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Spatio-temporal dynamics of woody vegetation structure in a human-modified South African savanna

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Abstract

Ecosystem services, nature's benefit to people, contribute to human well-being. Extensive reliance on, and unsustainable use of, natural resources is typical of the rural poor in developing countries and can lead to ecosystem degradation, decreased ecosystem service provision, and increased vulnerabilities of rural populations. Most ecosystem services are intangible or difficult to quantify, but fuelwood provisioning can be measured directly and can serve as a proxy for the status of other ecosystem services (e.g. aesthetic and spiritual services, nutrient cycling, carbon sequestration). South African rural communities have a high reliance on fuelwood despite extensive access to electricity. Within this context, live wood harvesting occurring around rural settlements in increasing amounts has been deemed unsustainable. However, the 'fuelwood crisis' of the 1970s, and subsequent predictions of woodland collapse through fuelwood supply-demand models, has still not occurred despite substantial population growth in developing countries. Hypothesised reasons for modelled supply-demand mismatches are based on underestimation of fuelwood supply and woodland regeneration, as well as overestimation of fuelwood demand by discounting behavioural adaptability of users. It is likely that the spatial configuration of fuelwood use allows for the co-adaptability of both humans and ecosystems. A lack of understanding of the spatial configuration of these social-ecological dynamics limits our insights into current and future adaptive responses and thus, the degree of sustainability. This thesis aimed to assess woody biomass stocks and vertical structure changes, as a proxy for provisioning ecosystem services, in a spatially and temporally explicit manner, to describe the status and impact of wood extraction in semi-arid, savanna communal lands. Using repeat, airborne light detection and ranging (LiDAR) data from 2008 and 2012, we surveyed three-dimensional woodland structure in Bushbuckridge Municipality communal lands – the grazing and harvesting areas for densely populated rural settlements in former Apartheid 'homelands' in South Africa. Woody biomass in 2008 ranged from 9 Mg ha^{-1} on gabbro geology to 27 Mg ha^{-1} on granitic geology. Land-use pressure was associated with compensatory regrowth of savanna tree species through post-harvest coppice in the 1-3m height class. Woody biomass increased at all sites, contrary to previous fuelwood models of the area. Change detection in the vertical canopy structure revealed that biomass increases were almost solely attributable to the 1-3m and 3-5m height classes. These changes were exacerbated by wood extraction intensity in the communal lands – the communal land with the highest wood extraction pressure experienced

the greatest biomass increases, likely a strong regrowth response to high harvesting levels. Within communal lands, areas closest to roads and settlements experienced substantial biomass increases as a result of shrub level gains. This relationship was mediated by the usage gradient – the greater the wood extraction pressure on the communal land, the larger and more spatially coalesced the 'hotspots' of shrub-level increases were in relation to ease of access to the communal land. However, biomass increases are not necessarily indicative of woodland recovery, as shrub-level increases were coupled with losses of trees >3m in height. To explore these tall tree dynamics further, we tracked >450 000 individual tree canopies over two years over contrasting landscapes – a private reserve containing elephants, two communal lands under different wood extraction pressures, and a nature reserve fenced off from both elephants and humans. Humans are considerable drivers of treefall (defined here as a ≥75% reduction in the maximum height of each tree canopy) in communal lands. Human-mediated biennial treefall rates were 2-3.5 fold higher than the background treefall rate of 1.5% treefall ha^{-1} (in the control site – the reserve containing neither elephants nor humans). Elephant-mediated treefall was five fold higher than the background rate. Rate and spatial patterns of treefall were mediated by geology and surface water provision in the elephant-utilised site where relative treefall was higher on nutrient-rich geology, and intense treefall hotspots occurred around permanent water points. Human-mediated rates and spatial patterns of treefall were influenced by settlement and crop-land expansion, as well as ease of access to communal lands. Frequent fires facilitated the persistence of trees >3m in height, but was associated with height loss in trees <3m. The combined loss of large trees and gain in shrubs could result in a structurally simple landscape with reduced functional capacity. Shrub-level increases in the communal lands are likely an interactive combination of newly established woody encroachers and strong coppice regrowth in harvested species. The more intensely used the communal land, the greater the bush thickening and the stronger the relationship between biomass gains and structural changes in the lowest height classes. The exacerbation of bush thickening in natural resource-dependent communities has critical implications for ecosystem service provision. There is potential for coppice regrowth to provide fuelwood to communities using 'tree thinning' programmes, but there is a lack of data on the quantity and quality of the regrowth, as well as the sustainability of coppice, the impacts of different harvesting methods, and the potential feedbacks with changing climate and CO_2 fertilisation. Woody resource spatial distribution in communal lands is centred around settlement-level wood extraction pressure, as well as natural resource accessibility in the woodlands. In highly utilised areas, woodland regenerative capacity has been underestimated. Additionally, natural

resource extraction is still highly localised, even at the communal land scale, with major structural changes occurring around the periphery or close to existing infrastructure. However, it is these underrated coupled adaptive responses in social-ecological systems that explain the failure of fuelwood supply-demand models' predictive abilities. Nevertheless, loss of large trees in the landscape and the persistence of 'functionally juvenile' coppice stands will have implications for seedling production and establishment in the landscape with repercussions for the future population structure and ecosystem service provision. I discuss the implications of increased natural resource reliance in an African development context and the positive feedback between rural poverty and environmental impoverishment. Potential constraints to the data are unpacked, together with opportunities for further research in this area.