

Impact of communal land use and conservation on woody vegetation structure in the Lowveld savannas of South Africa – Lidar results.

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Abstract – People in the rural, communal areas of South Africa rely on live fuel wood for more than 90% of their energy requirements. Using airborne lidar from the Carnegie Airborne Observatory (CAO) we compared tree canopy cover and height distributions between communal landscapes with heavy utilization to fully protected public and private reserves in the Lowveld of South Africa. Rangelands and fields in most of the communal sites had more vegetation cover in the 5-7m and >7m classes than most of the conservation sites, presumably due to the absence of elephants in communal rangelands. On granite substrates there was a 50% reduction in woody cover below 5m in communal rangelands. These results in conjunction with related studies, suggest that communal land use have a higher impact on the woody cover below 5m than both elephants and fire.

Keywords: Carnegie Airborne Observatory (CAO), Lidar, fuel wood, South Africa, Savannas, woody vegetation structure

1. INTRODUCTION

People in the rural, communal areas of South Africa rely on live fuel wood for more than 90% of their energy requirements and therefore are believed to have a large impact on woody vegetation biomass and structure. Particularly, in the Lowveld region where the average household use is in excess of 3 tons of fuel wood per annum (Shackleton and Shackleton, 2000; Twine et al., 2003). Therefore, there is great concern that these areas may be over-utilized to the point where the ecosystem may soon not be able to sustain the services on which the local people's subsistence livelihoods depend (Dovie et al., 2002; Higgins et al., 1999; Shackleton and Shackleton, 2000).

Lidar data have been extensively used to assess vegetation structure in forested environments (Lefsky et al., 2002; van Aardt et al., 2006), while savanna vegetation has received limited attention (Asner et al., 2009). The present study used high point density, small-footprint, multiple return discrete return lidar data to assess structural differences along a land use gradient, covering 25 000ha of African savannas. The objective of this study was specifically to quantify the differences in tree canopy cover and height distribution between Kruger National Park (KNP), SabiSand private game reserve (SSGR), and neighboring communal areas. The outcomes of this study contribute to an understanding of the influence of human utilization on savanna structure.

2. MATERIALS AND METHODS

2.1 Study area

The study area is located in the Lowveld of the savanna biome in the north-eastern part of South Africa. The topography is gently undulating with a slowly decreasing terrain height toward the east, average height ca. 450 m. Rains occur mainly in summer from October to May (wet season) and are generally in the form of convective thunderstorms. The mean annual precipitation (MAP) is approximately 630 mm. Dominant geology includes granite and gneiss with local intrusions of gabbro.

The three dominant land tenure systems are (i) state-owned conservation (Kruger National Park, KNP), (ii) privately-owned conservation (SabiSand Game Reserve, SSGR), and (iii) state-owned communal areas (Fig. 1). The communal lands of Bushbuckridge are former self-governing territories or "homelands" inherited from the resettlement policies during the apartheid era. The area supports high human population densities of between 150 and 300 people/km². People largely rely on land-based livelihood strategies that rely on a combination of farming, livestock husbandry, and harvest, consumption and/or trade on informal markets of various natural resources (Dovie et al., 2002; Shackleton et al., 2001).

The 25 000 ha covered by the lidar data covers 7 sites, from Land use site 1 (L1) in the east to Land use site 7 (L7) in the west (Fig. 1). L1 and L2 are located in KNP, L3 and L4 in SSGR and L5, L6 and L7 in the communal areas. Within the communal areas, a distinction was made between rangelands and cultivated fields. Areas under consideration are denoted as Lx(1-7)-geology(gabbro/granite)-land use (KNP/ SabiSand/ Rangelands /fields), for example L6-gabbro-fields.

2.2 Airborne lidar data

Discrete lidar data were acquired in April-May 2008 with the Carnegie Airborne Observatory (CAO) system (Asner et al., 2007), across the study sites covering 25 000ha. In April-May 2008, the CAO collected data over the study region from an altitude of 2000 m above ground level, providing combined HiFIS and LiDAR measurements at 1.1 m spatial resolution. The lidar was operated at a laser pulse repetition frequency of 50 kHz. Parallel flight lines were acquired with 50% overlap. From the laser point cloud data, a physical model was used to estimate top-of-canopy and ground surfaces (digital elevation models; DEMs). Ground returns for the DEMs were classified from the lidar point cloud using a user-defined search radius in which the lowest point is identified as a potential ground return; adjacent points are added

to this ground class if they fall below a user-defined threshold angle subtended at the original point. Vegetation height is then estimated by differencing the top-of-canopy and ground surface DEMs.

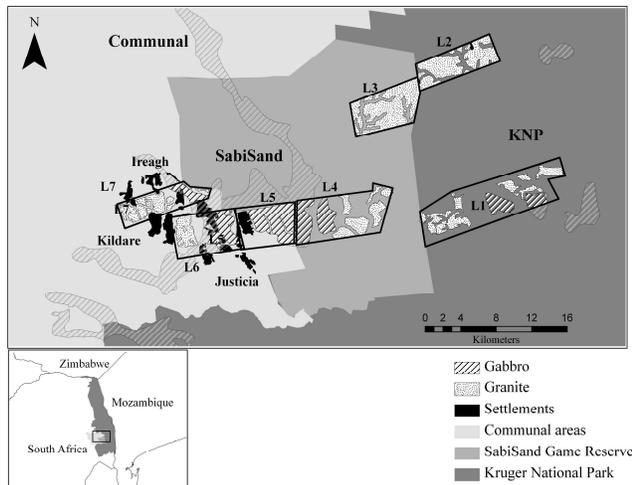


Figure 1. Study area in the Lowveld of South Africa, including (from east to west) Kruger National Park, SabiSand Game Reserve and communal areas. Sites are delineated as L1-7. Gabbro intrusions are indicated within the predominantly granitic landscape. Human settlements are also mapped.

2.3 Comparison of woody vegetation cover and height distributions

The goal was to compare the woody vegetation cover of sites per height class. The analysis concentrated on the vegetation canopy height surfaces as an indicator of the woody cover at various heights. The woody vegetation was binned into five functional height classes to facilitate ecological interpretation of the lidar data (1-2m, 2-3m, 3-5m, 5-7m and >7m). These classes relate to the influence of fire and herbivory, their function in the landscape, as well as human utilization (Bond and Midgley, 2000; Shackleton and Shackleton, 2004).

The spatial autocorrelation in vegetation height was investigated using omnidirectional semi-variograms applied to the 1.1m vegetation height surface (Beale et al., 2010). There was negligible spatial autocorrelation beyond a lag distance of approximately 50m (range). Therefore, samples taken 50m apart, or further, could be treated as independent (Beale et al., 2010).

Each site (L1-7) was sampled using 200m x 200m blocks, spaced 50m apart. The 200m block size was chosen as it optimally represents samples of the landscape which includes multiple terrain units, e.g., crest, midslope, valley bottom, in order to stabilize the inter-block variability whilst characterizing the site. The percentage area of each block covered by each height class was calculated. The average and standard deviation of percentage area woody cover per height class were calculated for each site (L1-7), geology (gabbro or granite), and land use (conservation, cultivated fields or rangeland) combination using all of the 200m blocks that were included in the relevant polygons.

3. RESULTS

3.1 Woody vegetation height distribution in rangelands and conservation areas

The average percentage area covered by woody vegetation in each height class for all 200m blocks in a site was plotted in histograms to visualize the structural vegetation differences (Figs x and y). The impact of communal land use on the woody vegetation structure was very diverse on the gabbro geology. Only 0.5% of the area of L6-gabbro-rangeland was covered by woody vegetation below 2m compared to the other sites, while more than 8% of L7-gabbro-rangelands were covered by woody vegetation at this height. The conservation sites, L1-gabbro-KNP and L4-gabbro-SabiSand fell between the two afore-mentioned extremes (Fig. 4). L6-gabbro-rangeland had less than half the woody vegetation cover in all height classes, indicating a high utilization impact (Fig. 3). L5-gabbro-rangelands was covered by significantly more woody vegetation in the 2-3m, 3-5m and 5-7m classes compared to all the other gabbro sites (Fig. 4), indicating a high abundance of small to large trees and thus low impact within this communal area or potentially attributable to bush encroachment.

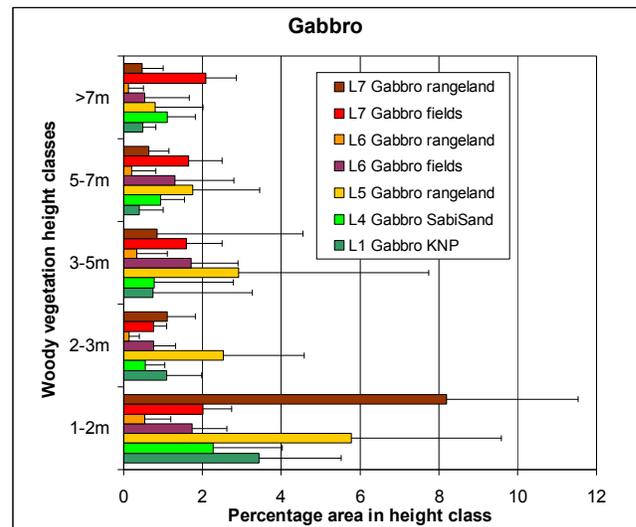


Figure 2. Percentage area of each site covered by vegetation in height class on gabbro geological substrate. The values are calculated as the average of all 200m blocks included in the site, while the error bars indicate the standard deviation.

On granite, the conservation sites L1 to L4, had very similar percentage woody vegetation in all classes below 5m (Fig. 3). The woody cover of L7-granite-rangeland was less than half that of conservation sites (L1 to L4) between 1 and 5m, demonstrating a very significant impact of rural utilization on the woody vegetation (Fig. 3). The biggest difference was in the 2-3m height class, where the cover of L7-granite-rangeland was approximately four times less than that of the conservation sites (L1 to L4). L7-granite-rangeland had a very similar vegetation height distribution to L6-granite-fields and L7-granite-fields. L4-granite-SabiSand had more than double the woody cover in the 5-7m and >7m classes when compared to any of the other granite sites. This site is a low lying area next to the Sand River covered by tall woodlands.

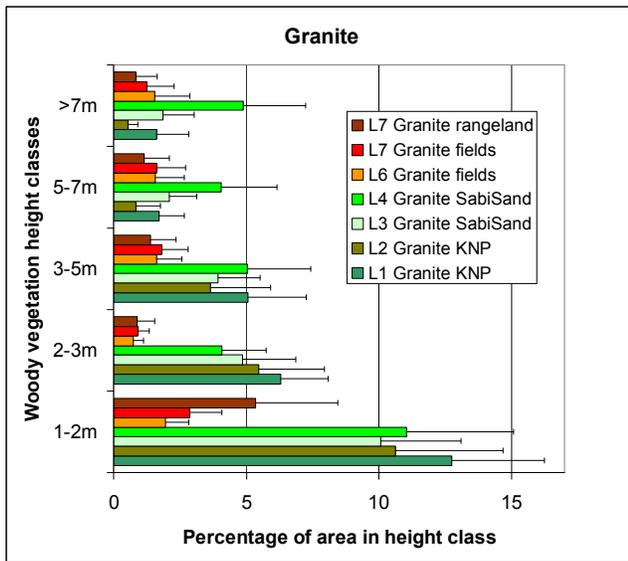


Figure 3. Percentage area of each site covered by vegetation in height class on granite geological substrate. The values are calculated as the average of all 200m blocks included in the site, while the error bars indicate the standard deviation.

3.2 Woody vegetation height distribution in communal fields

The overall woody vegetation cover of fields on granite substrates was only approximately 25% of the cover in conservation areas (Fig. 2). L6-granite-fields and L7-granite-fields have 4-6 times less woody vegetation cover in the 1-2m, 2-3m and 3-5m classes than the other granite sites, but mostly similar cover in the 5-7 and >7m classes (Fig. 3). A distinguishing feature of the fields on granite (L7-granite-fields, L6-granite-fields) was that there was more woody vegetation in each of the height classes above 3m than in the class 2-3m (Fig. 3).

4. DISCUSSION

Geologic substrate had an overriding influence on the impact of communal land use on woody vegetation. On the gabbro intrusions, this impact was diverse, ranging from a radical reduction in all woody cover in intensively used rangelands (e.g. L6) to a significant increase (e.g. L5, L7), depending on the current and historic management of the sites, which varied greatly. L6-gabbro-rangeland had very little woody cover remaining (Fig. 2) as a result of heavy utilization due to its location between two villages (Fig. 1).

When the woody vegetation of L5-gabbro-rangelands was compared to L4-gabbro-SabiSand just to the east in the SabiSand game reserve (Fig. 1), it was clear that L5-gabbro-rangeland had more than double the woody cover at all heights, except the >7m class (Fig. 4). This could be attributed to the relatively low utilization impact of the single village (Justicia) with access to this site which is nestled into a corner of SSGR (Fig. 1), as well as the reduction in woody cover due to the 16-fold increase in elephant

number in SSGR since 1993 when fences between SSGR and KNP (Hiscocks, 1999).

On the granite substrates the results were different. The overall woody vegetation cover of L7-granite-rangeland was less than half that of the conservation areas (L1 to L4). L7-granite-rangeland had less than 50%, 25% and 50% of the woody vegetation cover of conservation areas in the 1-2m, 2-3m, and 3-5m classes, respectively (Fig. 3). This supports the findings of Higgins et al. (1999) that woody biomass on granite substrates was lower in communal rangelands compared to conservation areas in the same study area. Interestingly, while woody vegetation cover in the communal rangelands was lower than that of the conservation areas on the granite substrate of L7 (9.8% vs. 25%), the woody cover was higher compared to conservation sites on gabbro substrate of L7 (11.8% vs. approx. 6%). While woody cover on L7-gabbro-rangelands was double that of conservation sites (L1 and L4 gabbro) in the 1-2m class, it was less than half that of conservation sites in L7-granite-rangelands.

Rangelands and fields in most of the communal sites had more vegetation cover in the 5-7m and >7m classes than most of the conservation sites, presumably due to the absence of elephants in communal rangelands and the active preservation of large fruiting trees, e.g. Marula (*Sclerocarya birrea*), Jackalberry (*Diospyros mespiliformis*) (Shackleton and Shackleton, 2004; Shackleton et al., 2002). However, the recruitment of new small trees is a major concern as there was very relatively little woody vegetation in the 2-3m height class in the fields compared to the classes above 3m (Fig. 3).

On granite substrates, which account for the majority of the study area, there was a 50% reduction in woody cover below 5m in communal rangelands. These results in conjunction with other studies based on the CAO lidar data for experimental burn plots and large mammal exclosures in KNP (Asner et al., 2009; Levick et al., 2009; Smit et al., in press), suggest that communal land use on granite substrates have a higher impact on the woody cover below 5m than both elephants and fire.

REFERENCES

- Asner, G.P. et al., 2007. Carnegie Airborne Observatory: in-flight fusion of hyperspectral imaging and waveform light detection and ranging (wLiDAR) for three-dimensional studies of ecosystems. *Journal of Applied Remote Sensing*, 1.
- Asner, G.P. et al., 2009. Large-scale impacts of herbivores on the structural diversity of African savannas. *Proceedings of the National Academy of Sciences of the United States of America*, 106(12): 4947-4952.
- Beale, C.M., Lennon, J.J., Yearsley, J.M., Brewer, M.J. and Elston, D.A., 2010. Regression analysis of spatial data. *Ecology Letters*, 13(2): 246-264.
- Bond, W.J. and Midgley, G.F., 2000. A proposed CO₂-controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology*, 6(8): 865-869.
- Dovie, D.B.K., Shackleton, C.M. and Witkowski, E.T.F., 2002. Direct-use values of woodland resources consumed and traded in a South African village. *International Journal of Sustainable Development and World Ecology*, 9(3): 269-283.

Higgins, S.I., Shackleton, C.M. and Robinson, E.R., 1999. Changes in woody community structure and composition under contrasting landuse systems in a semi-arid savanna, South Africa. *Journal of biogeography*, 26(3): 619-.

Hiscocks, K., 1999. The impact of an increasing elephant population on the woody vegetation in southern Sabi Sand Wildtuin, South Africa. *Koedoe*, 42: 47-55.

Lefsky, M.A., W.B. Cohen, G.G. Parker and Harding, D.J., 2002. Lidar remote sensing for ecosystem studies. *BioScience*, 52: 19-30.

Levick, S.R., Asner, G.P., Kennedy-Bowdoin, T. and Knapp, D.E., 2009. The relative influence of fire and herbivory on savanna three-dimensional vegetation structure. *Biological Conservation*, 142(8): 1693-1700.

Shackleton, C. and Shackleton, S., 2004. The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. *South African Journal of Science*, 100(11-12): 658-664.

Shackleton, C.M. and Shackleton, S.E., 2000. Direct use values of savanna resources harvested from communal savannas in the Bushbuckridge lowveld, South Africa. *Journal of Tropical Forest Products*, 61: 28-47.

Shackleton, C.M., Shackleton, S.E. and Cousins, B., 2001. The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. *Development South Africa*, 18: 581-604.

Shackleton, S.E. et al., 2002. Knowledge on *Sclerocarya birrea* subsp. *caffra* with emphasis on its importance as a non-timber forest product in South and southern Africa: a summary. Part 1: Taxonomy, ecology and role in rural livelihoods. *Southern African Forestry Journal*, 194: 27-41.

Smit, I.P.J. et al., in press. Effects of fire on woody vegetation structure in African savanna. *Ecological Applications*.

Twine, W., Moshe, D., Netshiluvhi, T. and Siphugu, V., 2003. Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo province, South Africa. *South African Journal of Science*, 99(9-10): 467-473.

van Aardt, J.A.N., Wynne, R.H. and Oderwald, R.G., 2006. Forest Volume and Biomass Estimation Using Small-Footprint Lidar-Distributional Parameters on a Per-Segment Basis. *Forest Science*, 52: 636-649.

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