Shaun Levick/CSIRO

Capturing Kruger in 3D

Izak Smit explains how lidar has been used in the Kruger National Park.

Savannas are particularly interesting in that they contain elements of both grasslands and forests, yet never become either one – they always remain a diverse mixture of trees and grass.

The reason for the coexistence of trees and grass, with neither totally replacing the other, has been one of the most pertinent questions for savanna ecologists over many decades. Why is grass biomass so high and tree cover so low in certain areas, compared to other areas close by? Does it change over time? What drives these patterns and dynamics, and how can management of fire regimes and grazing intensity influence it? What is causing bush encroachment or thickening in certain savannas, resulting in increased woody cover and a reduction in grass biomass, and can it be reversed? How will increasing levels of atmospheric carbon dioxide levels and other drivers of global change influence the tree–grass coexistence? These questions are fundamental to understanding savanna functioning.

One of the key variables that needs to be measured in order to answer some of these questions is the aerial cover of the woody vegetation – the trees and bushes. In recent years, lidar data has proven very useful in this regard, providing valuable insights into subtle patterns and dynamics of woody vegetation at great accuracy and over large scales.

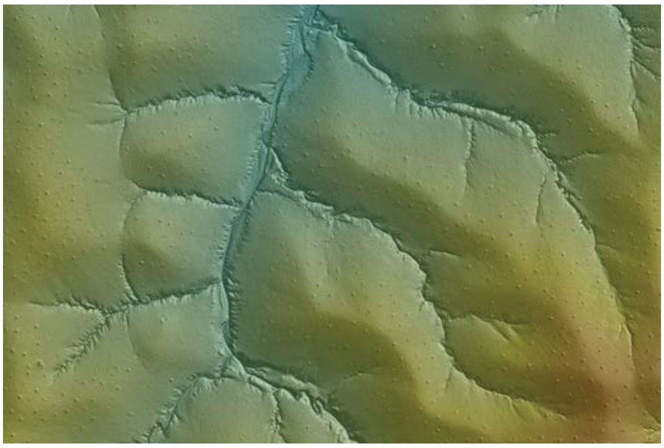
Lidar for landscape mapping

Lidar for large-scale mapping involves measuring the time it takes for laser light pulses – fired from an instrument on an airplane, drone, satellite or mobile platform – to return after reflecting off the ground or from objects on the landscape surface, such as buildings and trees. The data derived from lidar can be used to create two very different types of 3D models. The first, called a digital terrain model (DTM), creates very detailed topographical models by stripping all features off the landscape and only showing the underlying topography. The second type, a digital surface model (DSM), represents the elevation of all the features elevated above the 'bare' ground surface, including trees. By subtracting the DTM from the DSM, one can accurately measure the dimensions of all the features on the landscape, essentially by 'flattening' the underlying landscape and representing the cover and height of objects. Using this type of dataset of the absolute height of features relative to the ground, it is possible to measure the canopy height and dimensions of individual savanna trees over large areas.

Htoni, Wikimedia, CC BY-SA 3.0

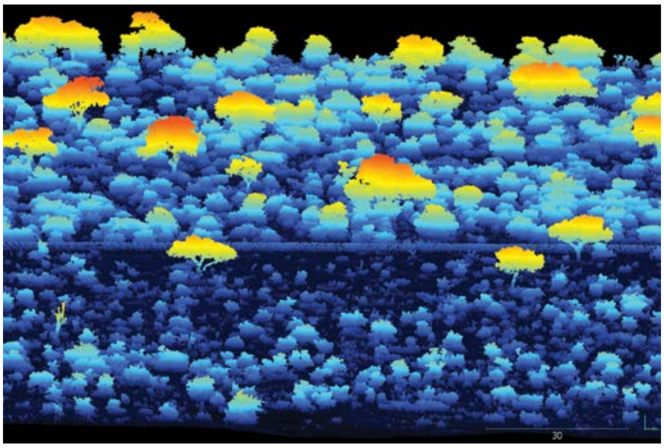
The Kruger National Park encompasses 1.9 million hectares in South Africa's north-eastern extreme.

Collecting lidar-derived tree structure data from specific experimental sites, or overlaying it with other spatio-temporal datasets such as elephant distribution, mean annual rainfall or soil type, can provide valuable insights. In the past decade, scientists from the Kruger National Park (KNP), in collaboration with the Carnegie Airborne Observatory (now the Global Airborne Observatory), Council for Scientific and Industrial Research (CSIR), University of the Witwatersrand and the Friedrich Schiller University



Shaun Levick/GAO

A digital terrain model showing detailed topographic features such as drainage lines and termite mounds, derived from lidar imagery.



Peter Boucher, Davies Lab, Harvard University

A lidar image reveals the contrast in woody vegetation cover and height inside (top half) and outside (bottom half) a fenced herbivore exclosure.

Jena in Germany, have used lidar technology to explore how different abiotic drivers (e.g. landscape positions, fire regimes), biotic drivers (e.g. elephants, termites) and human infrastructure (roads) or human uses (fuelwood harvesting) have influenced woody vegetation cover and height within the KNP and the surrounding communal rangelands.

Termites and trees

Lidar data proved very useful for identifying mounds built by termites from the genus *Macrotermes*. Mapping thousands of termite mounds across tens of thousands of hectares in the KNP allowed researchers to study the distribution, spacing and height of the mounds. This revealed that termites build their mounds at different topographic positions and make them different sizes depending on the long-term rainfall patterns in the specific landscape. This can be attributed to the fact that the rainfall regime determines the availability and distribution of clay particles in the landscape – and termites need adequate clay to build their mounds, of course.

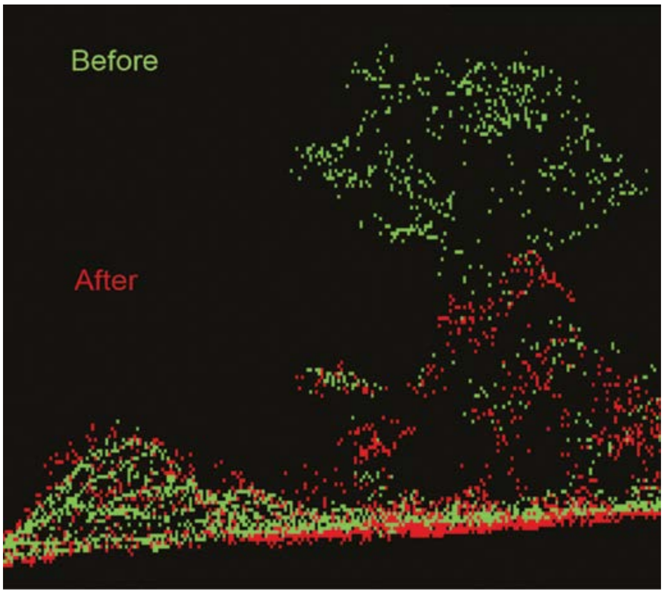
A further interesting finding emerged when comparing the size of trees at different distances from termite mounds. Trees within a 20 m radius of termite mounds were found to be taller than trees further away. In addition, by fencing trees in an exclosure to exclude large mammalian herbivores, it was revealed that trees closer to termite mounds seem to be more heavily browsed than those further away. This confirms the importance of termite mounds as nutrient hotspots for animals in the landscape. Considering the density of termite mounds in KNP, this 20 m zone of influence around termite mounds may affect as much as 20% of some landscapes. The role of these important insects in shaping the African savannas should therefore not be underestimated.

Elephants and treefall

The KNP has various experimental sites where the fire regime or the herbivore composition or density are manipulated, in order to tease apart and quantify the influence of fires and herbivores on vegetation structure.

Tim Ellis, CC BY-NC 2.0

Elephants have a major impact on vegetation structure, and account for the high rate of treefall in some areas of the park.



Shaun Levick/GAO

Lidar data collected over time allows detection of fallen trees. This lidar point cloud shows a tree before (green) and after (red) it toppled over.

Using lidar-derived data on woody structure inside and outside of these experimental sites, it is possible to compare the patterns and dynamics of woody vegetation under these different fire and herbivore regimes.

As such, lidar data was used to determine the location and height of trees in exclosures where all mammalian herbivore species larger than a hare have been excluded (using meshed and electric cable fence), as well as exclosures where only giraffe and elephant have been excluded (two high strands of electric cable fence allow free movement of other animals). The vegetation patterns were then compared between these two herbivore exclosure areas and the control areas outside the exclosures. Two years later, lidar data was collected from exactly the same areas, allowing researchers to determine the fate of the same trees and identify which trees were missing or had toppled over. Using this approach, it was estimated that the rate of treefall was about six times faster in areas where elephants and giraffes have access to the trees, compared to areas protected from elephants. Since giraffes do not topple trees, this study suggested that elephants have a significant effect on vegetation structure within an area next to a permanent river that is frequented by elephants.

This study was expanded to larger landscapes of the park outside of the exclosures, linking the fate of more than 10 million individual trees over hundreds of thousands of hectares over time with a range of spatial data layers, such as mean annual rainfall, soil type, landscape position, fire frequency, time since last fire, and elephant density. From the results, it was again apparent that elephants are a big driver of change in vegetation structure. But what was noticeable from the landscape-scale study, as opposed to the exclosure study, was that bull elephants are seemingly having a larger impact on woody vegetation structure than breeding herds, as the rate of treefall was higher for areas frequented by bulls rather than mixed herds. In addition, it was evident that the rate of treefall across the landscape was highly variable, with elephant–tree interaction a spatially heterogeneous process.

Fire intensity and tall trees

Similar to the studies exploring the effect of elephants on vegetation structure, we have also explored how fire influences vegetation structure under different experimental fire regimes. We found that if similar adjacent landscapes are burned at different times of the year, and under different climatic and grass-curing conditions, the difference in fire intensity results in very different vegetation structure outcomes. Very high-intensity fires – typically occurring late in the dry season – tend to reduce woody cover, at least in the short term, but also result in the toppling of significantly more tall trees (> 10 m height and > 6 m crown diameter). For example, it was found that two very high-intensity fires over a four-year period opened up a landscape in the short term by reducing overall woody cover, but at the same time toppled about one-third of all the tall trees, whereas two low-intensity fires over the same four-year period did not reduce woody cover, and a tree-toppling rate of only 3% was recorded.

Recently, additional lidar data was collected in order to determine what has happened to the vegetation structure in these landscapes since the experimental fires of variable intensity. Some observational data suggests that although these high-intensity fires may have reduced the

Izak Smit

High-intensity fires on hot, dry days towards the end of the dry season can open a landscape of woody cover, at least in the short term, but with high collateral damage to tall trees.

woody cover in the short term, they may increase woody cover in the long term by stimulating trees to grow back as multi-stemmed individuals, coppicing from roots and resprouting from the main stem. This is an ongoing project and the results will have implications for how fires of different intensities can or cannot be used in an attempt to address woody encroachment – a concern in savannas across many continents.

Roads and trees

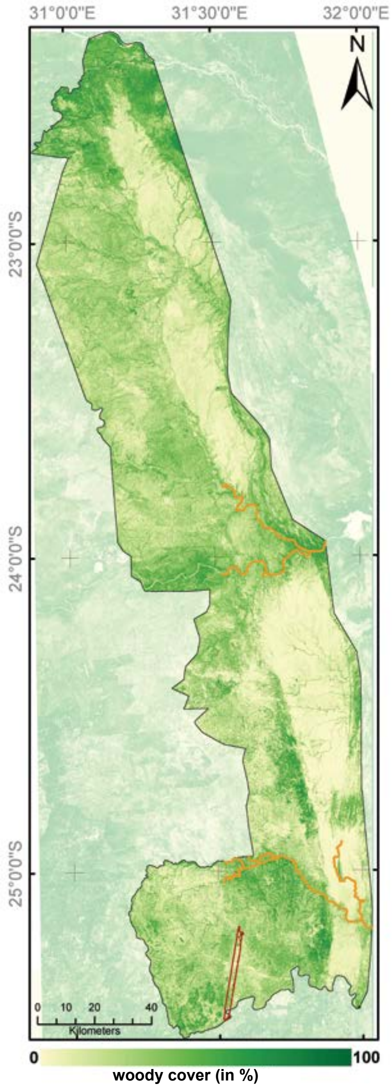
Another interesting insight from the lidar data was that tree cover is higher for trees growing closer to roads. This effect is seen up to about 10–15 m from roads, extending furthest from the road in areas with higher average rainfall conditions. It is expected that this 'hedging' effect alongside the roads may be due to roads 'harvesting' rainfall for the surrounding landscapes, via runoff from the hardened road surfaces. The hedging displays a typical distance-decay function, with the biggest increase in woody cover closest to the road (within 5 m) and then decreasing at increasing distance from the road, until background tree cover is achieved around 10–15 m from the road. Although these findings were consistent and very noticeable when analysing the lidar data across various soil and rainfall environments in the KNP, the effects are too subtle to see with the naked eye, and would have been very hard to detect with field-based surveys.

Lidar and satellite upscaling

Although lidar has many advantages and can provide detailed vegetation structural data over large scales, as illustrated by some of the case studies provided above, it can be costly to collect such data over very large landscapes, such as the KNP's entire 1.9 million hectares. In these cases, satellite imagery may be a more suitable remote-sensing product to use. Over large scales, satellite imagery is cheaper, or even free, and can be collected more frequently, although aerial lidar may still have an important role to play in focusing in on smaller areas. For example, lidar data was used in a recent study to calibrate and validate random forest models to estimate woody cover from the radar data collected by the European Space Agency's Sentinel-1 satellite sensor. The lidar calibration and validation imagery played an important role in creating a wall-to-wall woody cover map at 10 m spatial resolution for the entire KNP.

Allan Watt, CC BY-NC

Lidar data has revealed higher tree cover alongside KNP roads, creating a 'hedging' effect that is not apparent to the naked eye.



Urban et al. 2020, Koedoe, https://doi.org/10.4102/koedoe.v62i1.1621

Lidar data collected at the red and orange strips was used to calibrate and validate models to estimate woody cover across the entire KNP at a 10 m resolution, using radar time series from the Sentinel-1 satellite mission.

There may also be potential for using space-based lidar data in future, but this has not yet been explored for the KNP. For example, NASA's Ice, Cloud and land Elevation Satellite-2 (ICESat-2) and its Global Ecosystem Dynamics Investigation (GEDI) mission on the International Space Station – both launched in late 2018 – provide lidar data that may be useful for monitoring changes in canopy height and cover.

Lidar will never replace field-based studies, but has become an incredibly powerful tool in the toolbox of ecologists working in the KNP. Lidar has allowed small-scale patterns (e.g. location and height of individual termite mounds) and small-scale dynamics (e.g. fate of individual trees) in the KNP to be studied over large scales (thousands of termite mounds; tens of kilometres of road verges; >10 million trees; hundreds of thousands of hectares), and in many different and contrasting environmental contexts (different soils, rainfall, fire and herbivore conditions).

The KNP has become a popular lidar 'research destination', the most recent addition being a collaborative project by Harvard University and SANParks. The project explores what new insights can be gained from combining ultra-high resolution lidar data before and after fires with thermal imagery collected during active fires by means of a state-of-the-art drone system. Lidar is helping KNP scientists and collaborators better understand vegetation patterns and processes in order to inform management approaches to various ecological challenges.

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Lidar images by Shaun Levick created using data from the Global Airborne Observatory (GAO), Arizona State University (formerly Carnegie Airborne Observatory) unless otherwise indicated.

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