The Reforestation of Africa?

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There is a global obsession with deforestation, and not without reason, given the lessons of recent human activity in tropical systems. With this in mind, a recent paper in *Nature* by Higgins and Scheiter[1] poses a challenging question for African ecologists and environmentalists: do we, in the subcontinent, face not a contraction, but a vast and inevitable expansion of subtropical tree cover, driven by levels of CO_2 that have not been seen in the past several million years? Higgins and Scheiter's paper warrants our attention because it projects, for the first time, the continent-wide implications of the decade-old hypothesis, originally formulated by South African ecologists, of CO_2-driven woody expansion in fire-prone savannas.[2] The paper supports concerns that the expansion of woodlands and forest may be an imminent threat to ecosystem structure, function and biodiversity across extensive landscapes in the sub-continent.[3] If its projections are correct, then we stand on the brink of massive ecosystem change in the 'savanna–complex' vegetation (i.e. tropical grasslands, savanna and forests) of Africa. But how credible are these projections?

Unlike more intensively researched temperate ecosystems, the vegetation structure and land cover of huge tracts of sub-Saharan Africa may be highly sensitive to increasing levels of atmospheric CO_2. Vast areas of the subcontinent are currently dominated by C_4 grasses – a photosynthetic mode that owes much of its competitive advantage to the low CO_2 levels of pre-industrial and, even more so, glacial times.[4] Grasses do not require the large amounts of carbon that woody plants do to support their photosynthetic tissue. This low carbon demand for growth allows grasses to outcompete woody plants under low CO_2 conditions by building up a flammable layer of grass fuel – the savanna fire trap – that immolates slower growing woody plants and maintains the system in its grassy state. Under high levels of CO_2, trees are thought to regain the advantage, escaping the fire trap and converting the system into forest.[2] This mutable balance of trees versus grasses, mediated by atmospheric CO_2 levels and fire, results in 'bi-stable' systems[5] in which either grasses or trees could dominate. These bi-stable systems are highly prone to the infamous 'tipping point', an abrupt switch to an alternate stable state from which the original ecosystem does not easily recover.

C_4 grassland and savanna ecosystems spread globally only in the last 8 million years[6] – a spread that was primed by an extended period of low atmospheric CO_2 levels. Today, C_4 grassland and savanna ecosystems contain some of Africa's most iconic biodiversity and support a large fraction of Africa's human population. Together with subtropical savannas in other parts of the world, these ecosystems are vast enough to have a major impact on the earth system. However, fossil fuel emissions have now driven atmospheric CO_2 levels higher than those experienced by plants for at least the last 800 000 years,[7] and possibly several million years. If emissions continue on a 'business-as-usual' path, by mid-century, CO_2 levels will exceed those last seen more than 25 million years ago – far predating the rise of grasslands and savannas. Could these elevated CO_2 levels result in a widespread and abrupt shift from grassy to woody vegetation across Africa?

Higgins and Scheiter[1] attempted to answer this question using an adaptive dynamic global vegetation model (aDGVM).[8] Mechanistic models of this kind use established plant physiological mechanisms and spatially explicit climate data to simulate potential vegetation through modelling the growth of individual plants of a variety of 'functional types' (e.g. grasses, shrubs and trees), the outcome of competitive interactions between individuals, and processes such as disturbance by fire. Ultimately, vegetation types are categorised according to the relative cover and/or biomass of plant functional types. What makes their 'adaptive' approach unique, compared with other DGVMs, is that they model the ability of plants to adapt their phenology and growth so as to change their allocation of carbon to different plant compartments such as roots, stems and leaves. This model is a key advance that represents, more credibly than earlier DGVMs, the mechanisms behind the escape from the savanna fire trap. As a consequence, by turning fire on and off in their simulations, they are able to specifically identify 'bi-stable' areas which could support either trees or grasses.

Using the A1B emissions scenario from the Intergovernmental Panel on Climate Change Special Report Emissions Scenarios, Higgins and Scheiter projected large shifts in 'savanna–complex' vegetation types from 1850 to 2100. Key projections were:

1. A general shift to a more woody state across the continent as a result of reductions in C_4 grassy ecosystems, and the spread of forests, as a direct result of increases in atmospheric CO_2.
2. A rapidly accelerating shift to forest over this century. Between 1850 and 2000, the model projects only an incipient change. However, from 2000 to 2100, a 10-fold increase in woodiness is projected across the continent.
3. Bi-stable areas capable of sustaining both grassy and forest vegetation moving to largely non-overlapping areas between 1850 and 2100. Thus, while these bi-stable states continue to persist, they do so in different geographical locations in the future – a major challenge for conservation and adaptation planning.
4. Extremely abrupt changes from grassy to woody vegetation at the local scale (read 'tipping point'), but not synchronously across the continent. It is from this projection that the paper takes its rather ambiguous title – 'Atmospheric CO_2 forces abrupt vegetation shifts locally, but not globally' – meaning that the projected 'global' transition to woodiness across the continent will not occur as abruptly as it will at a given locality.

Are these projections credible? While the Higgins and Scheiter paper is a significant advance in dynamically simulating future African vegetation cover, there remain important uncertainties. For example, Higgins and Scheiter assumed constant rainfall over the 1850–2100 period because: 'The high uncertainty in precipitation change over Africa led us to assume that rainfall remained at ambient levels'[1]. Considering the fundamental effect rainfall has on net primary productivity[9] and tree mortality,[10,11] and the fact that rainfall frequency and intensity is likely to change in an evolving climate,[12] their assumption seriously compromises any assessment of the sensitivity of their projections to possible rainfall change – a remarkable omission. Another significant limitation of the model is that the aDVGM does not simulate nitrogen limitation of growth via nutrient cycling feedback at the ecosystem level. This shortcoming, which has been resolved in other DGVMs, could exaggerate the simulation of forest expansion. Additionally, changes in land use, including deforestation for growing crops, fire management and feedbacks between vegetation and climate, will also influence Africa's future land cover. The extent to which these drivers may counteract the forcing of elevated CO_2 and temperature is currently unknown.

What is particularly interesting is that the dramatic CO_2-driven ecosystem changes projected by Higgins and Scheiter are in stark contrast to a more traditional, climate-centric view of the world, where African vegetation appears to be highly stable.[13] Their model provides strong evidence that the equilibrium, 'one climate, one vegetation' approach[13] is inappropriate for Africa, where direct CO_2 effects on plants appear to be an important driver of vegetation.

Higgins and Scheiter's study therefore prompts urgent consideration of several key questions. Are African C_4 landscapes doomed under elevated CO_2? Will we see a 'reforestation' of subtropical Africa in the coming decades? Or are alternative drivers like changes in land use or rainfall likely to oppose the CO_2-driven trend? Currently, climate uncertainty and socio-economic uncertainty combine to create a murky view of the future. Only through an interdisciplinary approach can these knowledge gaps be spanned.

Recently, several funding initiatives in South Africa have emerged that promise to advance our understanding of African land-cover change. In 2010, strategic funding from the University of Cape Town initiated the formation of the Land Cover Change Consortium,[14] a group of interdisciplinary scientists from across South Africa that examines land-cover change from an experimental, observational and modelling perspective. Research initiatives such as these are now benefitting from funding allocated through the Department of Science and Technology's Global Change Grand Challenge, the National Research Foundation's ACCESS programme and funding from multinational partners (e.g. Southern African Science Service Centre for Climate Change and Adaptive Land Management, www.sasscal.org) that will support research (and students!) in this area until at least 2020. Additionally, there is an upswing in experimental facilities and field sites targeting global change research nationally. For example, Rhodes University has just committed to co-funding a National CO_2 Research Facility for plant sciences. With the clear imperatives for science to address societal challenges, and the support of government and funding agencies for these initiatives, it is an exciting time to be involved in CO_2 and land-cover change research in South Africa.

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