# WOODY ENCROACHMENT

## Study examines impact of mopane infestation on ecosystem services

*Studying the effects of woody encroachment on evapotranspiration in the semi-arid savanna region of southern Africa could provide insight into related groundwater and streamflow impacts at the landscape and biome scales. Article by Jorisna Bonthuys.*

At the Mthimkhulu research site located approximately 40 km north of Phalaborwa in northeastern Limpopo, PhD student Tiffany Aldworth and scientists from the South African Environmental Observation Network (SAEON) have been exploring the effects of large-scale changes in vegetation due to mopane encroachment on freshwater resources.

Mopane (***Colophospermum mopane***) is a tree or shrub species indigenous to central and southern Africa. It is one of the main encroaching species in the southern African region, where it often grows in dense, monotypic stands with little to no grass cover.

In the northeastern region of South Africa, the density of mopane has significantly increased over the last few decades, with implications for forage production, biodiversity, water resources and tourism activities. In particular, considerable concern has been raised over the impact on water resources. The region has a semi-arid climate with low and highly variable rainfall, and droughts are common. In addition, the area's growing rural population is increasing the water supply demand.

The topic of woody encroachment, also commonly known as bush encroachment, woody thickening or thicketisation, has long been an area of scientific focus for researchers linked to the SAEON. This network encompasses seven national research nodes and performs long-term environmental observation and research.

Aldworth did her research at the Mthimkhulu Game Reserve in Limpopo, a private reserve owned by a local tribal authority. The reserve is part of the Greater Kruger National Park region, comprising the Kruger National Park and the private game reserves located west of the Kruger National Park. The Mthimkhulu reserve shares open borders with the northeastern side of the park.

The seasonal Klein Letaba River, a tributary of the Letaba River, is situated adjacent to the study site, which receives an average of 467 mm of rain annually. The reserve's vegetation is classified as Lowveld Mopaneveld, a semi-arid savanna characterised by a dense cover of mopane shrubs, sparsely scattered trees and a limited grass understory.

At Mthimkhulu, mopane encroachment has likely been triggered by poor land management practices over the past century, particularly overgrazing by cattle, Aldworth points out. She recently published some of her findings on the effects of mopane encroachment on evapotranspiration at the Mthimkhulu reserve in MDPI's ***Hydrology*** journal (Visit: https://www.mdpi.com/2306-5338/10/1/9).

The term ***evapotranspiration*** refers to the sum of water that is lost to the Earth's atmosphere through plant transpiration and evaporation of soil water and rainwater collected by the plant canopy. ***Transpiration*** refers to the evaporation of water from stomata (the tiny pores found in the epidermis of leaves, stems and other plant organs). This natural evaporative 'cooling system' brings down the temperature of the trees – it allows gases such as carbon dioxide, water vapour and oxygen to diffuse into and out of plants.

Aldworth says that a stable balance of grassy and woody plants in savanna ecosystems is vital in ensuring that these savannas can effectively support and regulate ecosystem services to society. These 'services' are defined as the benefits humans derive from nature, such as clean soil, food, air, and water.

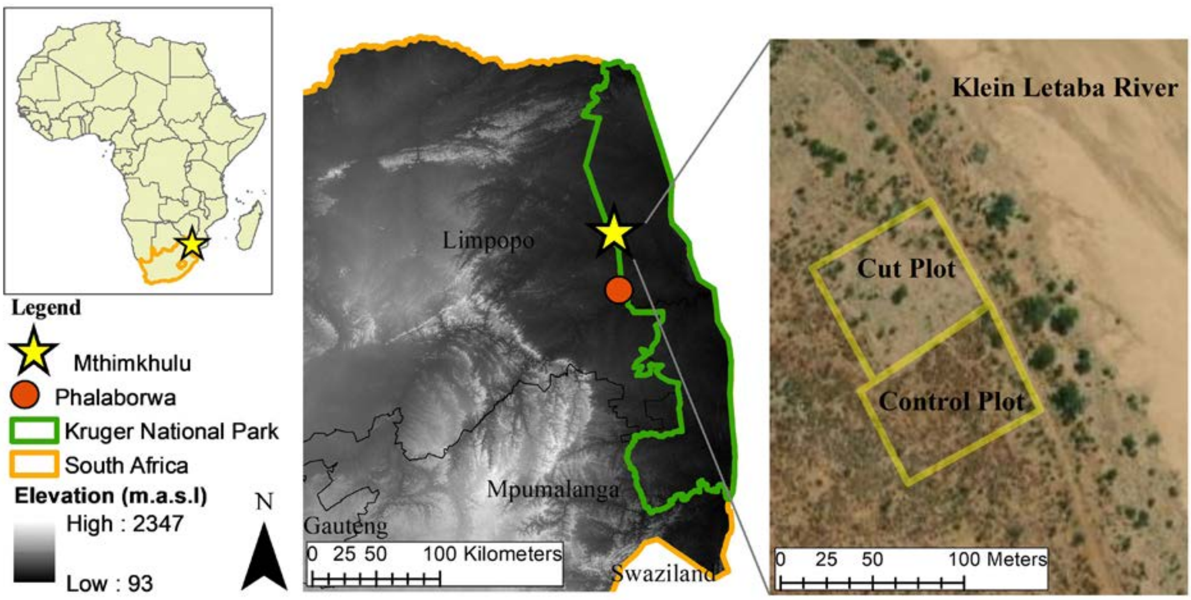
Woody encroachment alters the structure and functioning of ecosystems, she points out. This means that continued mopane encroachment could have significant implications for the supply and value of those ecosystem services delivered from them. For example, increased woody biomass can reduce streamflow, groundwater recharge, grazing capacity, and biodiversity.

There are, however, also several benefits linked to an increase in the density of mopane trees. Mopane can, for example, facilitate carbon sequestration to help mitigate climate change. In addition, it is used extensively for fuel and firewood (approximately 80% of rural households in northeastern Limpopo use wood as their primary energy source for cooking and heating), building material, and medicinal purposes. Furthermore, it is the host of the mopane worm, a highly nutritious protein source that provides food for many and sustains trade for income.

"It is, therefore, important to refine our understanding of the drivers and impacts of mopane encroachment in this area," she notes.

In 2015, the SAEON established an experimental woody plant clearing trial at the Mthimkhulu site. Experimental plots of either 60 metre x 60 metre or 120 metre x 120 metre were cleared of all mopane trees shorter than 4 metre, creating 'cut' treatments of open savanna adjacent to 'control' plots of dense savanna. No treatment has been applied to the control plots. Today, this site comprises five control plots and five neighbouring cut plots.

Researchers have been working with the local tribal authority to develop a long-term research platform in the area. Dr Tony Swemmer, the manager of the SAEON Ndlovu Node, has been instrumental in setting up this site. Aldworth has collaborated with Swemmer and other SAEON scientists to determine if woody encroachment affects the water cycle at the study site. This work forms part of a larger National Research Foundation programme that aims to model the effect of woody plant cover on evapotranspiration across South Africa.




*Location of the Mthimkhulu Game Reserve and the location of the control and cut plots within the reserve.*

Tiffany Aldworth

*Vegetation and research equipment at the control plot in the summer (top-left) and spring (top-right), and the cut plot in the summer (bottom-left) and spring (bottom-right).*

SAEON established the Mthimkhulu site to compare ecosystem functioning and biodiversity in a protected area and communal rangeland, and determine the costs and ecological impacts of bush-clearing. The scientists involved review the extent and causes of woody encroachment, evaluate its impacts, and interpret their results to inform appropriate policy responses at this site and elsewhere in the savanna region. They also consider active management options, proactive land management tools and potential best practices to manage woody encroachment.

**Understanding woody encroachment**

Woody encroachment has been amongst the most significant vegetation changes in the region over the past century, as is the case for many savannas globally. In southern Africa, such woody encroachment has been particularly widespread in arid and semi-arid savannas.

Overgrazing, fire suppression, rising temperatures, altered rainfall patterns and increasing atmospheric $CO_2$ concentrations (due to rising fossil fuel use) are considered some of the underlying drivers of this phenomenon. One of the biggest questions in this landscape is the impact of climate change and how elevated $CO_2$ levels help fuel rampant encroachment, Aldworth points out.

Scientists estimate that woody plants have encroached on 10 million to 20 million hectares of South Africa's savanna and grassland landscapes.

Savannas and grasslands comprise 46% and 29% of South Africa's land surface area, respectively. Since researchers first undertook national-scale aerial photography in the 1940s, woody biomass has significantly increased within these biomes due to woody encroachment and the spread of alien invasive plants.

Investigations on the hydrological impact of invasive alien plants occurring in the higher rainfall regions of South Africa have received much attention in the past and policy direction on these species is clear. Less research has, however, been conducted on woody encroachment in the drier parts of the country. Few studies have also measured changes in evapotranspiration in response to any encroaching species in southern Africa.

This study is the first of its kind, focusing on the evapotranspiration of mopane encroachment in a semi-arid savanna in the northeastern corner of the country.

"Mopane is considered an aggressive competitor for available soil water with shallow-rooted grasses and other woody plants," Aldworth says. "Its competitive advantage [to access water] is thought to be primarily attributed to the adaptations of its roots. Although the roots of mopane are not as deep as other trees, it has a large root biomass which extends horizontally well beyond the extent of its canopy, allowing access to soil water over a large area."

Studies have also found evidence that mopane roots can utilise soil water at a matric potential lower than that of grasses and other woody plants, allowing them to extract water from very dry soils.

Unpublished data from a mopane root survey conducted by the SAEON at a site roughly 30 km south of the Mthimkhulu reserve also showed that the highest mean root concentration occurs within the first 50 centimeters of topsoil, which is very shallow for a tree species. In addition, most coarse mopane roots extended horizontally to a distance of approximately 2 metres from the tree trunks. Some roots extended as far as 16 metres away from the tree trunks.

Furthermore, scientists predict a 1.5°C to 3.5 °C temperature increase and no or little decrease in precipitation by 2100 for the Kruger National Park area. While precipitation in the area is not projected to change greatly, available soil moisture in the region is expected to decrease as a result of the large temperature increases causing greater evapotranspiration. Under future modelling scenarios, mopane populations are at the same time expected to increase in the northern Kruger National Park region.

Aldworth says that long-term environmental observation is vital to understanding some of the large-scale ecological changes underway in the region. In this regard, SAEON's efforts at the study site provide a platform for studying some of the major environmental changes being detected in the Lowveld region. Researchers are, for instance, disentangling the impacts of climate, fire and herbivores (particularly elephants) on the productivity and biodiversity of the savanna ecosystem.

**Surface renewal method**

In her study, Aldworth set up instrumentation to measure the evapotranspiration losses from the vegetation. Surface renewal systems were deployed on one cut plot and its neighbouring control plot.

While the surface renewal method is not a new method, an increasing number of studies conducted worldwide report its successful application for estimating evapotranspiration over a wide range of surfaces, including open water, wetlands, grasses and agricultural crops. This method is also being trialled for various vegetation surfaces and climate types in South Africa by some of Aldworth's SAEON colleagues working in the Grassland-Forest-Wetlands Node.

The method often yields valuable data. Surface renewal analysis is based on the coherent structure theory, which assumes that air parcels near a plant canopy are continuously replaced or 'renewed' by ambient air parcels descending from the atmosphere above. While in contact with the canopy, the air parcels are heated or cooled, due to heat exchange between the air and the canopy.

Using high-frequency air temperature measurements taken above the canopy and plotting them against time, the temperature fluctuations of these individual air parcels exhibit organised, coherent structures, which resemble ramp events.

"Knowing the dimensions of these temperature ramps allows for an estimate of the heat exchange of the air parcel with the canopy," Aldworth explains. "This information, in turn, enables us to estimate the sensible heat flux to or from the canopy."

She used electrical sensors that measure temperature called fine wire thermocouples to collect high-frequency air temperature readings. These readings were needed to estimate sensible heat flux.

Aldworth then calculated latent heat flux indirectly as the residual of the shortened surface energy balance equation, along with net radiation and soil heat flux measurements. Finally, she converted the latent heat flux data into actual evapotranspiration data.

Aldworth employed the more widely used eddy covariance method to calibrate the sensible heat flux data estimated using surface renewal. She carried out week-long eddy covariance campaigns alongside the surface renewal systems in summer and spring to obtain calibration factors for each plot. This methodology allowed Aldworth to produce continuous evapotranspiration data for nearly three years (from November 2019 to July 2022) in two adjacent savanna plots of differing woody plant densities – the first such dataset for savanna ecosystems in South Africa.

"To our knowledge, this is the first validation test of the surface renewal method over semi-arid savanna-type vegetation worldwide," she says.

**Research gains**

Over the three hydrological years of the study, evapotranspiration was highly seasonal. It was typically highest during the wet season when it responded to increased soil water availability, and lowest during the dry season, due to the deciduous nature of the vegetation.

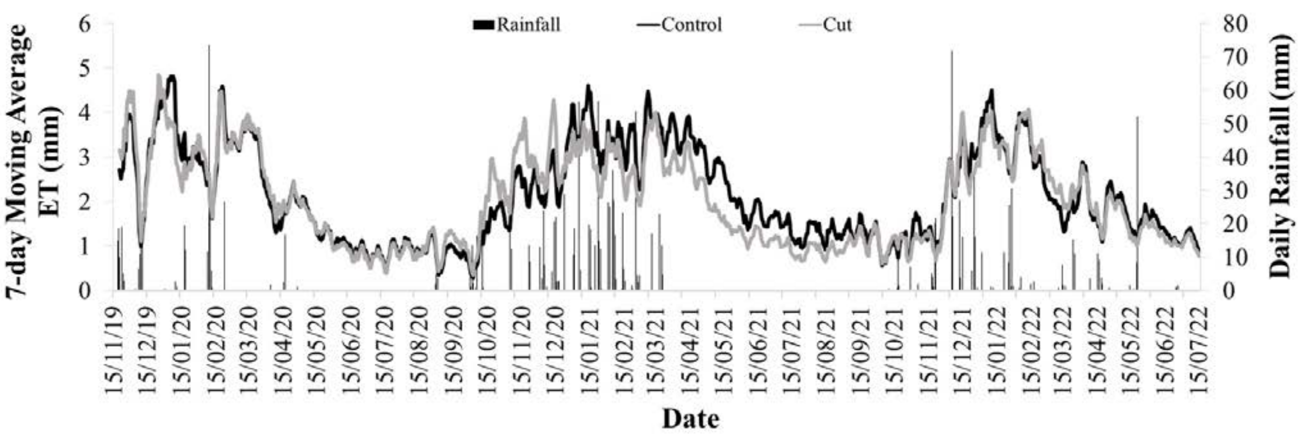
"The results suggest that grasses at the cut plot can expand their leaf area and start transpiration more rapidly than mopane trees once soil water becomes available at the beginning of the rainfall season, which fits phenology observations. However, towards the end of the wet season, the grass swards generally senesce before the mopane leaves, allowing the mopane to maintain higher evapotranspiration rates later into the growing season.

"The offset in their responses may have been a result of the mopane keeping its leaves until late into the growing season to meet a seasonal growth cycle, or the mopane's large rooting systems may have been able to access deeper soil water than the grasses as the upper soil layers dried up."

During the two drier years of the study, the removal of mopane trees had little effect on evapotranspiration at the study site. All rainfall evaporated regardless of the density of woody plants. However, for the wettest year of the study (2020-2021), removing mopane trees decreased evapotranspiration by 12%.

"These results support the hypothesis that woody encroachment

**Evapotranspiration graph**




*Daily values of evapotranspiration over the course of three hydrological years (2019-2022) at the Mthimkhulu research site. The black line shows the evapotranspiration measured in the control plot with a high cover of mopane shrubs, and the grey line in the open, cut (grassland) plot. The daily rainfall is given on the secondary axis.*

Photo supplied

*Mopane is a deciduous tree which limits its transpiration during the dry winter season by shedding its leaves. It typically retains its leaves longer into the dry season than other woody species and grasses growing in the same area. Depending on soil conditions and water availability, mopane can grow in shrub or tree form and it rarely grows taller than 5 metres high.*

in semi-arid savannas can increase evapotranspiration, at least during years of above-average rainfall, and thus may reduce groundwater and soil water profile recharge," she adds.

Another significant finding of the study was that the annual evapotranspiration exceeded the annual rainfall in all three years studied at the site. For the 2019–2020 hydrological year, the driest of the three years, the annual evapotranspiration exceeded the annual rainfall at both plots by 80%.

The following year (2020–2021) was much wetter. During this year, the annual evapotranspiration at the cut plot was similar to the annual rainfall, but the evapotranspiration at the control plot exceeded the annual rainfall by 11%. For 2021–2022, a year that had a more typical average rainfall, evapotranspiration exceeded the annual rainfall at the control and cut plots by 15% and 13%, respectively.

These results suggest that rainfall may not have been the only source of water used by vegetation during dry periods.

"There is the possibility that the vegetation, particularly the larger trees, used water from deeper soil stores or groundwater that rose to within the rooting depth by hydraulic lift," Aldworth says. "The water tables are likely shallow or perched since the plots are located near the riparian area of the Klein Letaba River." Hydraulic lift is a process where plant roots facilitate the movement of deep soil water towards shallower soil layers.

In a previous study at the site, scientists used stable isotopes to determine that mopane trees make use of deeper soil water than grasses. No groundwater samples were, however, taken to verify whether groundwater was a source of water used by the vegetation.

More research on evapotranspiration and soil water processes is needed to advance scientific understanding of the relationship between vegetation structure, vegetation water consumption and water supplies in semi-arid savannas. Further isotope studies are also needed to confirm the water sources used by the vegetation.

"We need to know more about the exact mechanisms involved and the consequences of this for groundwater and streamflow at landscape scales.

"The surface renewal approach with eddy covariance calibration offers a viable method for estimating evapotranspiration in semi-arid savanna vegetation."

Aldworth is currently working on two more research papers using data collected at the Mthimkhulu site. The first paper investigates how mopane encroachment affects soil water processes and how much water is stored in the soil. The second is based on her study of the impact of woody encroachment on hydrological processes, but upscaled to a larger scale using remote sensing tools.

"Mopane encroachment may have significant hydrological implications for the semi-arid savanna region of southern Africa," she concludes. "We must upscale our in situ results to determine how the hydrology of this region is being affected and to inform appropriate management responses."