The effect of Land Use Change and Management on the Vegetation Characteristics and Termite Distribution in Malawian Miombo Woodland Agroecosystem

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Abstract

Different land uses result in different vegetation condition and macro-fauna distribution in a landscape. Information on land use condition is paramount for development of strategies that enhance biodiversity conservation and sustainable resource use. A study was conducted to characterise the vegetation and termite distribution in the three land use types of protected area (PA), harvested woodland (HW) and traditional agriculture (TA) in Salima District, Malawi. Data were collected from 42 plots on tree species, diameter at breast height, regeneration, termite species and abundance. R Statistical package version 3.4.2 and GenStat Release version 14.2 were used for statistical analyses. There was significantly ($p< 0.05$) higher tree species diversity and stem density in the HW and TA than in the PA, supposedly, due to a positive tree harvesting effect on tree regeneration in the HW and TA as a form of disturbance. The HW and TA showed stable tree population while PA was characterised with an ageing tree population. Highest similsrity on tree species composition was recorded between TA and HW (48%). Regeneration was also significantly higher ($p< 0.05$) in HW and TA fields than in the PA. *Macrotermes natalensis* termite species dominated in all land uses with highest density and abundance in TA while *Psammotermes allocerus* was only found in the HW. We conclude that strict management of forest reserves may not achieve tree diversity; and recommend a ‘suite’ of management measures to balance conservation and promotion of tree diversity. Integrated pest management approach is proposed to prevent field crop losses due to termites.

Key words: tree density, vegetation structure, regeneration, *Macrotermes natalensis*

Introduction

The dependency on woodlands have resulted in land transformations that have threatened biodiversity and ecological sustainability in the Miombo ecoregion. This has led to policies promoting protection of some forests in the form of reserves as a management option (Possingham et al. 2006). This approach has a conflicting dimension since most local people rely on natural resources for their daily livelihoods (Geldenhuys 2015). This calls for a balanced understanding of the ecological behaviour of woodlands and the needs of the local people surrounding the woodlands (Geldenhuys 2010). Well managed natural resources ensure that desired products, services and values are obtained from ecosystems to meet the needs of the environment and the societies (Ribeiro et al. 2015). It is essential to develop an understanding on the impacts of landscape manipulation/disturbance on forest/woodland functioning (Geldenhuys 2010).

Forest specific studies in central and eastern Africa show that tree species diversity reduces with increasing age of land use while strictly protected forest reserves have low tree species richness and diversity (Banda et al. 2006; Banda et al. 2008; Tambara et al. 2012). Forest disturbance in Miombo woodland is associated with increased tree regeneration compared to non-disturbed forests (Neelo et al. 2015). These studies in the Miombo ecoregion are narrowed to the specifics of defined land use or species (Ribeiro et al. 2015). Therefore, there are still gaps existing on knowledge on tree biodiversity in Miombo woodlands especially focussing on a disturbance gradient from protected area, harvested natural woodlands to agricultural land, which has a bearing on conservation options. The proper understanding in tree species composition trend, and pattern is key in planning and managing both undisturbed and disturbed habitats for continued flow of ecosystem services; and yet such information is limited in most African countries (Ryan et al. 2011; Kalaba et al. 2012; Neelo et al. 2015). Moreover, information on general woody composition in an area can be used as a baseline in understanding regeneration capacity, understory dynamics, tree mortality, growth rates and spatial disturbance (Isango 2007).

As part of the woodland system, termite population is also affected by any induced modifications in the system. Some studies show that disturbed areas harbour low termite population (Zeidler et al. 2002; Sileshi and Mafongoya 2005; Poovoli and Rajmohana 2016). Termites as key bio-indicator of disturbance are considered ecosystem engineers because of their role in nutrient cycling, decomposition, soil fertility modification and water movement improvement (Aquino et al. 2008). Some termite species have been identified as pests in agroecosystems and forestry (Sileshi et al. 2007). This complex role of termites demands an extensive array of studies to understand and manage their action in various land use types in ecosystems (DeSouza and Cancello 2015).

Specifically, in Salima, Malawi, the multifunctional landscapes have woodlands adjoining and or intercepted by agricultural fields. The area is also adjacent to a strictly protected Thuma Forest Reserve (protected area). Furthermore, outside this reserve, there are woodlands in the landscape that are at different intervals (<5, 6-10, ≥11 years) of development following variations in use by the communities. Some woodlands were previously under the protected reserve but currently under community use for tree cutting and crop growing. This study aimed at assessing vegetation characteristics (floristic composition, structure and biomass content) and termite distribution (diversity, density and abundance) across different land use disturbance and/or management levels. Specifically, aimed at answering the following questions: (i) How different are the tree species composition, structure and density in the protected area (PA); harvested woodlands (HW); and in traditional agriculture (TA)? (ii) What termite species occur in the three land use types? (iii) How does termite density and abundance vary with the land use type?

Materials and methods

Study area

This study was conducted in Salima District, central Malawi. Salima District covers 2,196 km^2 and is located at 13.78° S and 34.43° E. The district is characterised by three major seasons of cool dry (May to July), hot dry (August to October) and warm wet (November to April). The rainfall pattern is unimodal ranging from 860 mm to 1400 mm annually. The maximum monthly temperature is 28.7°C and the minimum 20°C with recent records exceeding 30°C (Malawi Meteorological Office, Unpublished data). The vegetation is dominated by Miombo woodland with major species being *Diplorhynchus condylocarpon*, *Brachystegia spp.* and *Julbernardira globiflora* (Moyo et al. 1993, Beedy et al. 2015, Ribeiro et al., 2015). The vegetation varies from tall medium open to dense depending on management applied. Some grass species include *Themeda triandra, Hyparrhenia filipendula, Hyparrhenia rufa, Andropogon schirensis, Andropogon amplectens* and *Bewsia biflora*. Some common agricultural systems being practiced include pure crop production, crop integrated with different forms of agroforestry (AF) and conservation agriculture (CA), and livestock production. AF involves tree integration in the agricultural systems while the CA focusses on minimum soil disturbance (Rosenzweig and Hillel 2015).

Data collection

Vegetation assessment

The main treatments of observation were the traditional agriculture (TA) and harvested woodlands (HW) which were divided into yearly intervals of 1-5, 6-10 and 11+ as period under use by the community. Circular plots of sizes shown in Fig. 1 were randomly established for data collection in the TA, HW and the protected area (PA). A total of 42 plots (six plots in the PA, six in each yearly interval in HW and TA) were selected**.** The preliminary assessment in all the three land uses showed uniformity of tree structure and tree size in the PA while HW and TA had high variations. This formed the basis for the number of plots to be sampled (Royle 2004). Large trees of ≥ 30 cm diameter at breast height (DBH) were sampled from each plot of radius 22.6 m and small trees from plots of radius 11.28 m, while regeneration was sampled in 5.65 m radius at the central circle (Geldenhuys and Murray 1993; Syampungani et al. 2015). For regeneration, this study adopted the following criteria: ≤ 1 m height as seedlings; > 1 m height and ≤1 cm DBH as saplings; 1-5 m height but < 5 cm DBH as poles. The regeneration was recorded as counts while smaller (5 < DBH ≤ 30 cm) and large trees (≥ 30 cm DBH) were recorded as counts as well as DBH.

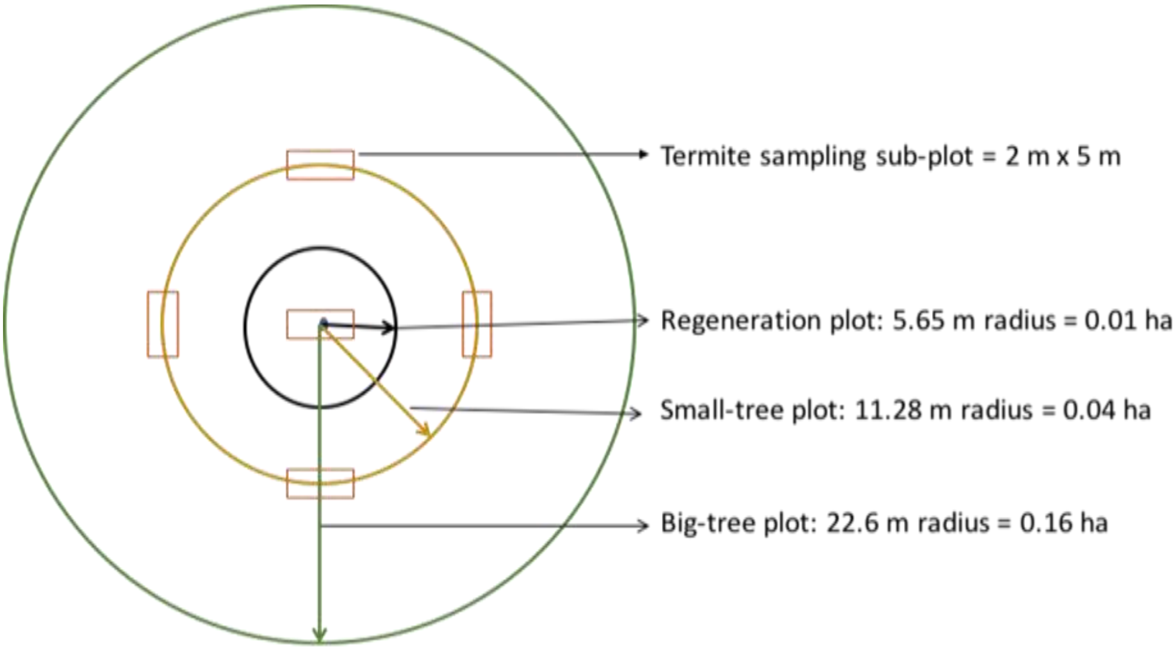

Fig. 1 A schematic illustration of sampling plots for tree, tree regeneration and termite data collection in Salima District, Malawi

Termite sampling

Termites were sampled using a quadrat method (Eggleton et al. 1999; Dahlsjo et al. 2014). The total area sampled for termites from each plot was 50 m^2, hence, from the 42 plots of 5 m x 2 m, a total of 2,100 m^2 were searched for termites. Termites were searched in their microhabitats of humus and litter, tree bases, beneath and inside dead wood, root area where possible, carton sheeting, mounds, ground runways, on vegetation or trees up to height of two meters in plot section (Palin et al. 2011). The sampled termites were stored in 70-80% alcohol (Borror et al. 1981) for identification at Entomology Laboratory of Forest Research Institute of Malawi (FRIM).

Data analysis

Vegetation characteristics

The trees were identified by a taxonomist to species level. Shannon-Wiener diversity index (H) and the Pielou Equitability Index (E) were used to calculate tree diversity and evenness (Magurran 2004) respectively in each disturbance category.

$$H = -\sum_{i=1}^{s} pi \ln pi$$

Where: H = Shannon-Wiener diversity index, p_i= number of individuals of species i/total number of samples, s = number of species.

The Pielou Equitability Index $(E) = (lnS)^{-H}$

Where: H = Shannon-Wiener diversity index, S = number of species.

The Important Value Index (IVI) has widely been used to explain vegetation composition and structure (Syampungani et al. 2015). The IVI is given by the formula:

$$\boldsymbol{Importance\ Value\ Index} = Relative\ dominance + Relative\ frequency + Relative\ density$$

$$\boldsymbol{Relative\ Dominance} = \frac{Dominance\ of\ a\ species}{Total\ dominance\ of\ all\ species} x\ 100$$

$$\boldsymbol{Relative\ Frequency} = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} x\ 100$$

$$\boldsymbol{Relative}\ = \frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species} x\ 100$$

Species richness was computed using Chao2 procedures (Chao 1984) given by the formula:

$$S_{max} = S(n) + \frac{L^2}{2M}$$

Where:

S_{max} = Chao species estimation

S(n) = number of observed species in a plot

L = number of species found in only one plot

M = number of species found only in two plots

A species composition similarity among the PA, HW and TA was determined using Jaccard Similarity Index (Jaccard 1912). Similarity was considered high from 50% and above (Jaccard 1912; Chao et al. 2006). The formula is given below:

$$Sj = a/(a + b + c)$$

Where:

Sj = Jaccard Similarity Index (%)

a = number of species in both sites

b = number of species in second site only

c = number of species in first site only

The diameter size class distribution (SCD) was computed for each disturbance category in the land uses using Weilbull fitting distributions (Ricci 2005; Muller 2014).

Termite distribution

Termite species were identified at the Forest Research Institute of Malawi (FRIM) Entomology Laboratory. The termites were identified to species level. Relative abundance was calculated as percentage of total termites recorded per land use type while density was recorded as number of termites per m^2 (Zida et al. 2011) in a land use type.

$$\textbf{Relative abundance} = \frac{Number\ of\ termites\ per\ land\ use}{Total\ number\ of\ all\ termites} x\ 100$$

$$\textbf{Relative density} = \frac{Density\ of\ termites\ per\ land\ use}{Total\ density\ of\ all\ termites} x\ 100$$

Poissson regression analysis was performed to predict termite's density in relation to land use (Assédé et al. 2015).

Stem (DBH ≥ 5 cm) density were tested for normality and homoscedasticity using Shapiro-Wilk normality test and Levene test, respectively. Where homoscedasticity was observed, one-way ANOVA as well as Tukey's post-hoc analyses were performed to compare means whereas a non-parametric Kruskal-Wallis as well as Tukey's post-hoc analyses were used in cases of lack of homoscedasticity. The level of significant difference was taken at $p< 0.05$. R Statistical Software version 3.4.2 (R Development Core Team 2017) and GenStat Release version 14.2 (GenStat 2011) were used for data analysis. In this study, stem density applied to only woody species whose DBH was ≥ 5 cm. This was done for easy linking of stem density, basal area and biomass.

Results

Vegetation characterisation

A total of 81 tree species were recorded. The species belonged to 60 genera and 32 Families. The dominant Families were Fabaceae, Combretaceae and Euphorbiaceae. The taxonomic status showed more diversity in the HW categories and lowest in the PA (Table 2). Tree species composition (Fig. 2) and dominance depended on land use. The Shannon-Wiener diversity index value for tree diversity was high in HW. The Index showed low diversity values in PA and TA. The Pielou Equitability index followed a similar trend. A Jaccard Similarity Index assessment showed low similarity values in terms of species composition among PA, HW and

TA. A similarity between TA and HW was 48% while that of TA and PA was 19%. The similarity between HW and PA was 29%.

Table 1 Tree species richness, diversity and evenness in the disturbance categories in Salima District, Malawi

Disturbance category	Average species number per plot	Species richness	Shannon-Wiener diversity index	Pielou Equitability Index
TA1-5 years	9	29	1.43	0.42
TA6-10 years	8	27	1.62	0.49
TA11+years	8	20	1.53	0.51
HW1-5 years	13	36	1.84	0.51
HW6-10 years	13	39	1.88	0.51
HW11+years	14	46	1.94	0.51
PA	8	22	1.51	0.49

(PA= protected area, HW= harvested woodland, TA= traditional agriculture)

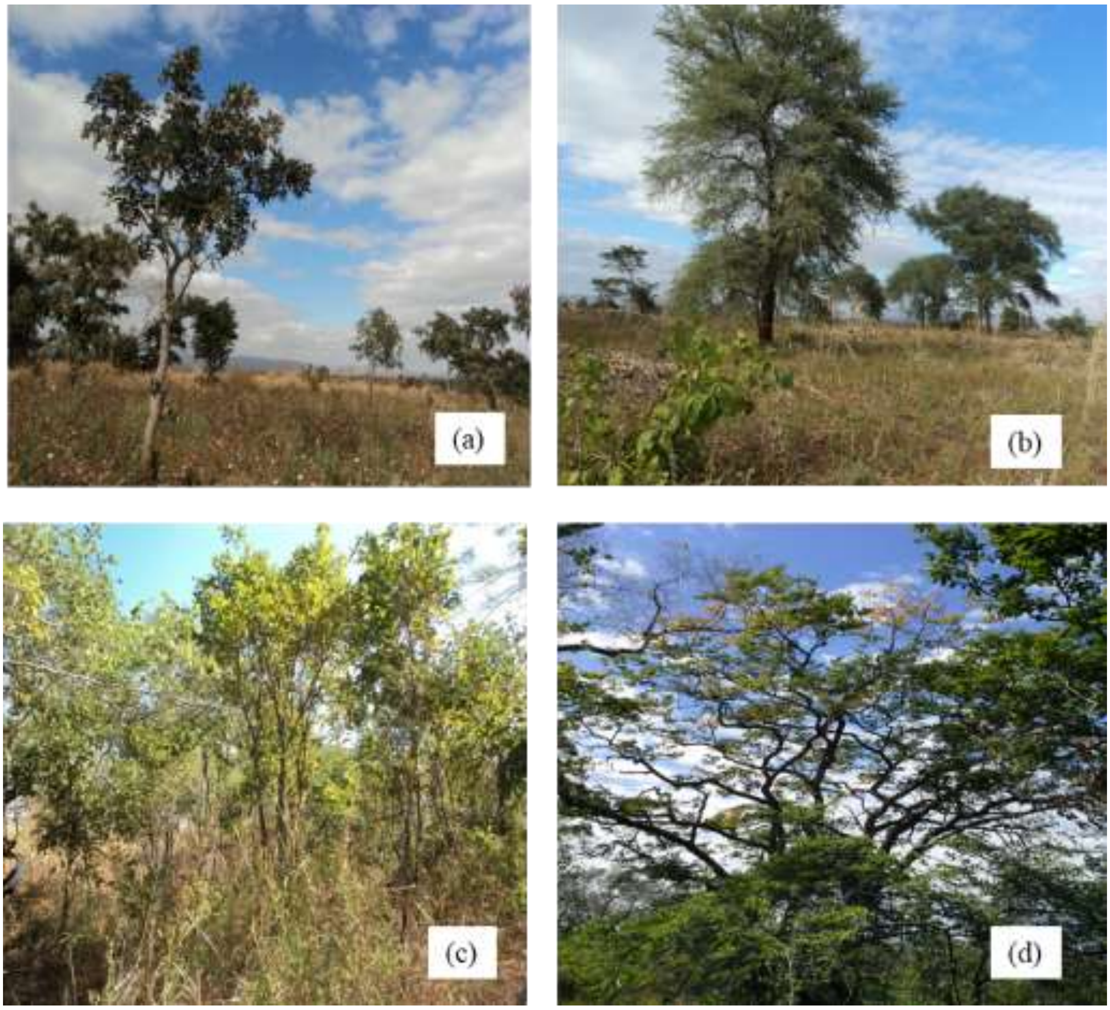

Fig. 2 Tree species of *Philenoptera violacea* (a), *Faidherbia albida* (b) in TA11+ sites, *Combretum spp*. (c) in HW6-10 and (d) *Pterocarpus rotundifolius* in PA in Salima District, Malawi

The most important species based on Important Value Index (IVI) in various disturbance categories are shown in (Table 3). Traditional agriculture (TA1-5) had a number of species also found in HW but the composition changed towards TA6-10 and TA11+ where *P. violacea, F. albida, Senna siamea, Azadirachta indica, Sclerocarya birrea* and *Pterocarpus angolensis* dominated. Species most important in the PA and HW were becoming less important in the TA categories. Of importance to note, was the limited abundance of *Brachystegia spiciformis* and *Julbernardia globiflora,* the defining species in Miombo woodlands. However, a few of Brachystegia (*B. floribunda, B. stipulata, and B. utilis)* were recorded.

Table 2 Important Value Index (IVI) for tree species in different disturbance categories in Salima District, Malawi. Values in bold represent most important species. (PA= protected area, HW= harvested woodland, TA= traditional agriculture)

Species	PA	HW 1-5 years	HW 6-10 years	HW 11+years	TA 1-5 years	TA 6-10 years	TA 11+years	Mean value
Tamarindus. indica					**38.61**			0.92
Faidherbia albida			8.24		28.13	**54.96**	**49.35**	3.35
Bauhinina petersiana	23.64	**54.29**	**33.30**	**35.12**	**42.75**	21.58	13.24	5.33
Philenoptera violacea	11.99	**38.32**	17.34	26.43	**36.56**	**49.12**	**42.35**	5.29
Pterocarpus rotundifolius	**45.26**	28.21	-	16.08				2.13
Combretum apiculatum	**32.21**	**42.00**	**34.61**	29.89	29.46	17.66	13.48	4.75
Vachellia polyacantha	19.64	**33.46**	**30.50**	**40.57**	28.71	12.07		3.93
Diplorhynchus condylocarpon	21.77		25.82	**45.94**	20.51	20.24		3.19
Senna siamea			8.93				**40.77**	1.18
Zanha africana	11.75			**32.83**	18.78	**35.63**	23.99	2.93
Vitex mombassae				23.92				0.57
Stereospermum. kunthianum		28.52	16.90			14.83	**32.59**	2.21
Azediracta indica	-						22.75	0.54
Uapaka kirkiana	22.30							0.53
Brachystegia utilis	22.19							0.53
Vachellia goetzei		11.25	**31.88**	29.43	-	10.82		1.99
Philenoptera bussei		27.24				17.14	16.73	1.46
Sclerocarya birrea							20.24	0.48
Pterocarpus angolensis		11.78		24.45	23.55		18.24	1.85
Combretum collinum	19.21	26.05	19.21	17.38	23.38		14.05	2.84

Table 2 Continued

Species	PA	HW 1-5 years	HW 6-10 years	HW 11+years	TA 1-5 years	TA 6-10 years	TA 11+years	Mean value
Lannea discolor	15.00	14.59	27.96					1.37
Diospyros kirkii			26.41	19.12			13.09	1.39
Albizia harvey		20.60		13.45		21.88	15.10	1.69
Piliostigma thonningii		18.22	13.34		22.12	15.11		1.64
Brachystegia stipulata			15.53					0.37
Vachellia galpinii	15.52							0.37
Dalbegiella nyassae		15.35						0.37
Psorospermum febrifugum				15.28				0.36
Terminalia sericea				17.91	15.57	12.06		1.08
Markhamia obtusifolia	16.10	17.32	13.89			13.93	14.39	1.80
Sterculia quinqueloba					15.01			0.36
Raphia farinifera					14.49			0.35
Khaya anthotheca					14.27			0.34
Strychnos spinosa						13.02		0.31
Ziziphus abyssinica	12.49							0.30
Pseudolachynostylis maprouneifolia	12.00							0.29

The ANOVA and Tukey's post hoc results showed significant difference for average stem density ($p < 0.05$) across the disturbance categories (Table 4). The HW had more stems/ha followed by the PA and TA sites. The HW1-5 had the highest number of stems/ha while TA1-5 had the lowest stems/ha.

Table 3 ANOVA results for average stem density in different disturbance categories in Salima District, Malawi.

Disturbance category	Stem density/ha
Traditional agriculture (1-5 years)	58.9±19.25a
Traditional agriculture (6-10 years)	65.6±9.16a
Traditional agriculture (11+ years)	86.5±15.93a
Harvested woodland (1-5 years)	384.9±53.53b
Harvested woodland (6-10 years)	278.6±78.96b
Harvested woodland (11+ years)	285.4±29.62b
Protected area	122.9±24.03a
Probability-value	0.001

The diameter size class distribution (SCD) showed varying curve shapes across the disturbance categories (Fig. 3). The SCD for PA followed Weibull distribution ($p > 0.05$) with bell-shaped curve. The categories of TA1-5, TA6-10 and TA11+, HW1-5, HW6-10 and HW11+ did not follow Weibull distribution ($p < 0.05$). Based on the cumulative distribution function (CDF), the HW1-5, HW6-10 data appeared to fit well in gamma distribution while the rest in lognormal distribution. The PA had more large trees with DBH averaging 22.51 ± 2.34 cm. The HW and TA disturbance categories showed inverse J-shapes. Their average DBH ranged from 7.13-10 cm.

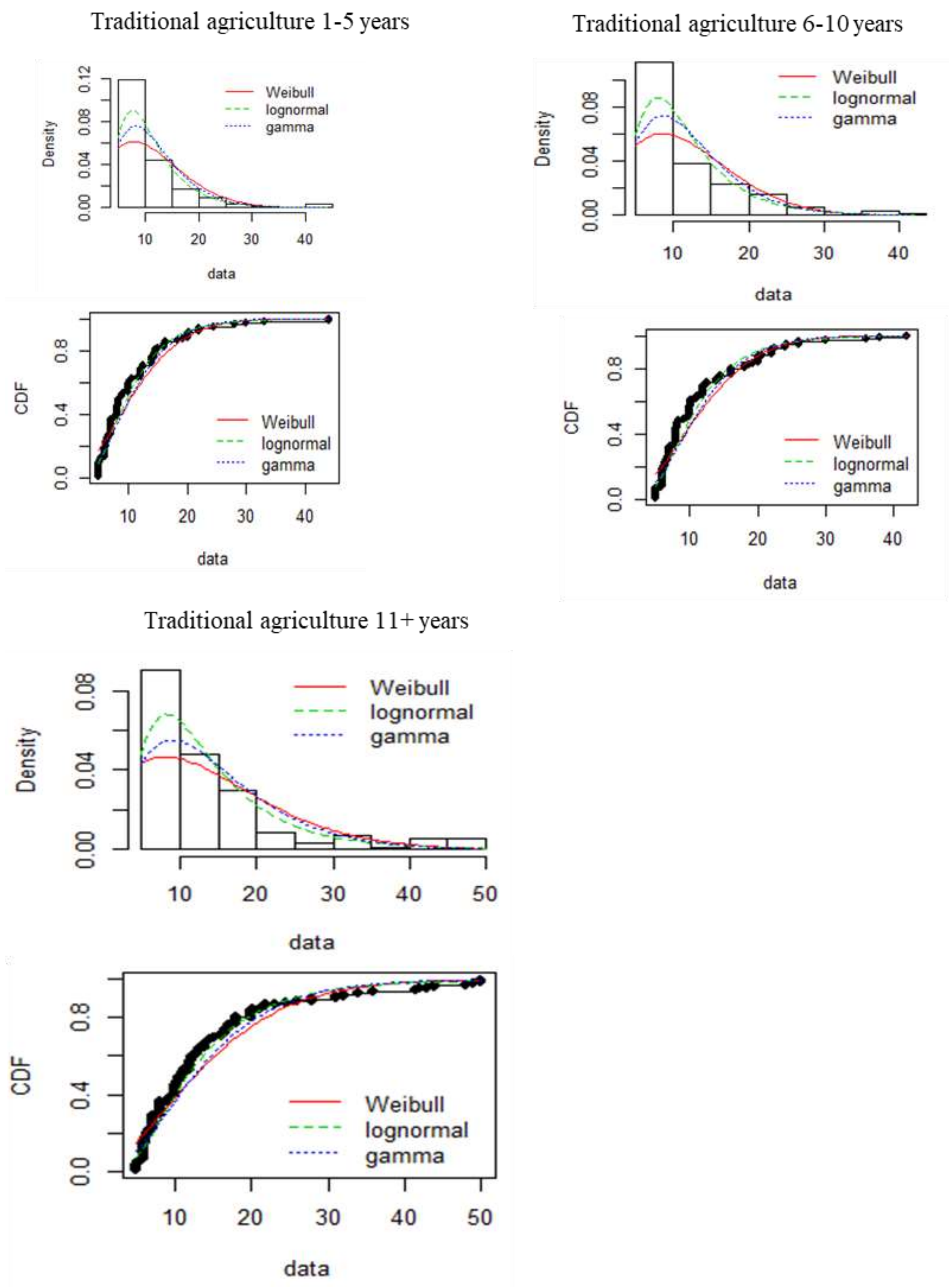

Fig. 3 Diameter size class distributions for trees of ≥ 5 cm in the three land uses in Salima District, Malawi. (CDF = cumulative distribution function)

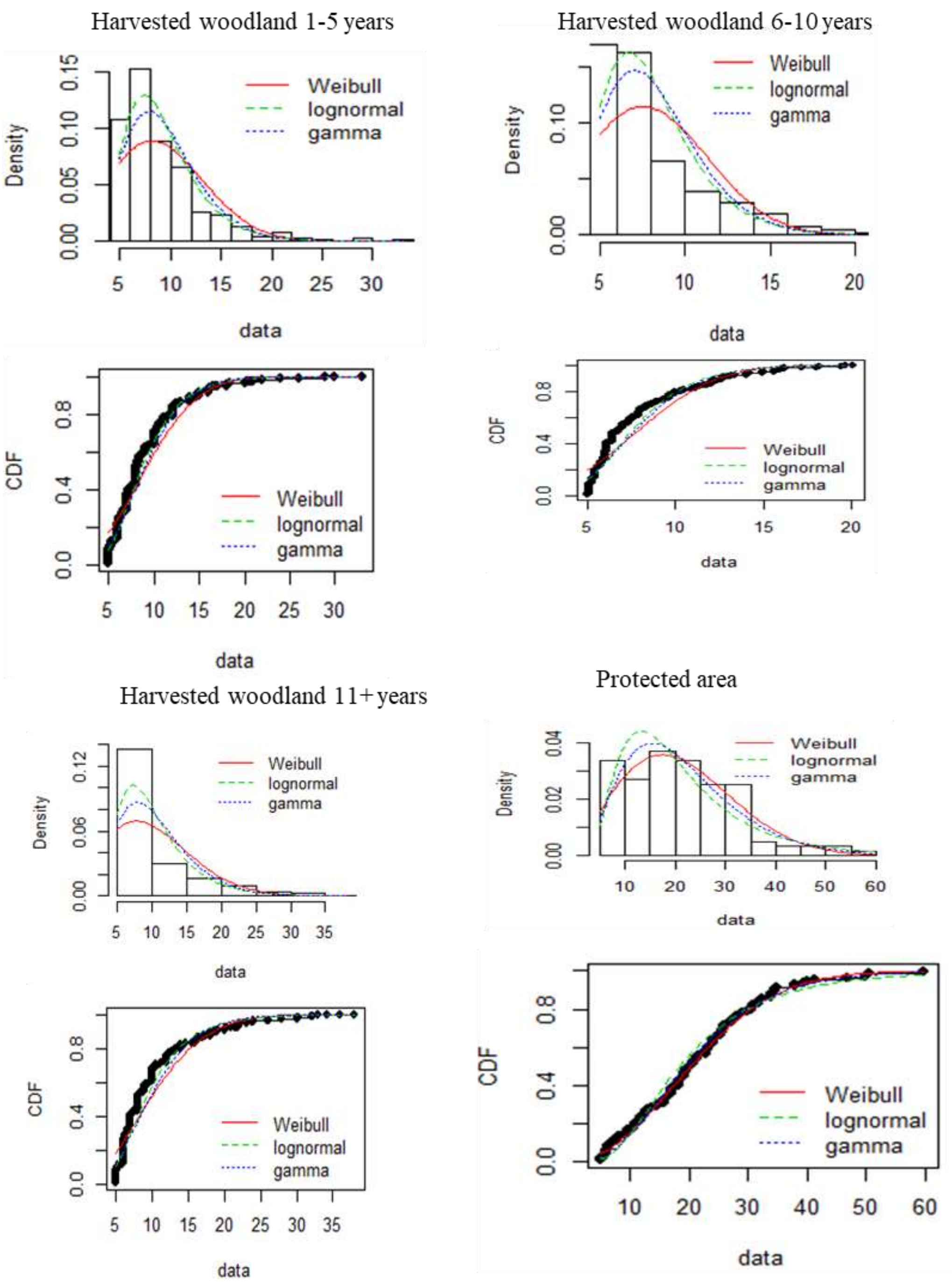

Fig. 3 Continues

The Fisher's protected least significant test showed significant difference of density for seedlings, saplings and poles ($p < 0.05$) across the disturbance categories in the land uses (Fig. 4a, b and c). The PA and HW had respectively the least and highest regeneration density for seedlings, saplings and poles.

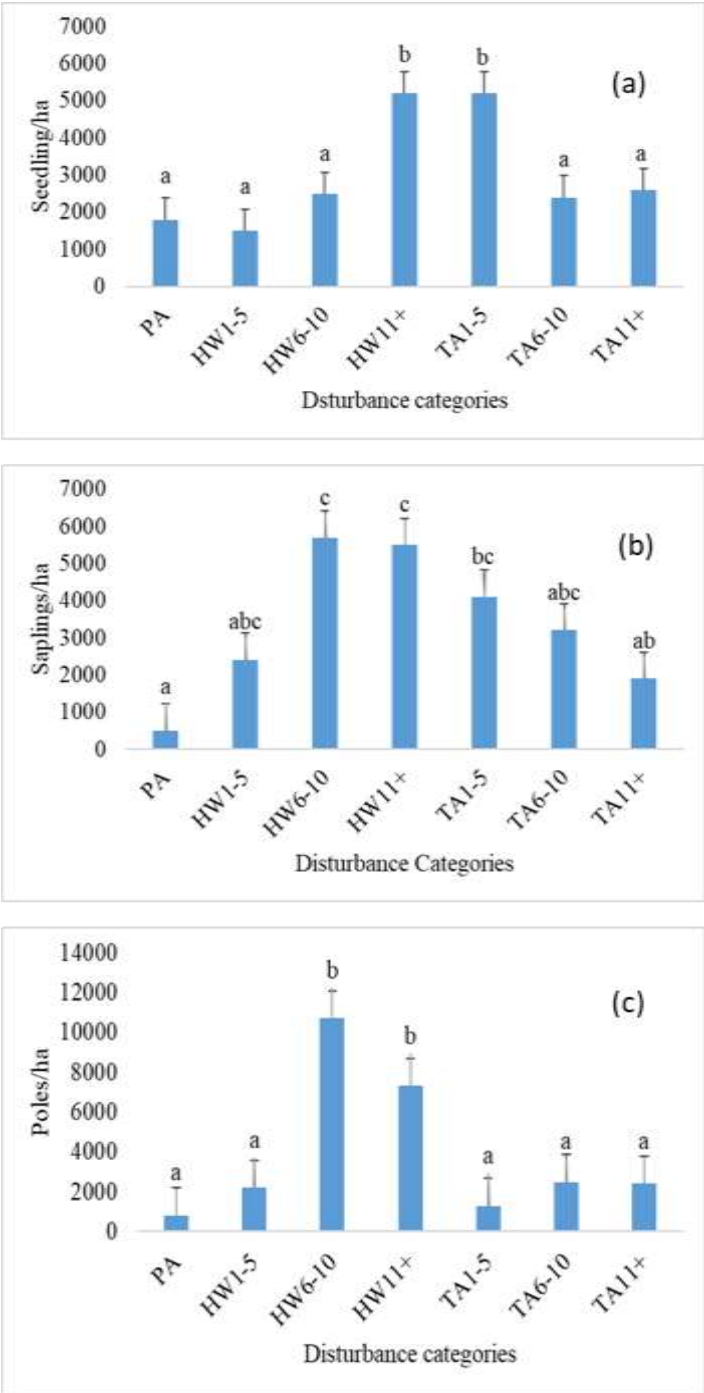

Fig. 4 Tree regeneration density for seedlings (a), saplings (b) and poles (c) in disturbance categories of varying years. Similar letters along the bars show no significant difference in Salima District, Malawi. (PA= protected area, HW= harvested woodland, TA= traditional agriculture; 1-5.6-10,11 indicate years under use)

Termite occurrence across the land use types

Two termite species were recorded in the study area. *Macrotermes natalensis* (Haviland) was found in all the three land uses (TA, HW and PA) while *Psammotermes allocerus* (Silvestri) was only recorded in the HW. Only 53% of the total plots had termites. Of the 13,078 termite individuals inventoried in the study (Table 5), 95% comprised *M. natalensis* species. The abundance ranged from 491 in the PA to 13,078 in the TA. The density of termites was low ranging from two termites m^{-2} in the PA to 11 termites m^{-2} in TA and this range was significantly different (Table 6).

Table 4 Termite abundance and relative density in the protected area, harvested woodland and traditional agriculture land use types in Salima District, Malawi

Land use	Plots with termite (%)	Total termites	Relative abundance (%)	Relative density (m-2)
Protected area	100	491	4	2
Harvested woodland	33	2,913	22	3
Traditional agriculture	55	9,674	74	11
Total		13,078	100	16

Table 5 Results of Pairwise comparison using Wilcoxon rank sum test for termite density in Salima District, Malawi

	Harvested woodland	Protected area
Protected area	0.431	
Traditional agriculture	0.012*	0.038*

*= significant at p <0.05

Results from Poisson regression showed a significant effect (p<0.0001) of land use type on termite density (Table 7). This effect was positive whatever the land use type. Considering the PA as reference, the termite density will increase from PA to HW and TA respectively.

Table 6 Poisson regression estimates for the influence of land use on termite density in Salima District, Malawi. (Std Error= Standard error, Pr= Probabilty value)

Parameter	Estimate	Std. Error	Z value	Pr(>|z|)
(Intercept	0.493	0.319	1.544	0.123
Harvested woodland	0.437	0.345	1.266	0.205
Traditional agriculture	1.162	0.327	3.551	0.000*

*= significant at p <0.05

The highest Incidence Rate Ratio (IRR) was obtained for TA (Table 7). The density of termite will increase from PA to HW and TA respectively by 1.548 and 3.195 times the one observed in PA.

$$\lambda b \ = \ 1.548\lambda a$$

$$\lambda c = 3.195\lambda a$$

Where λa, λb, λc represented termite density in the PA, HW and TA respectively.

Table 7 The Incidence Rate Ratio (IRR) for estimates of Poisson regression for termite density as predicted by land use type in Salima District, Malawi. (Std. Error=Standard error, CI= Confidence Interval)

Parameter	IRR	Std. Error	95% CI	95% CI
(Intercept	1.637	0.261	-0.019	1.005
Harvested woodland	1.548	0.444	-0.434	1.308
Traditional agriculture	3.195	0342	0.491	1.833

Discussion

Vegetation characterisation

As defining species in Miombo woodlands, more *Brachystegia spiciformis* could have been expected in the PA (because of good canopy environment) and more *Julbernardia globiflora* in the HW (limited shade environment). Seedlings of *B. spiciformis* thrive well under canopy conditions while those of *J. globiflora* under unshaded environment (Grundy et al. 1994). Their absence in PA, HW and TA could be attributed to historical land use, whereby these species may have been preferentially harvested. Additionally, factors related to ecological unsuitability within the PA, HW and TA as a result of management regime may also be responsible. This is evidenced by dissimilarities in spccies composition in the three management regimes. So, despite a wider view that *B. spiciformis* and *J. globiflora* dominate in Miombo woodlands, at local scale level, these may not be as dominant as evidenced in the sampled plots for this Salima study. Grundy (1995) recorded similar trend in Zimbabwe.

The low diversity (< 2) in the study area could be due to intensity of land use. A Shannon-Wiener Index of <2 is treated as low diversity (Giliba et al. 2011). History of disturbance, intensity of use and climatic conditions especially rainfall in the area may contribute to low tree diversity (Jew et al. 2016). Evenness similarity in the disturbance categories could be attributed to having only few species being highly dominant (Maliondo et al. 2005). For example, *F. albida* and *P. violacea* dominated in TA1-5 and TA6-10; *Vachellia polyacantha*, *Diplorhynchus condylocarpon, Combretum apiculatuma* and *Bauhinia petersiana* in HW categories. These scenarios of few species dominating may probably show health reduction in an ecosystem (Lameed and Ayodele 2010). The more tree species in community accessed woodlands may be because, when forests are disturbed, diversity reduces in the short term but during recovery, more tree species increase in diversity once again and the species may not necessarily be the same as those that originally inhabited the area (Noble and Dirzo 1997). The HW open access had more stumps for sprouting, unshaded environment for seed emergence for regeneration hence more species. The HW and TA is exposed to more disturbances like fires which might have influenced the increase of species that differ from those in the protected PA. This could show that the disturbance in the HW and TA provided conducive environment for new species to colonise.

The availability of non-fertility improvement regenerant species like *Steriospermum kunthianum* and *P. angolensis* in the TA shows that farmers value other species in the field apart from leguminous tree species. For example, in Zambia, *P. angolensis* has been reported to be preferred for timber (Syampungani et al. 2011) and this partially may explain the importance of the species in the agricultural land.

The inverse J-shape size class distribution in TA and HW could mean that trees are subjected to selective management regimes of tree species at different stages in the different land use systems. This results in the protection of important species such as leguminous trees in TA (especially TA11+) that grow into larger diameter classes and clearing of large stems in HW with only small trees, saplings and/or regenerants left**.** It is also probable that the rarity of large trees in HW could be due to charcoal making and other household uses. For example, Lowole et al. (1995) noted that the community members using poles from Chimaliro Forest Reserve, northern Malawi, targeted trees of greater than 5 cm DBH. In Tete, Mozambique, Sedano et al. (2016) reported a demand of trees ≥ 15 cm for charcoal production which fall in the HW land use system. The increasing regeneration density in TA and HW compared to the PA indicate the effects of disturbance on regeneration status. When trees are cleared, there is high sprouting of stumps (Luoga et al. 2004) and that some previously dormant seeds also take advantage to germinate due to sunlight penetration and reduced competition (Peter 2005). This could explain more seedlings in TA1-5 sites, though continuous seasonal cultivation causes removal of these ‘bushy’ seedlings to pave way for crop production. More regeneration has been reported in forests exposed to harvesting than in protected intact forests (Missanjo et al. 2014).

Conservation options

The three land uses have shown the effects of management on vegetation condition with PA restricting regeneration, HW changing to small-tree-dominated forest and TA having soil improvement species. Based on most important species and regeneration capacity, species with less regeneration need to be targeted to promote their abundance. These include *Pseudolachynostylis maprouneifolia* (for charcoal), *Pterocarpus angolensis* (poles/timber), *Uapaca kirkiana* (fruits) and *Brachystegia* spp. Except for *P. angolensis*, the rest seem to face survival challenges in the HW. Therefore, integrated management is advised. The management of the PA should hinge on promoting conditions that perpetuate species regeneration. The current single-large tree stand seems unconducive for diversity conservation. The *F. albida* and *P. violacea* in agriculture land should be complemented with *Senna siamea* and *Vachellia polyacantha* for soil fertility improvement.

Termite density and abundance in the land uses

Contrary to other studies in Kenya (Kitivo et al. 2015) and India (Poovoli and Rajmohana 2016), higher density and abundance were recorded in TA than in PA area and HW. Increasing cereal litter in TA land might have influenced the high termite density. Crop type and general residue type could also have contributed to the differences in the termite density and abundance across land uses. It was observed, albeit not statistically tested, that higher actual abundance of termites was found in maize dominated fields compared to other (cowpeas, soya beans, cotton) crop fields in the TA; and most termites were found attacking maize crop residues or in their structures on soil surface. Unlike other macrofauna, *Macrotermes natalensis* (Macrotermitinae) digest hard-material cereals such as maize and sorghum with ease hence they out compete others and flourish in an area (Zida et al. 2011). High density and abundance of Macrotermitinae in such environment have been recorded especially in agricultural fields with maize/sorghum litter in Burkina Faso (Zida et al. 2011) and under conservation agriculture (with maize as main crop) in Zimbabwe (Mutema et al. 2013). In the current study, field observations showed that there was an association between termites and the following tree species: *Albizia harvey, F. albida, S. birrea, Kigelia africana, Markhamia obtusifolia, Zanha africana, P. violacea, D. condylocarpon, Lannea discolor, Combretum collinum, Tamarindus indica, Terminalia sericea, S. kunthianum, V. polyacantha, P. angolensis*. Termite or their biogenic structures were observed on tree stems. Whether there is specific ecological reason for this association was not clear. Most of these tree species have cracked and rough outer bark parts which might be food for these termites. The damage caused by termites to maize may be minimised if trees are integrated in maize production. Higher maize yield is likely realised if maize is integrated with trees such as *Gliricidia sepium, Sesbania sesban, Leucaena leucocephala and Acacia anguistissima*. (Sileshi et al. 2005). Of the five tree species (*M. obtusifolia*, *D. condylocarpon, B. petersiana, F. albida* and *Combretum imberbe*) commonly observed in mounds in this study, only *Combretum imberbe* had also been observed with high density in mounds in South Africa (Davies et al. 2015).

Conclusion

Across disturbance categories, the species richness, diversity, abundance, tree regeneration and stem density may be better achieved in areas where tree harvesting is done as opposed to intact forests/woodlands. Disturbance through tree harvesting in a forest generally results in more stable (more small trees replacing removed big trees-species sustainability) tree population compared to intact forests. This study has shown that tree species diversity cannot be achieved in strictly protected reserves, therefore, a ‘suite’ of management measures are required to balance conservation and use to promote tree species diversity. Management regimes may be responsible for the dissimilarities in tree species composition in the three areas. Efforts that promote tree species perpetuity should be encouraged. *Macrotermes natalensis* (Haviland) and *Psammotermes allocerus* (Silvestri) dominate in all land uses. The TA conditions favoured more *M. natalensis* density and abundance. Both *M. natalensis* and *P. allocerus* species are pests, therefore, proper integrated pest management measures are advised to prevent field crop losses and damage to trees.

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