effective on the gabbro soil which are much darker and the index was found to be sensitive to cross track brightness variation and BRDF effect which were quite severe on LU4,5,6 where most of the gabbro sites are located. No bare cover data were produced for the gabbro LU sites. Granite is the dominant geological substrate in the area and is more sensitive to degradation than gabbro.

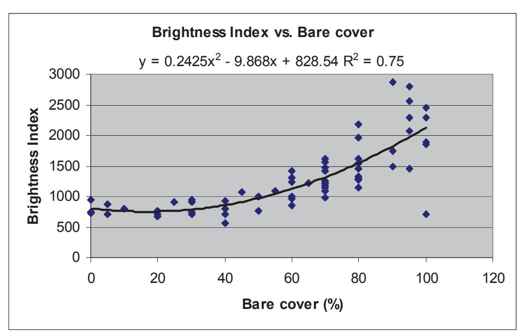


Fig.2 Relationship between the Brightness Index (visible bands) and the percentage of bare cover for granite sites.

3. RESULTS & DISCUSSION

Tree canopy cover results are given in Table 2. LU6 (highly used) is situated on a gabbro patch between two settlements and has the lowest percentage tree canopy cover (2%). In contrast, LU5 and LU7 gabbro (highly and moderately used, respectively) have about double the tree cover of LU1 and LU4 in conservation areas (11% vs. 6%). As expected tree cover in granite areas is much higher than on gabbro patches in conservation area (24% vs. 6%). For both gabbro and granite no significant difference is apparent between privately manage reserves and state-owned conservation areas. The tree cover in moderately impacted communal areas LU7 is less than half that observed in conserved areas (LU1-4). However, LU8 has a tree cover of 37%, probably because of a higher rainfall, its topographic location along a ridge, and its status as a communal semi-reserve for the collection of medicinal plants.

Table 2. Total % of tree canopy cover (TCC) as a function of the land use and geology (woody plant > 1 m height)

Land use type	Site No.	Use intensity	TCC gabbro (%)	TCC granite (%)
KNP	LU1	-	6.28	27.9
KNP	LU2	-	NA	21.6
SSGR	LU3	-	NA	22.9
SSGR	LU4	-	5.85	27.7
Com. L.	LU5	High use	11.8	NA
Com. L.	LU6	High use	2.0	NA
Com. L.	LU7	Mod. use	11.8	9.8
Com. L.	LU8	Low use	NA	37.0

The impact of communal land use on the tree canopy structure differed significantly between LU5,6 (high use) and LU7 (medium use) on gabbro substrate (Figure 3a). About 40% of LU5,6 tree canopy component was covered by trees lower than 3m and 50% by trees between 3 and 8 m, while LU7 showed the opposite pattern, 74% and 22% respectively. The high figure in the range 1-3 m for LU7 is due to an abundance of small "coppiced" trees, mainly silver cluster-leaf (*Terminalia sericea*) and sicklebush (*Dichrostachys cinerea*). Interestingly Sabie Sabie GR has less small trees (40% below 3 m) and more tall trees (20% above 8 m) than KNP (54% and 7% respectively). Patterns in granite areas appears similar than those observed in gabbro sites (Figure 3b). LU7 in communal areas also had markedly more tree canopy pixels in the 1-3m range and fewer in the 3-4 to 4-5m range than the conservation areas (LU1, 2, 3, 4) and the low use communal lands LU8. LU4 in Sabie Sabie GR was very similar to the communal reserve in LU8 in that they had more than double the amount of canopy pixels between 6-7 and 12-13m than the other granite sites (Figure 3b). However, patterns in SSGR are not always consistent as SSGR LU3 is more similar to KNP LU1 and LU2.

The Bhattacharyya distance was used to express the relative dissimilarity of the canopy height distributions of the sites (Figure 4). Communal areas were often just as dissimilar from one another as they were from conservation areas. For instance LU7 on gabbro was very different from other communal lands LU5,6 and conserved SSGR LU4, but similar to KNP LU1. Similarly the

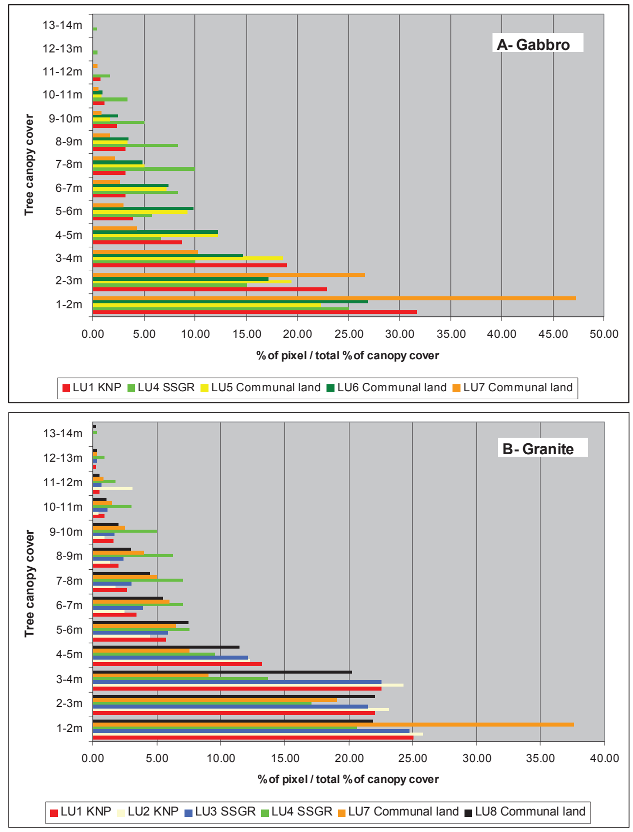


Fig. 3 Distribution of tree canopy height for the land use types and geological substrates a) gabbro and b) granite.

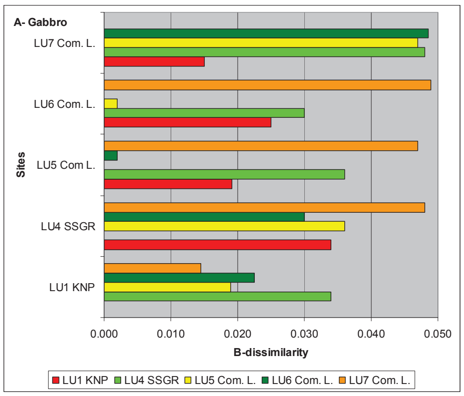
Table 3. Total percentage of bare cover as a function of the land use types and topographic position for granite geological substrates.

Land use type	Site No.	Use intensity	BC (%)	BC UL (%)	BC LL (%)
KNP	LU2	-	6.9	6.4	6.8
SSGR	LU3	-	3.0	1.3	4.7
Com. L.	LU7	Mod. use	2.7	3.3	2.3
Com. L.	LU8	Low use	1.9	1.4	2.0

BC bare cover UL up land LL low land

most different tree profile from KNP LU1 was the privately-conversed area LU4, both in gabbro and granite areas. LU5 and LU6 on gabbro had very similar height distributions, although % canopy cover very different 11.7% vs. 2%. Overall LU4 in Sabie Sabie GR was most dissimilar due mainly to the high relative abundance of very high trees, especially on gabbro. LU7 in communal area did not have a very dissimilar tree canopy height distribution to the conservation areas, but had a less than half the canopy cover (Table 2).

Percent bare cover was generally small across all land use types with less than 10% of the total area (Table 3). The highest percent bare cover was found in the KNP (7%) but this also corresponds to the lowest rainfall. LU7,8 receive 200 mm more rain than L2 which is a large difference in semi-arid savannas. Although some signs of active erosion (e.g. gullies) where found in the communal sites the total bare cover was very small with only 3% of the total area. These values are very low as compared to values reported elsewhere [13] and suggest that the herbaceous layer of communal rangelands might not be as severely degraded than previously thought [4-5].



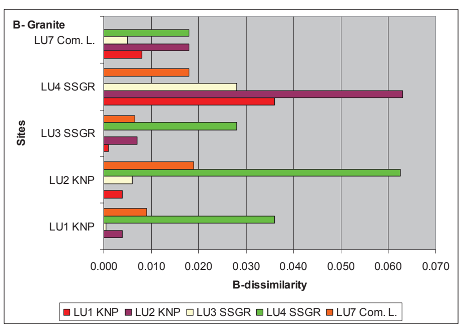


Fig. 4 Relative dissimilarity of tree canopy height distribution using the Bhattacharyya distance a) gabbro and b) granite geological substrates.

5. CONCLUSION

High resolution airborne hyperspectral and discrete return LiDAR data were used to assess tree cover and bare cover differences along a land use transect consisting of state-owned, privately-owned conservation areas, and communal areas in South African savannas. The results show that tree cover is much higher in conservation areas as compared to communal areas where local populations yield fuel wood for personal consumption. Low impact communal sites (limited use) tend to have higher tree cover than higher impacted communal sites. Generally communal areas have altered tree height distribution but in diverse way depending on the geology or the level of human pressure. Bare cover was generally found to be quite low (< 10%) in all different land uses, suggesting that the degradation level in communal areas might not be as high as generally perceived.

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