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The effect of charcoal production and other land uses on diversity, structure and regeneration of woodlands in a semi-arid area in Kenya

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ABSTRACT

Woodlands in Kenya are under pressure from agriculture, livestock keeping and a host of timber and non-timber forest uses, including charcoal production. However, the exact influence of charcoal production and other anthropogenic factors on different dimensions of woodlands is still unknown. We examined the effect of charcoal production and different other land uses on woodland structure, species composition, biomass and regeneration in a woodland area in Kenya. Information collected from 71 sample plots (50m × 20m) and from a recent land cover map was used to classify the woodland area into ten land use categories based on land cover, charcoal production intensity, grazing presence and land ownership. The results show that species diversity, tree density and biomass decreased with increasing intensity of land use, with agriculture and charcoal production being the leading causes. The influence of land cover was confirmed by the significant differences in diameter size class distributions ($p < 0.001$) and density ($p = 0.01$) between farmlands, transitional woodlands and woodlands. Redundancy analysis (RDA) of species abundance also clearly separated the various land uses. Charcoal production intensity caused significant differences on diameter size class distributions ($p = 0.02$) and stem density ($p = 0.002$). The results of land ownership are less pronounced. Overall, our results suggest the need of integrated land use management in order to balance the various land uses and ensure sufficient regeneration of woodland species valuable for the livelihood of the inhabitants and the ecological values of the region.

1. Introduction

Dry woodlands make up to 40% of the forest cover in the tropics (Eshete et al., 2011; Abbot and Homewood, 1999) and over 50% of Africa's vegetation (Ribeiro et al., 2013). While their dynamics are poorly understood (Gerhardt and Todd, 2009) dry woodlands have often been neglected in monitoring and modelling (Grainger, 1999). Dry woodlands are central to the lives of over 50 million people in Africa. Due to fluctuating rainfall in many of the woodland ecosystems, agricultural productivity is often limited, and agropastoral and pastoral communities within and nearby woodland areas rely on dry woodlands as part of their livelihood portfolio (Campbell et al., 2000). Besides economic income from woodfuel, timber and non-timber products dry woodlands also provide a range of ecosystem services such as micro climate regulation, soil quality maintenance, flood control and carbon sequestration and storage (Kalema et al., 2014).

Human pressure on dry woodlands is steadily increasing leading to degradation, loss of carbon stocks, reduction in biodiversity and soil degradation (Syampungani et al., 2009). To safeguard sustainable use and health of dry woodlands, information about composition diversity, structure and regeneration of plant species in dry woodlands are of great management and conservation importance. A healthy, stable population of woodland species which recruits regularly over time is crucial for the sustained populations and hence management of woodland resources (Mwavu and Witkowski, 2009; Worku et al., 2012). Numerous factors affect the composition, diversity and structure of dry woodlands and these can be roughly categorized into biotic and abiotic factors (Schwartz and Caro, 2003). Abiotic factors such as soil, topography, precipitation, temperature and drought not only influence woodland plant species composition (Randriamalala et al., 2016), but also determine early sapling survival and growth (Príncipe et al., 2014). Biotic factors are classified into naturally occurring

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processes such as invasive alien species, herbivore grazing and browsing, and anthropogenic activities. The major anthropogenic determinants of woodland degradation in African savannas are collection of woodfuel and building materials, fire, livestock grazing and browsing and land clearing for agriculture (Zida et al., 2007; Malimbwi and Zahabu, 2008; Ouedraogo et al., 2010).

An example of degradation due to excessive human use (e.g. wood harvesting and livestock grazing) is the adverse effect on vegetation diversity and structure (Kunwar and Sharma, 2004). Selective harvests leads to a reduction in tree diversity and changes in size class distribution and species composition (Luoga et al., 2002; Hitimana et al., 2004). Grazing influences species composition and ecosystem functioning by removing species from important functional groups (Neil et al., 1995). Furthermore grazing may prevent young seedlings from reaching mature stages, changes morphology of individual trees by turning single stem into multi-stemmed individual and cause death through trumping and uprooting (Zida et al., 2007; Wassie et al., 2009). Continous and intensive grazing may cause soil degradation through compaction and erosion (Wassie et al., 2009). Human activities such as wood harvesting and land use can reduce or eliminate biomass of trees and shrubs, thereby altering their ability to provide ecological and economic services such as woodfuel and carbon sequestration (Shackleton and Scholes, 2011; Mograbi et al., 2015). Estimation of woody biomass in trees and dry woodlands is therefore crucial for sustainable management (Henry et al., 2011).

The impact of human land use on vegetation structure is complex (Nacoulma et al., 2011) and is often influenced by land ownership and/or protection status (Luoga et al., 2004; Ræbild et al., 2007). Several authors have studied and compared the impact of human use on private, communal and protected woodlands (see e.g. Higgins et al., 1999; Luoga et al., 2002; Wessels et al., 2011). The general consensus was that land ownership often leads to woodland vegetation structure change with communal utilization leading to lower woody stem density and depressed regeneration as compared to private and protected woodlands. For example, Luoga et al. (2002) concluded that the levels of tree harvesting in eastern Tanzania were unsustainable in public lands as harvesting exceeded the mean annual increment of woody biomass. Protection status often leads to changes in vegetation attributes such as density, due to the limitation of land clearing and mitigation of human activities such as logging and grazing (Traoré et al., 2012). For example, Ndegwa et al. (2016) showed a significant difference in tree composition between protected and unprotected woodlands for a case study in eastern Kenya.

In many sub-Saharan African countries, charcoal production is an important anthropogenic activity that generates income from woodlands by selective logging of charcoal species (Malimbwi and Zahabu, 2008; Butz, 2013). Concerns about the impact of charcoal production have led to vigorous debates on the role of charcoal in woodland degradation (see e.g. Zulu and Richardson, 2013; Aabeyir et al., 2016). Charcoal production is mainly an informal sector activity. The informal nature of charcoal production causes constraints to its sustainable management (Schure et al., 2013). Charcoal production often leads to degradation of tropical woodlands and is seen as a leakage under the REDD+ mechanisms (Chidumayo and Gumbo, 2013). Charcoal is a major source of greenhouse gas emissions in many African countries, with studies in West Africa reporting that for every kilogram of wood converted to charcoal, 160 g of carbon are released into the atmosphere mainly as carbon monoxide, carbon dioxide and methane (Brocard et al., 1998). Several authors indicate a negative influence of charcoal production on woodland and forest tree density (Oduori et al., 2011; Chidumayo and Gumbo, 2013) and vegetation structure (Wurster, 2009). Species composition, physiognomy and ecosystem functioning can be affected by charcoal production, e.g. through delayed regeneration around kiln sites (Okello et al., 2001). Furthermore, charcoal production has been observed to increase 'accidental fires' in miombo woodlands (Luoga et al., 2002). The fire susceptibility of woodlands is further increased when slow growing tree species used for charcoal production are replaced by faster growing secondary species. Secondary species are more susceptible to fires (Naughtontreves et al., 2007) and have less carbon sequestration capacity compared to primary species. It has been shown that a shift towards fast-growing species in tropical forests could lead to a 34% decrease in carbon storage (Bunker et al., 2005). However, the effect of charcoal production on long-term vegetation structure is not well understood (Wurster, 2009). Many studies have tried to quantify these effects, by focusing on regeneration after tree harvesting in African woodlands (Luoga et al., 2004; Chidumayo, 2013; Kalaba et al., 2013). These studies show that dry woodlands can return to their near original status when land is abandoned or through different strategies such as growth of suppressed seedlings, layering, germination of buried or dispersed seeds, re-sprouting of stumps or by root suckers (Arnold et al., 2006; Ky-Dembele et al., 2007). However, the extent of dry woodland regeneration and the resilience to exploitation is dependent on the type of woodland use (Schwartz and Caro, 2003). Besides charcoal production, other land use activities such as grazing are acknowledged to influence dry woodland dynamics, but the interplay between the various management activities which constitute a land use option is often ignored (Higgins et al., 1999) and is therefore not well understood (Marinho et al., 2016).

The objective of this paper is to enhance the understanding of the impact of different land use activities on four dimensions of woodland, namely species composition, woodland structure, woody biomass and regeneration, for a study area in Kitui, Kenya. We have chosen the dry woodlands of Kitui, Kenya as these woodlands have been undergoing rapid socio-economic, climatic and environmental change (Zaal and Oostendorp, 2002; Lasage et al., 2008). Human activities, such as over-grazing, woodfuel collection and charcoal production are believed to have led to widespread degradation, land cover change, fragmentation and reduction of ecosystem integrity (Hayashi, 1996; Hitimana et al., 2005; Ruuska, 2013). As currently over 70% of Kenya's charcoal comes from dry woodlands (Luvanda et al., 2016), viable management measures are needed in order for the dry woodlands to contribute optimally to the wellbeing of the communities dependent on the dry woodlands as well as to maintain sustainable environmental conditions and plant diversity under conditions of subsistence farming and charcoal harvesting (Worku et al., 2011).

Within this context, the specific aims of this study are to (1) assess the effect of charcoal production on species diversity, size class distributions and regenerative capacity of the dry woodlands, (2) asses the effect of other land uses such as livestock grazing and subsistence farming on species diversity, size class distributions and regenerative capacity of the dry woodlands and (3) compare the woodland characteristics of privately owned woodland as compared to government owned woodland in the adjacent game reserve conservation area.

2. Materials and methods

2.1. The study area

The study area is located in Kitui county in Kenya about 150 km east of Nairobi (Fig. 1) and covers an area of 442 km^2. The altitude is about 550 m above sea level. The average yearly rainfall for Kitui is around 1000 mm with large local differences. The rainfall pattern is bimodal consisting of "long rains" between March and