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Carbon Fertilisation is the Primary Driver of Shrub Encroachment in South African Savannahs

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Woody plant encroachment has been documented for savannahs and grasslands in nearly all continents. Yet the drivers of this process remain unclear, with a range of local and global factors postulated. The traditional ecological narrative dictates that shrub encroachment is a localised phenomenon, resulting from poor land management regimes. The most frequently proposed mechanisms are overgrazing and suppression of fire, both of which are common management techniques in sub-Saharan Africa. More recently, increased focus has been directed at the role of global factors in woody cover dynamics. As savannah woody cover is constrained by both total and wet season rainfall, changes in precipitation regime have been proposed as drivers of shrub encroachment. This theory has been supported by small-scale field experiments showing shrubs disproportionally benefiting from increases in rainfall frequency, amount, and variability. A further potential global factor is the ongoing rise in atmospheric CO_2 concentrations since the industrial revolution. A theoretical understanding of water limitations to woody cover in savannahs makes it reasonable to assume that CO_2-driven increases would be concentrated in water-limited environments. This has been observed across South Africa using aerial photography and globally using satellite-derived Rain Use Efficiency (RUE).

Here, we combine satellite-derived fractional woody cover maps with a suite of potentially explanatory variables, to elucidate on the potential drivers and mechanisms of woody cover change, in South African savannahs. The study area consists of the Limpopo and North West Provinces in northern South Africa. These municipalities cover a plurality of the savannah biome within South Africa (193,200 km^2, 49% of the total savannah area), in addition to containing 33,830 km^2 of grassland.

More specifically, we test the three, abovementioned, competing hypotheses on the drivers of woody encroachment for South African savannahs. Our modelling framework was developed using Generalised Additive Models (GAM). We collated a series of 11 variables that have a hypothetical basis for explaining woody cover changes. These variables can be grouped into three categories: rainfall-derived, human, and natural factors.

Fractional woody cover changes were mapped using Landsat-derived % woody cover layers, based on the methodology developed in Higginbottom et al. (2018, ISPRS Journal Ph&RS, 139, 88-102). In summary, two five-year epochs (1984-1988 and 2008-2012) of Landsat imagery were used to generate pixel-level seasonal spectral variability metrics, at 120 m resolution. Reducing the pixel resolutions improves the classification accuracies, and is more suited for observing overall trends. High-resolution imagery were classified into woody/non woody masks, and used as training data for a Random Forest regression for the fractional cover of each 120m-pixel. The Random Forest model was applied to the Landsat metric stacks to generate the two epochal maps. We then calculated both the absolute percentage change, and the relative percentage change in woody cover between the two maps.

The fitted models had R^2 values of 0.39 for absolute change and 0.41 for relative change. The results show that the modelled variables most closely matched the *a-priori* responses of the carbon fertilisation hypothesis. In recent years, this explanation has been postulated by studies using a variety of methods to account for the observed woody encroachment. Further work in this arena is still necessary, particularly where the data sources are sub-optimal. Land-use history and rainfall dynamics are especially difficult to quantify and would require further investigation. Furthermore, additional factors, such as reactive nitrogen deposition and mega-fauna extinctions, are likely to be relevant but where not included in our models. If carbon fertilisation is the key driver of shrub encroachment in savannahs, it would raise concerns for future environmental change: as CO_2 levels continue to rise more savannahs and grassland are likely to experience an increase in woody cover levels, which has been linked to savannah land degradation.