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Estimating aboveground tree biomass in three different miombo woodlands and associated land use systems in Malawi

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ABSTRACT

Trees outside forests support smallholder farmers' livelihoods and play a critical role in the global carbon cycle. However, their contribution to climate change mitigation through carbon storage is not obvious because of limited information regarding their extent, and inadequate methods for biomass quantification. This study evaluated the distribution of aboveground biomass (AGB) in three 100 km^2 benchmark sites in Kasungu, Salima, and Neno districts in Malawi. In 67 sample plots covering 37 cultivated fields and 30 woodland plots, a total of 2481 trees were inventoried over 6 ha. Tree species documented were 56 in Kasungu, 35 in Salima and 33 in Neno. The corresponding values of the Shannon diversity index and its standard error (SE) were 3.45 (0.01) for Kasungu, 2.78 (0.01) for Salima and 2.73 (0.01) for Neno. The three most dominant species in terms of biomass were *Faidherbia albida* (47.8%), *Piliostigma thonningii* (11%), and *Mangifera indica* (9%), all found in cultivated fields. Large trees with diameter at breast height (DBH) >40 cm formed only 3% of the total population inventoried in Salima, but held over 80% of the biomass. These high biomass trees were hardly found in Kasungu and Neno. Smaller trees (DBH < 10 cm) dominated all the sites, representing 93% of all the trees measured. These stock 14, 1, and 67% of the biomass in Kasungu, Salima, and Neno, respectively. The biomass estimates established in this study provide a useful reference against which future estimates can be compared, and sets a baseline for calculating changes in carbon stocks over time.

1. Introduction

The miombo woodlands represent a significant portion of tree cover in Malawi, although a greater part of these have been heavily modified [1]. Modification of the miombo woodlands has been attributed to land use and land use change and associated resource utilization [2,3]. The miombo woodlands diversify the income of the rural smallholders, improve nutrition and food security [4], and are a major source of fuelwood and building materials for households [2,5]. Fuelwood comprises over 90% of the primary energy supply in Malawi, mainly utilized as firewood and charcoal. The supply of fuelwood in Malawi has declined over the years, because of

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increasing population and the subsequent widespread over-utilization of wood resources [5,6]. This has led to degraded forms of miombo woodlands that are characterized by land plowed for crop production, and unplowed sections used to provide fuelwood and other wood products [1]. At the same time farmers selectively retain or introduce trees of interest in fields cleared for agriculture [7]. Further, fast growing species such as eucalypts and pines have been grown in large scale plantations, woodlots and around homesteads in order to meet the increasing demand for fuelwood [7,8]. While clearing the woodlands for agriculture and settlement and extraction of wood for fuel are known to reduce tree cover, it is presently difficult to quantify losses or gains related to these processes, in terms of biomass and carbon stocks, due to lack of ground data and appropriate biomass equations.

Awareness is growing about the potential to combat climate change by increasing trees in farming areas. Studies already show that adding trees to land traditionally used for agriculture raises productivity and secures both mitigation and adaptation benefits [9,10]. Further, trees in agricultural lands provide ecosystem services that support agricultural production, such as pollination, biological pest control, nutrient cycling, restoration fertility, and hydrological services [4]. These trees also sequester carbon from the atmosphere, contributing to climate change mitigation through reduction of atmospheric greenhouse gas concentrations. A study by Makumba et al. [11] showed that tree covered systems stock larger quantities of carbon than agricultural systems without trees. Despite these critical functions, the locations, cover, and nature of biomass of trees in agricultural landscapes are not well known in many countries [12]. This is contrary to the trees within forests, which are well described and their biomass is fairly documented. As a result, there is growing demand for information on the biomass content of trees outside forests.

Allometric equations have been proposed for rapid assessments of tree biomass and these can be used without cutting down trees [13]. Allometric equations provide a useful link between field inventory and modeling, or remote sensing-based approximations and ground measurements. These equations have been widely used in forests assessment, such as those by IPCC [14] and few have been published for specific agricultural landscapes [15–18]. There exists also biomass equations developed for specific miombo ecoregions [19–23]. Considering the heterogeneous distribution of trees in miombo woodlands and associated land use systems, there is a need to identify suitable allometric equations that account for the diversity of trees in these mosaics prior to biomass estimation. This study aimed to establish landscape biomass and carbon stocks in three different miombo woodlands and associated land use systems in Malawi.

2. Methodology

2.1. Study site

The study was conducted in three 100 km^2 benchmark sites located in (1) Kasungu and (2) Salima districts in the central region, and (3) Neno district in the southern region of Malawi. The three locations (together with Ntchisi) constitute the Africa Soil Information Service (AfSIS) benchmark sites in Malawi build on the land degradation surveillance framework [24]. The AfSIS sites consist of 10 km × 10 km blocks, each divided into 16 sub-blocks (clusters, 2.5 km × 2.5 km) with 10 plots in each cluster. The blocks represent stratified random sample of landscapes in Africa south of the Sahara [24]. Vågen et al. [24] provide detailed information about the AfSIS sites.

Kasungu block is located in the neighborhood of Kasungu National Park at latitude 12°48′S, longitude 33°21′E, with an elevation range of 1000–1200 m above sea level. Kasungu district receives mean annual rainfall of between 800 and 1600 mm. The rainfall is unimodal and occurs between November and April [25]. Mean annual temperature ranges from a maximum of 22–24 °C to a minimum of 12–14 °C. The vegetation around Kasungu consists of miombo woodland with trees of medium height and moderate grass cover. Marsh and dambo grasslands occupy poorly drained (wetland) areas. The major crops grown in the area are tobacco, maize and groundnuts.

Salima block is located near the lakeshore plains at latitude 13°40′S, longitude 34°17′E, and an average elevation of 590 m. The district receives unimodal rainfall between October and May, ~1000 mm per annum [25]. The mean annual temperature is 24.1 °C with a mean maximum of 29.2 °C and a mean minimum of 19.6 °C. Most of the land in Salima is agricultural, dominantly used for production of maize, groundnuts, and cotton and rice. There are also patches of cassava, sorghum, sweet potatoes, and mangoes production fields. Tree cover is mainly *Brachystegia*, *Faidherbia albida* and interspersed fallows with dry grasslands.

Neno district is located at latitude 15°31′S and longitude 34°41′E, with an elevation range of 250–500 m. The mean annual rainfall varies from 300 to 800 mm per annum, falling between November and March [25]. The mean temperature varies between 20 and 26 °C. The topography of the district is largely mountainous and hilly. The natural vegetation is open-canopy miombo woodland interspersed with montane grassland [26]. There is low diversity of large canopy trees. The main cash crop in the area is citrus fruits, while maize is grown for subsistence.

2.2. Field measurements

A systematic sampling design was adopted, where three plots (30 × 30 m) in each of the 16 clusters per site was selected for inventory (the plots are already randomized within the clusters) in Kasungu, two plots in each cluster in Salima, and one plot in each cluster in Neno. The variations arose after it became difficult to sample three plots in each of the clusters in each site due to terrain problems and absence of trees in selected plots. A total of 67 plots were sampled: 36 plots in Kasungu, 21 plots in Salima, and 10 plots in Neno. The systematic sampling design ensured an even spread of the sample plots throughout the woodland and associated farming areas and thus increased the chances of including all vegetation types in different land uses. The 30 × 30 m plot size was considered sufficient to capture floristic characteristics of the miombo vegetation, including the spatial variation of biomass in trees of different seizes and species.

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