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Management approaches of conservation areas: Differences in woody vegetation structure in a private and a national reserve

J.T. Fisher [a,b,c,*], B.F.N. Erasmus [a], E.T.F. Witkowski [b], J. van Aardt [d], G.P. Asner [e], K.J. Wessels [f], R. Mathieu [c]

[a] Centre for African Ecology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, WITS, 2050 Johannesburg, South Africa
[b] Restoration and Conservation Biology Research Group, School of Animal, Plant & Environmental Sciences, University of the Witwatersrand, WITS, Johannesburg 2050, South Africa
[c] Ecosystems Earth Observation, Natural Resource & Environment, Council for Scientific and Industrial Research (CSIR), P.O. Box 395, Pretoria 0001, South Africa
[d] Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623, USA
[e] Department of Global Ecology, Carnegie Institution for Science, 260 Panama Street, Stanford, CA 94305, USA
[f] Remote Sensing Research Unit, Council for Scientific and Industrial Research (CSIR), Meraka Institute, P.O. Box 395, Pretoria 0001, South Africa

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ABSTRACT

Management approaches taken in protected areas will affect their ability and effectiveness to conserve biodiversity. MalaMala (a concession within Sabi Sand Wildtuin, a private game reserve), and an adjacent area in the Kruger National Park (Kruger, statutory protected area) in South Africa provide a comparison of different types of conservation management. We measured three-dimensional woody vegetation structure, as an integral component of biodiversity, across 6200 ha in the two reserves using a LiDAR (Light-Detection-and-Ranging) sensor. We compared how different management approaches in the two reserves affected woody structural diversity. Vertical canopy diversity was measured using: i) percent cover of woody vegetation extracted from LiDAR canopy height models, ii) a volumetric pixel (voxel) approach to extract 3D vertical canopy-height profiles; and iii) horizontal diversity using landscape metrics. MalaMala had higher vegetation density than Kruger in the <3 m (2.5 times) and >6 m (2.7 times) height classes. This vegetation was in the form of larger, more cohesive patches as a result of the legacy of previous land-use (cattle ranching) and current management practices (bush clearing) and the recent increase in megaherbivores. Length of exposure to, and recent higher densities of, megaherbivores (particularly elephants) has altered the density of tall trees in the two reserves, thus affecting structural heterogeneity and associated habitat options for small-bodied vertebrates. These differences in vegetation structure are exacerbated by current management practices (e.g. bush-clearing and fire regime), with potential implications for faunal biodiversity conservation across a wide range of scales.

1. Introduction

People have been living in African savannas for at least 250 000 years, shaping patterns and processes through resource utilization and land management (Freitag-Ronaldson and Foxcroft, 2003; Scholes and Walker, 1993). Human impact on landscapes is often only considered in areas outside of reserves, but even in protected areas humans influence savanna dynamics by altering fire frequencies, introducing and removing animals and especially in smaller private reserves, bush clearing may be practiced. In a perfect world we would be able to leave natural areas ungoverned, but with only 12% of the earth's surface formally protected (Chape et al., 2005), people need to manage these ecosystems to ensure that all aspects of biodiversity are conserved. Many reserves are managed to protect key species that are threatened with extinction (Mills et al., 1993) but there is a shift towards protecting ecosystems as arenas for biodiversity rather than the conventional species-centric approach, especially in the face of climate change (Coetzer et al., 2013; Beier & Brost, 2010).

With an understanding of the need for a greater contiguous area of land under conservation, the fence between two neighboring reserves, Kruger National Park (KNP, a statutory protected area) and Sabi Sands Wildtuin (SSW, a private game reserve), was removed in 1993. The two reserves (southern section of KNP and SSW) shared an essentially similar land-use history until 1922 (Joubert, 2007; Mabunda et al., 2003; http://www.malamala.com/history_of_malamala.htm). Prior to this date, hunting for sport in the area, from 1836 to 1902, significantly reduced wildlife populations, which was further exacerbated in 1896 with the rinderpest epizootic which killed off cattle and wildlife, and also resulted in a lifting of all hunting restrictions (Carruthers, 1995). The decimation of wildlife eventually led to the beginning of proactive conservation in the area and the Sabi Game Reserve was established in 1898 (Carruthers, 1995; Mabunda et al., 2003), which was a mosaic of government land, and company- and private-farms (Joubert, 2007).

Abbreviations: CAO, Carnegie Airborne Observatory; Kruger, Kruger National Park; LiDAR, Light-Detection-and-Ranging; MalaMala, MalaMala Private Game Reserve; SSW, Sabi Sand Wildtuin; Voxel, Volumetric pixel.

* Corresponding author at: School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, WITS, 2050 Johannesburg, South Africa. Tel.: +27 11 717 6408; fax: +27 11 717 6494.
E-mail address: jolenefisher@gmail.com (J.T. Fisher).

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Modern day KNP was proclaimed as a statutory protected area in 1926 with the passing of the National Parks Act, while the area to the western boundary became private game reserves. In 1922 the Transvaal Consolidated Land and Exploration Company (TCL) purchased MalaMala, a private farm within the Sabi Game Reserve and it was a shared area for cattle and wildlife, although from 1922 to 1928 over 500 lions were shot in defense of cattle. From 1927 to 1939 farms surrounding MalaMala were purchased by various individuals and operated as private game farms for game viewing and hunting (http://www.malamala.com/history_of_malamala.htm). In 1934 MalaMala and surrounding farms formed a conservancy now known as Sabi Sand Wildtuin (SSW), but each farm/concession maintained separate management within SSW. The present day MalaMala is still contained and unfenced within the SSW boundary, however, it is no longer part of the conservancy. A later outbreak of foot-and-mouth disease and continued hunting on the private lands led to the construction of a boundary fence separating Kruger and SSW in 1961 (http://www.sabisand.co.za/ssw-history.html), drawing an official line between the two different management approaches until the removal of the fence in 1993. The different management approaches of each reserve (i.e. fire regime, management of herbivores and bush clearing) are likely to have had an impact on the woody structural diversity; however, this has not been quantified.

Plant ecologists traditionally have used field-based methods to measure vegetation structure, e.g., sampling vegetation using transects or plots. While these studies are effective at measuring a relatively large number of trees, in the order of 10^2–10^5, they typically cover small areas (<5 ha) (Higgins et al., 1999; Shackleton, 2000; Witkowski and O'Connor, 1996). However, the inherent heterogeneity and patchiness in savannas (Scholes and Archer, 1997) require alternative methods to measure vegetation structure over larger extents and at various spatial scales to ensure that heterogeneity at all scales is captured. Light Detection and Ranging (LiDAR), which is based on an accurate measurement of the return trip distance of emitted laser pulses, is now widely used in terrestrial environments to assess woody vegetation structure and map landscape topography (e.g., Lefsky et al., 2002). With small-footprint (<1 m), discrete-return LiDAR (which collects point-based x, y, z data of all terrestrial structures), we are able to measure large areas at fine resolutions, obtaining fine scale results similar to field studies (Lefsky et al., 2002; Turner et al., 2003). LiDAR data are costly, but it is still more cost-effective per unit area compared to field studies when large tracts of land need to be analyzed (Kirton et al., 2009). Such data can be used to assess structural variation across landscapes (e.g. Wessels et al., 2011; Fisher et al., 2012).

We measured woody structural diversity in KNP and in the neighboring MalaMala private game reserve within SSW using small-footprint, discrete-return LiDAR collected with the Carnegie Airborne Observatory Alpha sensor package (CAO, Asner et al., 2007) to evaluate the woody structural heterogeneity in these protected areas. The aim of our investigation was to describe the differences in woody vegetation structure between the two reserves. Although we cannot ascribe the differences to specific management interventions, either because the information is not available at a fine scale (KNP) or is not accessible (MalaMala), we provide possible reasons for the current woody vegetation structure. We furthermore assess the usefulness of small-footprint, discrete-return LiDAR to measure woody vegetation structure at the landscape scale in semi-arid savannas.

2. Methods

2.1. Study area

The two study sites border one another on the boundary between KNP and MalaMala in Mpumalanga Province, north-eastern South Africa (Fig. 1), spanning a total of 6200 ha (2900 ha in KNP and 3300 ha in MalaMala). The sites have the same landtype and vegetation types, and similar geologies, altitudinal range and mean annual precipitation and temperature, but different management objectives (Table 1). Vegetation structure comprises tall shrubland with a few trees and relatively dense low woodland. Dominant woody species include the trees *Terminalia sericea*, *Combretum zeyheri*, *Combretum apiculatum*, *Acacia nigrescens*, and the shrubs *Dichrostachys cinerea* and *Grewia bicolor*. Common grass species include *Pogonarthria squarrosa*, *Tricholaena monachne*, *Eragrostis rigidior*, *Panicum maximum*, *Aristida congesta*, *Digitaria eriantha*, and *Urochloa mossambicensis* (Mucina and Rutherford, 2006).

2.2. Light Detection and Ranging (LiDAR) data

LiDAR data were used to measure woody vegetation structure in the two study sites. The 3D point cloud provides a means to measure both the height (top of canopy–size class distributions) and vertical (arrangement of vegetation within the vertical profile) structure of woody vegetation. LiDAR data were collected in April 2008 using the Carnegie Airborne Observatory (CAO) Alpha system for 6200 ha in the Kruger National Park (2 900 ha) and MalaMala Private Game Reserve in Sabi Sand Wildtuin (3 200 ha). The CAO combines both imaging spectroscopy (hyperspectral imaging) and LiDAR technologies to study ecosystems at the regional scale (Asner et al., 2007). The CAO was operated in Alpha mode, which is intended for high-resolution mapping of up to 20 000 ha/day at a 0.5–1.5 m spatial resolution. The spectrometer can acquire imagery in up to 288 channels of 1.8 nm bandwidth in the 400–1050 nm wavelength range and has a swath of 1500 pixels. The spectrometer is co-mounted with the LiDAR sensor which can acquire both waveform and discrete-return data; however, only discrete-return data were used for this study. The integrated GPS-IMU subsystem in the CAO provides the position and orientation of the sensors in 3D, while the CAO algorithms ensure that data inputs from both the spectrometer and the LiDAR system are co-located and precisely projected to ensure geographically aligned output (Asner et al., 2007). The CAO Alpha LiDAR sub-system provides 3D vegetation structural information, as well as high resolution digital elevation models. For this

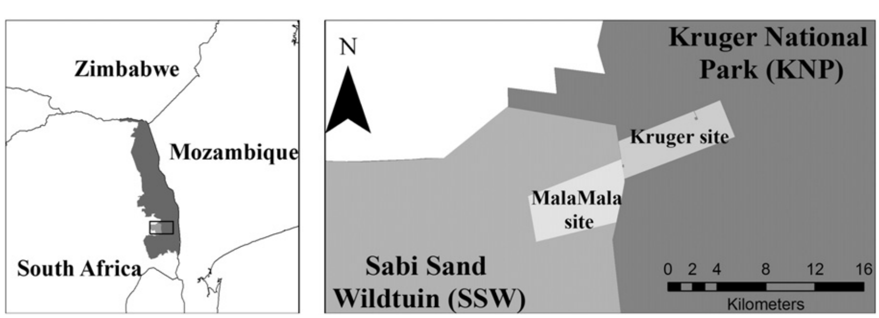

Fig. 1. Location of study sites within the Kruger National Park and Sabi Sand Wildtuin (MalaMala Private Game Reserve), South Africa.