Forest Ecology and Management 304 (2013) 99–109

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Floristic composition, species diversity and carbon storage in charcoal and agriculture fallows and management implications in Miombo woodlands of Zambia

Felix Kanungwe Kalaba[a,b,*], Claire Helen Quinn[a], Andrew John Dougill[a], Royd Vinya[b]

[a] Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK
[b] School of Natural Resources, Copperbelt University, P.O. Box 21692, Kitwe, Zambia

ARTICLE INFO

Article history:
Received 5 December 2012
Received in revised form 14 February 2013
Accepted 17 April 2013
Available online 23 May 2013

Keywords:
Above ground carbon
Species diversity
Fallow
Floristic composition
Miombo woodland
REDD+

ABSTRACT

Globally, there are increasing demands for land use changes aimed at restoring Carbon (C) and biodiversity in degraded forest ecosystems. This study provides an integrated understanding of aboveground (AG) C storage, structural and floristic composition in charcoal and agriculture fallows in Miombo woodland systems of Zambia. We present the findings of ecological surveys; measuring tree diameters and assessing species composition on twenty-four 0.25 ha plots in undisturbed woodlands, and 58 plots re-growing after agriculture (5–58 years) and charcoal production (5–44 years). Undisturbed Miombo stored 39.6 Mg C ha^{-1} AG, while after clearance, C stocks accumulated at 0.98 and 1.42 Mg C ha^{-1} $year^{-1}$ in agriculture and charcoal fallows respectively. There were no significant differences in C stocks between woodlands and $\geqslant$20 year old fallows, implying that in terms of AG C storage, woodlands sufficiently recover after 20 years. Stem densities were significantly higher in charcoal than agriculture fallows but the difference decreased with fallow age. Importance values (IVI) of tree species show low presence of less fire resistant tree species such as *Uapaca kirkiana* in the initial regrowth of post-agriculture fallows. Shannon diversity indices showed high diversity in both woodlands and fallows though the Jaccard similarity coefficient indicated low species similarities, suggesting that though Miombo systems recover relatively fast in terms of species diversity and C storage, species composition takes longer to recuperate. The findings show that agriculture and charcoal fallows hold enormous management potential for emerging C-based payments for ecosystem services such as through United Nations Reduction of Emissions from Deforestation and forest Degradation-plus (REDD+) programme and Voluntary Carbon Market projects. Forest management should consider managing fallows for C sequestration and biodiversity restoration through natural succession in Miombo systems. In view of the uncertainty of species recovery, mature Miombo woodlands should be conserved for continued ecosystem functioning and supply of ecosystem services.

1. Introduction

Forests are one of the most important terrestrial biomes contributing immensely to carbon (C) sequestration and storage, and regulating other climate related cycles (Nasi et al., 2002; Gibbs et al., 2007). There is growing interest in understanding the capacity of forest ecosystems to sequester and store C in developing countries (Walker and Desanker, 2004), which is fundamental in quantifying the contribution of trees to climate mitigation because they indicate the amount of C that can be offset (Ditt et al., 2010). Forests have great potential to provide financial resources through C-based payment for ecosystem services (PESs) (Baker et al., 2010), but their functions as dynamic C-pools in biogeochemical cycles is largely unknown (Schongart et al., 2008). Miombo woodland is the most extensive dry forest formation in Africa, with an estimated area of 2.7 million km^2 (White, 1983; Frost, 1996), and is rich in plant diversity, with about 8500 species of higher plants of which 54% are endemic (Chirwa et al., 2008), making them one of the world's high-biodiversity hotspots (Mittermeier et al., 2003).

The C cycle in Miombo and other tropical woodlands is comparatively understudied (Williams et al., 2008; Bombelli et al., 2009). In southern Africa, there is relatively scarce knowledge of growth rates and wood biomass in natural woodlands due to the focus on fast growing exotic plantations which have been prioritized by governments (Grundy, 1995), thereby making the total C stores in woodlands uncertain (Bryan et al., 2010). Understanding C stores, the rates and extent to which forests recover from

* Corresponding author at: Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK. Tel.: +44 783 1220911; fax: +44 (0)113 3435259.

E-mail addresses: kanungwe@gmail.com, eefkk@leeds.ac.uk (F.K. Kalaba).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.04.024

disturbances and how C-stores change in this recovery trajectory has important implications in the emerging C-based PES schemes (Mwampamba and Schwartz, 2011) which are taking centre- stage in United Nations Framework Convention on Climate Change (UNFCCC) climate negotiations for the post-2012 climate regime after the expiry of the Kyoto Protocol commitment period. Quantifying C under different land use scenarios will help in making future land use decisions to ensure optimal land use benefits (Ditt et al., 2010), hence informing forest conservation and sustainable management (Schongart et al., 2008) especially in developing countries which have high poverty levels, and where people's livelihoods often depend on the forest resource. Slash and burn agriculture and charcoal production are the major causes of forest loss in Miombo woodlands (Stromgaard, 1987; Chidumayo, 1991; Malambo and Syampungani, 2008), and have been linked to huge losses of C and biodiversity of forest systems (Kotto-Same et al., 1997). Vegetation structure and floristic compositional changes in forest recovery has been discussed mainly in post-slash and burn agriculture abandonment sites in tropical rainforests (Guariguata et al., 1997; Ferreira and Prance, 1999; Denslow and Guzman, 2000), with a few studies in African woodlands (Williams et al., 2008; Syampungani et al., 2010), though floristic composition in regrowth sites remains contested. Some studies (e.g. Stromgaard, 1985; Kappelle et al., 1996; Syampungani, 2009) have reported the presence of dominant tree species of old-growth on young (i.e. <10 years-old site) slash and burn regrowth sites, while others have reported absence of old-growth dominant species in regrowth of the same age (Saldarriaga et al., 1988; Williams et al., 2008). Furthermore, some studies have suggested it takes centuries for forest to return to primary forest species composition and argue that forests may not return to their original composition after severe disturbances (Jacobs et al., 1988; Meng et al., 2011).

An integrated understanding of C storage, and the structural and floristic composition of trees in succession stages, is important in understanding forest restoration processes and in designing forest management strategies in different forest disturbance regimes (Gutiérrez and Huth, 2012). The aim of this study was to quantify the aboveground (AG) C contained in selected sites of the Miombo woodlands and to assess species composition and forest biodiversity richness in undisturbed woodlands and regrowth sites after slash and burn and charcoal abandonment at various successional stages. This is both timely and important due to global interest among policy makers on C-based PES as a way of incentivizing reductions in carbon loss from deforestation and degradation (Baker et al., 2010; Stringer et al., 2012).

2. Research design and methods

2.1. Study area

This case study was conducted in the Miombo woodlands of Copperbelt Province of Zambia (12°49′S to 13°36′S and 28°22′ to 28°42′E, and elevation of 1292–1300 m above sea level). The Copperbelt province is bordered by the Democratic Republic of Congo on the north and east, and lies on the central African plateau (Fig. 1). It is a high rainfall area (average 1200 mm per annum), and experiences three weather seasons that are distinguished based on rainfall and temperature, namely; hot dry (September–November), rainy season (December–March) and the cold dry season (April–August) (Chidumayo, 1997).

In the entire Miombo eco-region, Zambia has the highest diversity of trees and is the centre for endemism for *Brachystegia* tree species (Rodgers et al., 1996) which is one of the Miombo's key species.

2.2. Site selection and data collection

The study sites were selected using stratified purposive sampling (Creswell, 1998). Three different land use categories (i.e. treatments) were identified for Miombo woodlands; (1) undisturbed Miombo, (2) Slash and burn fallows, and (3) Charcoal fallows.

We used analogous sites to provide insights on changes in floristic composition and carbon storage overtime. Investigating succession using analogous sites (spatial) rather than temporal chronosequence has a limitation of ensuring various stands of different ages along the identified chronosequence have similar soils, vegetation composition, climatic histories, and previously subjected to similar disturbances (Schoonmaker and McKee 1988). This challenge was addressed by conducting the study in the same sub-region agro-ecological zone and creating a criterion for sample selection in the different land-use categories (Table 1).

2.2.1. Sampling and plot establishment

2.2.1.1. Undisturbed Miombo. Ground inventories were done in the identified land use categories. Twenty-four 50 m × 50 m (0.25 ha) plots were established in undisturbed Miombo (i.e. 16 plots in Mwekera Forest Reserve and 8 in Katanino Forest Reserves). In Katanino, plots were established between Bwengo village and the Katanino Forest Reserve border along a transect line perpendicular to the Oposhi road junction. In Mwekera Forest Reserve, the plots were established along the Mwekera Forest reserve main road from the rail line near *Kamfisa* Prison through the Zambia Forest College to *Mabote* village. Plots were randomly established along the road at distances of at least 100 m between them to avoid overlapping.

2.2.1.2. Recovering Miombo. The vegetation survey in recovering Miombo employed double stratified random sampling. The sites were first stratified according to pre-abandonment land use (i.e. slash and burn agriculture or charcoal, after the criteria summarised in Table 1), and then age of fallows, after which plots were established at random locations within the identified age categories. Land-use history and fallow age were obtained through informal interviews with local farmers, charcoal producers and traditional councillors (*Ba filolo*). 18 respondents were interviewed following a snowball sampling approach (Patton, 1990). This processes started by holding discussions with the traditional authorities, asking if they knew of any member of the community who had fallows. The leaders provided contact details of possible interviewees. This process was iterative, as participants provided details of other possible interviewees consistent with other studies in Miombo woodlands (Robertson, 1984; Walker and Desanker, 2004; Syampungani, 2009; Mwampamba and Schwartz, 2011).

Slash and burn recovering fallows ranged between 5 and 58 years. 24 plots were established with 4 plots in each identified age class. The ages of charcoal fallows ranged from 5 to 44 years, in a total of 34 plots. These age ranges represented the available fallow land in the study area which had undisturbed portions after abandonment. In these sites, 10 m × 20 m plots were established (Chidumayo, 1997; Munishi and Shear, 2004). The use of smaller plots in regrowth plots is due to the many species and high density of these plots which makes the use of larger fixed plots time consuming (Syampungani et al., 2010). At least 4 plots were surveyed in recovering Miombo for each identified fallow age. These fall within the plot numbers used in similar studies (Williams et al., 2008; Syampungani, 2009).

2.2.2. Field measurements

In the established plots, the tree diameters were measured using a diameter tape at breast height (i.e. 1.3 m above ground)