Structure, regeneration and carbon stocks of woody plants in the Litwang'ata village land forest reserve, Southwest Tanzania

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Abstract
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The plant biodiversity status of many village land forest reserves is little known to support meaningful implementation of sustainable forest management objectives in Tanzania. This study was conducted to assess the status of Litwang'ata village land forest reserve in Ludewa district, Southwest Tanzania through 20 square sample plots of 10 × 10 m. A total of 20 woody plant species belonging to 12 families and 19 genera with DBH ≥ 5 cm were identified in the study forest. The most important species with their importance value index were *Brachystegia spiciformis* (78.02), *Brachystegia boehmii* (22.05), *Faurea saligna* (15.18), *Uapaca kirkiana* (14), *Acacia amythethophylla* (13.07), *Pseudolachnostylis maprouneifolia* (12.76) and *Gardenia ternifolia* (10.36). The forest had a Shannon diversity index (H') of 2.27, indicating medium diversity. Stand structure comprised 1,330 ± 523 stems ha^{-1}, basal area of 18.97 ± 6.81 m^2 ha^{-1} and stand volume of 142.36 ± 52.17 m^3 ha^{-1}. The mean above- and belowground carbon stocks were 46.97 ± 17.23 Mg ha^{-1} and 23.90 ± 8.58 Mg ha^{-1} respectively. The higher tree densities, basal area, stand volume and carbon stocks recorded in this study compared to other Miombo woodlands indicate that Litwang'ata forest is still in good condition, and managment efforts should be strengthened to bolster biodiversity conservation for present and future generations.

Keywords
carbon stock, plant biodiversity, species composition, species diversity, wet Miombo woodlands, Tanzania

Introduction

Tanzania is endowed with natural resources with disproportionate amount of plant biodiversity compared to its share size. It is reported that almost 35% of the country is preserved as protected areas in different forms including national parks, nature reserves, game reserves, game-controlled areas, conservation areas and forest reserves (URT, 2021). In the category of forest reserves, there are forest reserves owned by Central Government, Districts and villages authorities. Forests owned by villages are formally known as village land forest reserves (VLFRs), and constitute at an estimate of over 60% of all forests found in the country. These forests are owned by villagers under the governance of village councils but the day-to-day operations are run by the elected Village Natural Resources Committees (MNRT, 2007). In most cases, these forests are prone to over-exploitation, deforestation and degradation

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due to among other elite capture, ignorance and poor governance (Treue et al., 2014).

Several initiatives have been established to conserve village forests and maximize socio-economic as well as environmental benefits. Participatory forest management (PFM) was one of the arrangements put in place for better utilization and management of VLFRs in the early 1990s (URT, 1998; Topp-Jorgensen et al., 2005; Blomley and Iddi, 2009). The PFM is mainly implemented using joint forest management and community based forest management (MNRT, 2022). Community-based forest management is one of the PFM approaches that take place on village lands leading to the establishment of village forests (Blomley and Iddi, 2009). There are several broad purposes for establishing these forest reserves including biodiversity conservation, water catchment protection, and sustainable use of forest products to generate revenues to be used by the communities (Treue et al., 2014; Lusambo et al., 2016; Mwakalukwa et al., 2023). In most cases, village forest reserves act as buffer zones to other protected areas of national and global importance such as the Eastern Arc Mountains (Topp-Jorgensen et al., 2005; Vyamana, 2009). However, PFM did not reach areas of Ludewa in the Southwest of Tanzania. It is estimated that the natural forest in Ludewa covers about 42,040 ha of which 24% are non-reserved forests. Designating these areas as some forms of protected areas is important to increase the chances of areas that are serving as buffer zones for the protection of other sensitive areas ecologically.

Litwang'ata village land forest reserve in Ludewa district, Southwest Tanzania was declared as VLFR in 2019. The declaration was due to the importance of this forest in biodiversity conservation as the forest occurs within the Eastern Afromontane biodiversity hotspot (Mombo et al., 2017). However, according to Andrew et al. (2023) the forest suffers a loss of significant amount of forest cover in the last 20 years (1996–2016). It is suspected that anthropogenic activities such as wildfires and those through which the household uses as a means to derive forest-based incomes might have affected the condition of the forest in terms of species composition, diversity, structure as well as regeneration.

Since deterioration of forest structure tends to affect the ability of the forest to provide ecosystem services and functions such as biodiversity and carbon sequestration, it is thought that the forest's capacity to absorb or store carbon as a strategy to mitigate the effects of climate change might have also been affected. Successful restoration efforts and sustainable forest management require adequate knowledge of the structure, regeneration and carbon stocks of woody plant species. Therefore, this study was initiated to objectively assess: i) species composition, richness and diversity, ii) stand structure in terms of basal area and diameter class distribution, iii) regeneration status, and iv) above- and belowground carbon stocks of woody plant species in Litwang'ata village land forest reserve located in Ludewa dis-

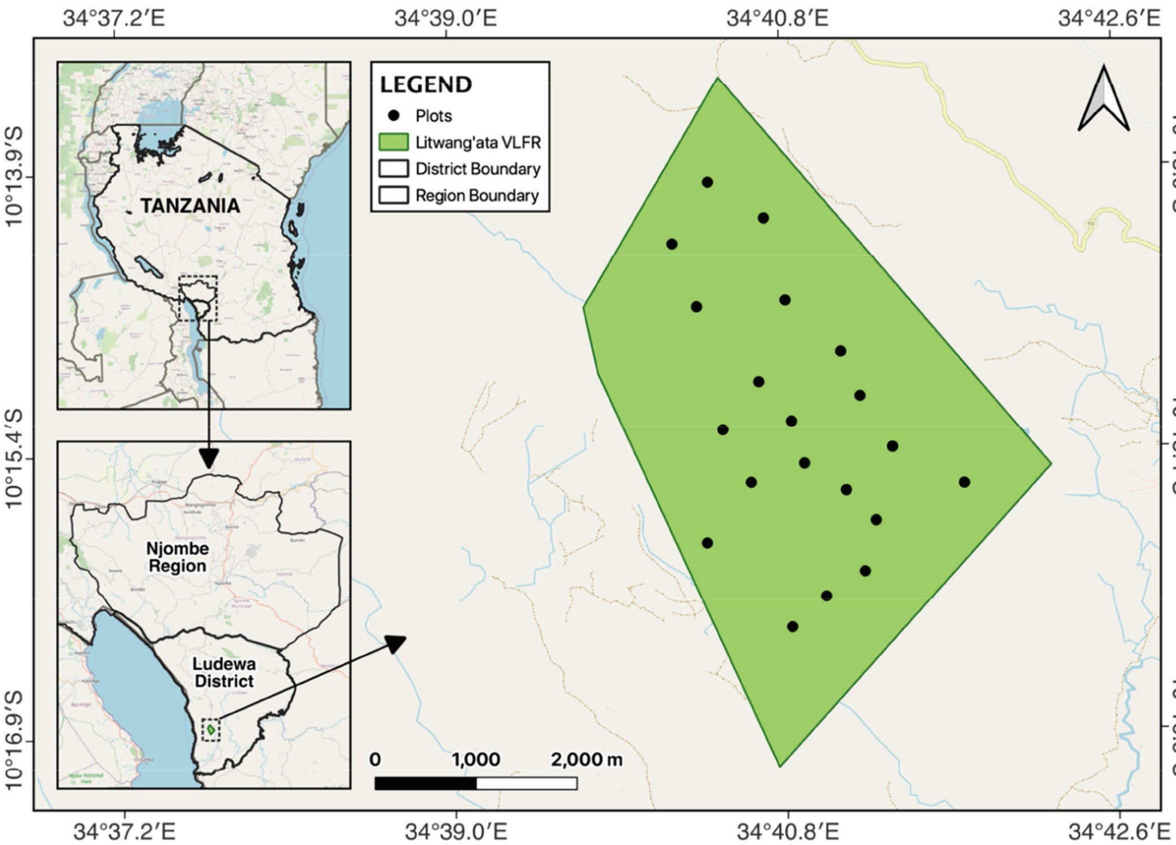

Fig. 1. A map of Tanzania showing Litwang'ata village land forest reserve, Ludewa District, Tanzania. The background maps show administrative divisions of Tanzania along with an OpenStreetMap base layer (https://www.openstreetmap.org/#map).

trict, Southwest Tanzania. The findings may help to set the baseline information important for sound implementation of management plans and future monitoring objectives.

Materials and methods

Study area

Litwang'ata village land forest reserve (LVLFR) with a total area of ca. 285.6 ha is located in Ludewa District, Njombe Region Southwest of Tanzania (Fig. 1). The average elevation at the town centre is 1,579 m asl while the temperature is 19.2 °C and receives an average annual rainfall of 1,215 mm in Ludewa. Nkomang'ombe village where LVLFR is found is located about 35 km from Ludewa town on the main road connecting Ludewa and Nyasa District. Litwang'ata forest is within the ranges of Livingstone Mountains and is also part of the Eastern Afromontane biodiversity hotspot area known to harbour flora and fauna species of global importance.

The vegetation is described as wet Miombo woodland (White, 1983). The forest is bordered to the south by Liwolelu River which is seasonal and drains its waters into Lake Nyasa which is at the transboundary between Tanzania, Mozambique and Malawi. To the west, the forest is bordered with the Mchuchuma River which drains its waters into Lake Nyasa too. To the southeast, the forest reserve is bordered with a reserved coal mining site. The main economic activities in the village are rain-fed agriculture and livestock keeping with small businesses at Nkomang'ombe village centre.

Data collection

The field survey was conducted between 2015 and 2016 and involved randomly established 20 square plots of 10 × 10 m in the Litwang'ata VLFR of 285.6 ha. Randomization of plots was carried out to ensure that areas selection biases are minimally reduced and to enhance reliability of results. Plots were positioned at least 450 m apart and their geographic locations were recorded using a standardized hand-held global positioning system (Garmin Map 76cx). The diameter at breast height (DBH) was measured using a caliper for all stems with DBH ≥ 5 cm in plots. Regenerants were also identified, counted and recorded in the 10 × 10 m plot. Plant species were identified in the field to species level, and unidentifiable plants were collected, pressed and sent to the Arusha National Herbarium of Tanzania for identification. In addition, collected voucher specimens for all species encountered in the field for identity confirmation were later deposited at the same herbarium.

Data analysis

Data collected was analyzed for species richness, diversity, evenness, density (number of stems ha^{-1}), and basal area per ha. Total species richness (*S*) was computed as the total number of species across all 20 plots. Species diversity was computed using the Shannon-Wiener diversity index (*H'*) and Simpson's diversity index (*D*). We also used Simpson's diversity index because it assesses the most abundant species in the community and is more sensitive to changes in the forest community. Shannon diversity index was computed as

$$H' = \sum_{i=1}^{s} \text{Pi, ln Pi},$$

where H′ is Shannon diversity index, s is number of species in a community and Pi is proportion of individuals of the i^{th} species expressed as a proportion of total abundance in the sample.

Simpson's diversity index was calculated as

$$1-(\text{D})^2 : D = \frac{n}{N},$$

where *D* is Simpson's index, *n* is the total number of individuals of a particular species and *N* is the total number of individuals of all species. The importance value index (IVI) was determined as the sum of relative density and dominance (basal area) and expressed in percentage (Kent and Coker, 1992). Relative density was computed as density of woody plant species /total density of all woody species × 100. Forest structure was expressed through stem density and basal area for species against diameter classes. The plant species accumulation curve was generated using the R package 'BiodiversityR' (Kindt and Kindt, 2023). Data on DBH was used to estimate the volume and aboveground and belowground biomass. The allometric model used for volume was given as volume (m^3 tree^{-1}) = 0.00016 × DBH$^{2.46300}$ (Mauya et al., 2014) while the one for aboveground biomass (kg tree^{-1}) was 0.1027 × DBH$^{2.4798}$ and yet belowground biomass (kg tree^{-1}) was 0.2113 × DBH$^{1.9838}$ (Mugasha et al., 2013) where DBH represented diameter at breast height (cm). Carbon stock was estimated by multiplying biomass with a conversion factor of 0.49 (Manyanda et al., 2020) and presented per hectare basis (Mg ha^{-1}). Data summarization was done using MS Excel 2007 and analysed in R free software version 4.2.0 (R Core Team, 2022).

Results and discussion

Woody plant species composition and richness

The results for species richness for plants with DBH ≥ 5 cm and that of regenerants with DBH < 1 cm in Litwang'ata VLFR are presented in Tables 1 and 2, respectively. A total of 20 tree and shrub species with diameters ranging from 5 to 32 cm belonging to 12 plant families were identified (Table 1). Tree and shrub species from the family Fabaceae contributed the most (35%) to the total number of species, followed by those from the family Anacardiaceae (10%) and Phyllanthaceae (10%). Nine (9) families contributed 5% each to the total abundance in composition. Trees contributed 40% (5 plant families) and shrubs 60% (8 plant families) of the species. The most significant number of species that contributed higher to the abundance in

Table 1. Checklist of woody plant species identified in Litwang'ata village land forest reserve Southwest Tanzania sorted by importance value index (IVI), frequency (%), Shannon diversity index (*H'*), Simpson diversity index (D), stem density (mean ± SE), basal area (mean ± SE), stand volume (mean ± SE), above ground carbon (AGC, mean ± SE) and below ground carbon (BGC, mean ± SE)

No.	Species name	Family	Habit	IVI	Frequency (%)	H'	D	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Stand volume (m^3 ha^{-1})	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})
1	*Brachystegia spiciformis* Benth	Fabaceae	Tree	78.02	85	0.37	0.14	505 ± 105	7.66 ± 1.35	57.69 ± 10.70	19.04 ± 3.54	9.65 ± 1.70
2	*Brachystegia boehmii* aub.	Fabaceae	Tree	22.05	35	0.24	0.01	145 ± 67	2.61 ± 0.94	21.32 ± 7.73	7.06 ± 2.56	3.29 ± 1.18
3	*Faurea saligna* Harv.	Proteaceae	Tree	15.18	35	0.18	0.00	85 ± 30	1.34 ± 0.55	10.46 ± 4.88	3.46 ± 1.62	1.68 ± 0.69
4	*Uapaca kirkiana*	Phyllanthaceae	Shrub	14.00	25	0.21	0.01	110 ± 49	1.42 ± 0.67	9.90 ± 4.79	3.26 ± 1.58	1.80 ± 0.84
5	*Acacia amythethophylla* Steud. ex A. Rich.	Fabaceae	Tree	13.07	25	0.15	0.00	65 ± 36	1.54 ± 0.86	11.94 ± 6.75	3.94 ± 2.23	1.93 ± 1.09
6	*Pseudolachnostylis maprouneifolia* Pax	Phyllanthaceae	Shrub	12.76	35	0.18	0.00	90 ± 32	1.17 ± 0.54	8.62 ± 4.13	2.84 ± 1.36	1.48 ± 0.68
7	*Gardenia ternifolia* Schumach. & Thonn.	Rubiaceae	Shrub	10.36	10	0.12	0.00	50 ± 35	0.63 ± 0.44	4.45 ± 3.11	1.46 ± 1.02	0.79 ± 0.56
8	*Combretum zeyheri* Sond.	Combretaceae	Tree	9.45	40	0.14	0.00	60 ± 20	0.83 ± 0.34	5.90 ± 2.56	1.94 ± 0.84	1.05 ± 0.43
9	*Parinari excelsa* Sabine	Chrysobalanaceae	Tree	6.89	35	0.11	0.00	45 ± 15	0.92 ± 0.42	7.39 ± 3.53	2.45 ± 1.17	1.16 ± 0.53
10	*Diplorhynchus condylocarpon* (Müll.Arg.) Pichon	Apocynaceae	Shrub	3.06	10	0.10	0.00	35 ± 24	0.13 ± 0.09	0.64 ± 0.45	0.21 ± 0.15	0.16 ± 0.11
11	*Syzygium guineense* (Willd.) DC.	Myrtaceae	Tree	2.53	15	0.07	0.00	25 ± 14	0.10 ± 0.06	0.49 ± 0.28	0.16 ± 0.09	0.12 ± 0.07
12	*Pericopsis angolensis* (Baker) Meeuwen	Fabaceae	Tree	2.41	5	0.06	0.00	20 ± 20	0.08 ± 0.08	0.41 ± 0.41	0.13 ± 0.13	0.10 ± 0.10
13	*Ochna schweinfurthiana* F.Hoffm.	Ochnaceae	Shrub	1.98	10	0.05	0.00	15 ± 11	0.05 ± 0.04	0.27 ± 0.23	0.09 ± 0.08	0.07 ± 0.06
14	*Lannea schimperi* (Hochst. ex A.Rich.) Engl.	Anacardiaceae	Shrub	1.61	15	0.05	0.00	15 ± 8	0.06 ± 0.03	0.29 ± 0.16	0.09 ± 0.05	0.07 ± 0.04
15	*Dalbergia nitidula* Welw. ex Baker	Fabaceae	Shrub	1.45	5	0.05	0.00	15 ± 15	0.17 ± 0.17	1.12 ± 1.12	0.37 ± 0.37	0.22 ± 0.22

Table 1. Continued

No.	Species name	Family	Habit	IVI	Frequency (%)	H'	D	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Stand volume (m^3 ha^{-1})	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})
16	*Cyphostemma junceum* (Webb) Desc. ex Wild & R.B.Drumm.	Vitaceae	Shrub	1.29	10	0.05	0.00	15 ± 11	0.10 ± 0.09	0.57 ± 0.53	0.19 ± 0.17	0.12 ± 0.11
17	*Vitex iringensis* Gürke	Lamiaceae	Shrub	1.24	10	0.04	0.00	10 ± 7	0.03 ± 0.02	0.16 ± 0.11	0.05 ± 0.04	0.04 ± 0.03
18	*Senna singueana* (Delile) Lock	Fabaceae	Shrub	1.02	5	0.02	0.00	5 ± 5	0.07 ± 0.07	0.44 ± 0.44	0.15 ± 0.15	0.08 ± 0.08
19	*Bauhinia petersiana* Bolle	Fabaceae	Shrub	0.85	10	0.04	0.00	10 ± 7	0.03 ± 0.02	0.16 ± 0.11	0.05 ± 0.04	0.04 ± 0.03
20	Ozoroa insignis Delile	Anacardiaceae	Shrub	0.77	5	0.04	0.00	10 ± 10	0.03 ± 0.03	0.14 ± 0.14	0.04 ± 0.04	0.04 ± 0.04
	Total			200	425	2.27	0.18	1,330 ± 523	18.97 ± 6.81	142.36 ± 52.17	46.97 ±17.23	23.90 ± 8.58

tree category was found in Fabaceae (50%), followed by Chrysobalanaceae (13%), Combretaceae (13%), Myrtaceae (13%), and Proteaceae (13%), whereas for shrub species were from Fabaceae (25%), followed by Anacardiaceae (17%) and Phyllanthaceae family (17%). The five families contributed only 8% each to the total abundance.

In terms of frequency of occurrence for trees and shrubs with DBH ≥ 5 cm, *Brachystegia spiciformis* was the most frequent species (85% of plots), followed by *Combretum zeyheri* (40%), *Brachystegia boehmii* (35%), *Faurea saligna* (35%), *Parinari excelsa* (35%) and *Pseudolachnostylis maprouneifolia* (35%) (Table 1). Plant species followed the following pattern according to importance value index (IVI): *Brachystegia spiciformis* (78.02), *Brachystegia boehmii* (22.05), *Faurea saligna* (15.18), *Uapaca kirkiana* (14), *Acacia amythethophylla* (13.07), *Pseudolachnostylis maprouneifolia* (12.76) and *Gardenia ternifolia* (10.36) (Table 1).

Overall, the average number of species per plot was found to be 4 species (range 1–6 species per plot). The species accumulation curve indicated the rate of encountering new species (Fig. 2) whereby the number of species increased rapidly up to the 10^{th} plot and slowed down thereafter up to the 20^{th} plot. However, since only 20 plots were sampled, the later result implies that any further increase in sample size might have included additional new species.

For regenerants, 16 tree and shrub species belonging to 11 plant families were identified (Table 2). Tree and shrub species from the family Fabaceae contributed the most (25%) to the total number of species, followed by those from Phyllanthaceae (13%) and Rubiaceae (13%). Eight (8) plant families contributed 6% of the total abundance. Trees contributed 75% (9 plant families) and shrubs/small trees 25% (3 plant families) of the species. The most significant number of species that contributed higher to the tree category was found in the Fabaceae family (25%) followed by Phyllanthaceae (17%). The remaining seven (7) plant families contributed 8% each to the canopy cover. While for shrubs/small trees, species that contributed higher to the shrubs/small trees category was found in Rubiaceae family (50%). The remaining two plant families of Apocynaceae and Fabaceae contributed 25% each. For frequency of occurrence for regenerants with DBH < 1 cm, *Brachystegia spiciformis* was the most frequent species (65% of plots), followed by *Brachystegia boehmii* (35%), *Combretum zeyheri* (20%), *Faurea saligna* (20%), *Acacia amythethophylla* (15%), *Lannea schimperi* (15%), and *Uapaca kirkiana* (15%) (Table 2).

The species richness of 20 for trees and shrubs and 12 plant families reported in this study is low when compared with other studies conducted in the wet Miombo woodland areas. For instance, Shirima et al. (2011) studied woody plant species at the south-eastern foothills of the Udzungwa Mountains in Nyanganje Forest Reserve (rainfall of 1,400 mm annually) in Tanzania and reported 35 tree species using four 1-ha sample plots. Similarly, using 24 sample plots of 50 × 50 m (0.25 ha) the research reported a total of 83 species belonging to 53 families from high rainfall area (average 1,200 mm per annum) of wet

Table 2. Checklist of regenerants identified in Litwang'ata village land forest reserve Southwest Tanzania sorted by frequency (%), Shannon diversity index (*H'*), Simpson diversity index (D) and stem density (mean ± SE) for tree and shrub species (S) with a minimum DBH < 1 cm

S/no.	Species name	Family	Habit (%)	Frequency	*H'*	D	Density (stems ha^{-1})
1	*Brachystegia spiciformis* Benth.	Fabaceae	Tree	65	0.37	0.13	575 ± 148
2	*Brachystegia boehmii* Taub.	Fabaceae	Tree	35	0.28	0.02	180 ± 85
3	*Combretum zeyheri* Sond.	Combretaceae	Tree	20	0.18	0.00	85 ± 47
4	*Faurea saligna* Harv.	Proteaceae	Tree	20	0.18	0.00	35 ± 18
5	*Acacia amythethophylla* Steud. ex A.Rich.	Fabaceae	Tree	15	0.16	0.00	35 ± 22
6	*Lannea schimperi* (Hochst. ex A.Rich.) Engl.	Anacardiaceae	Tree	15	0.16	0.00	40 ± 27
7	*Uapaca kirkiana* Müll.Arg.	Phyllanthaceae	Tree	15	0.16	0.00	90 ± 59
8	*Parinari excelsa* Sabine	Chrysobalanaceae	Tree	10	0.10	0.00	35 ± 26
9	*Bauhinia petersiana* Bolle	Fabaceae	Small tree	5	0.06	0.00	5 ± 5
10	*Diplorhynchus condylocarpon* (Müll.Arg.) Pichon	Apocynaceae	Small tree	5	0.06	0.00	10 ± 10
11	*Dombeya rotundifolia* (Hochst.) Planch.	Malvaceae	Tree	5	0.06	0.00	25 ± 25
12	*Gardenia ternifolia Schumach.* & Thonn.	Rubiaceae	Small tree	5	0.10	0.00	15 ± 15
13	*Pseudolachnostylis maprouneifolia* Pax	Phyllanthaceae	Tree	5	0.06	0.00	5 ± 5
14	Rothmannia spp.	Rubiaceae	Shrub	5	0.06	0.00	30 ± 30
15	Syzygium spp.	Myrtaceae	Tree	5	0.10	0.00	10 ± 10
16	*Vitex iringensis* Gürke	Lamiaceae	Tree	5	0.06	0.00	5 ± 5
	Total			235	2.13	0.18	1,180 ± 537

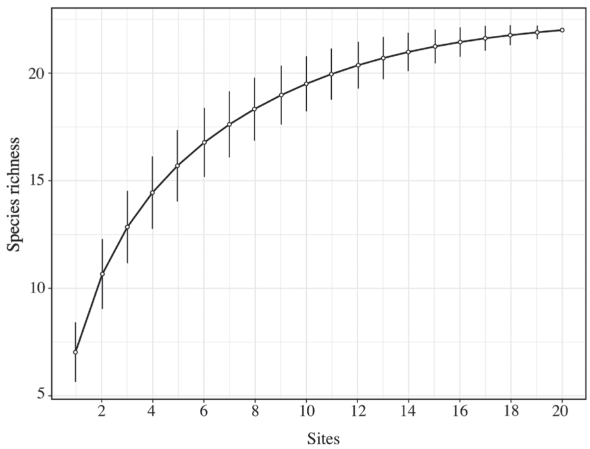

Fig. 2. Plant species accumulation curve for Litwang'ata village land forest reserve Southwest Tanzania.

Miombo woodland of Copperbelt Province in Zambia (Kalaba et al., 2013). On the other hand, the reported species richness of 20 in this study was higher compared to that reported by Mwampashi (2013) from wet Miombo woodland of Iwuma Forest Reserve in Mbozi District, Tanzania which receives rainfall ranging from 1,350 to 1,550 mm per annum, who reported 11 species using 37 rectangular plots measuring 20 × 40 m (0.08 ha) each. Nevertheless, the overall species richness in this study falls within the range of species commonly found in Miombo woodland (both wet and dry) of 11–229 species (Mwampashi 2013; Mwakalukwa et al., 2014; Shirima et al., 2015; Jew et al., 2016).

Woody plant species diversity

Overall Shannon-Wiener diversity index (*H'*) and Simpson (D) diversity indices were 2.27 and 0.18, respectively for Litwang'ata VLFR (Table 1). Species that were observed to have the greatest contributions to *H'* were *Brachystegia spiciformis* (0.37), *Brachystegia boehmii* (0.24), *Uapaca kirkiana* (0.21), *Pseudolachnostylis maprouneifolia* (0.18) and *Faurea saligna* (0.18). For regenerants *H'* was 2.13 while D was 0.18, respectively (Table 2). Regenerant species that were observed to have the most remarkable contributions to *H'* were *Brachystegia spiciformis* (0.37), *Brachystegia boehmii* (0.28), *Combretum zeyheri* (0.18), *Faurea saligna* (0.18), *Acacia amythethophylla* (0.16), *Lannea schimperi* (0.16) and *Uapaca kirkiana* (0.16).

The values of *H'*= 2.27 and D = 0.18 for all woody plants in the present study are lower than those documented by Kalaba et al. (2013) from wet Miombo woodland of Copperbelt Province in Zambia who reported H′ value of 2.8 and D of 0.92. However, the values of the Shannon-Wiener index (*H′*= 2.27) and Simpson diversity index (D = 0.18) reported in this study are higher than those reported by Mwampashi (2013) from wet Miombo woodland of Iwuma Forest Reserve in Mbozi District, Tanzania who reported *H′* value of 1.3 and D value of 0.4. Reported values in the present study are also higher than those reported by Shirima et al. (2011) from Nyanganje Forest Reserve in Tanzania who reported *H′* values of 1.9 and 2.2 and D values of 0.3 and 0.2 respectively. Overall, the diversity (*H′*) value of 2.27 in this study falls within the range of *H′* values commonly found in Miombo woodland of 1.05–4.27 (Shirima et al., 2011; Mwakalukwa et al., 2014; Jew et al., 2016). Usually, the value normally varies between 1.5

and 4.5 and rarely exceeds 5, and a threshold value of 2 has been mentioned to be the minimum value, above which an ecosystem can be regarded as medium to highly diverse (Magurran, 2004). Therefore, a value of 2.27 found in this study implies that the LVLFR is a medium-diverse forest. The Simpson index of dominance value calculated was 0.18 which is certainly not low suggesting that there is a certain level of dominance of few species in LVLFR (Ingram et al., 2005).

Woody stem density

The total mean stem density for trees and shrubs with DBH ≥ 5 cm was 1,330 ± 523 stems ha^{-1} (Table 1, Fig. 3). Among the most abundant species were *Brachystegia spiciformis* (38% of 1,330 ± 523 stems ha^{-1}), *Brachystegia boehmii* (11%), *Uapaca kirkiana* (8%), *Pseudolachnostylis maprouneifolia* (7%) and *Faurea saligna* (6%). For regenerants, the total mean stem density was 1,180 ± 537 stems ha^{-1} and the most abundant species were *Brachystegia spiciformis* (49% of 1,180 ± 537 stems ha^{-1}), followed by *Brachystegia boehmii* (15%), *Uapaca kirkiana* (8%) and *Combretum zeyheri* (7%). Generally, the distribution of trees to size classes showed the usual reverse J shape suggesting a normal and stable forest (Fig. 3).

The mean stem density of 1,330 ± 523 stems ha^{-1} for the woody species with DBH ≥ 5 cm reported in this study is higher than other studies conducted in other wet Miombo woodland areas. For instance, Katani et al. (2016) from wet Miombo woodland of Angai Village Land Forest Reserve, Tanzania reported a value of 658 ± 143 stems ha^{-1}; Kalaba et al. (2013) from wet Miombo woodland of Copperbelt Province in Zambia, reported a value of 592 ± 28.01 stems ha^{-1}; Mwampashi (2013) from wet Miombo woodland of Iwuma Forest Reserve in Mbozi District, Tanzania reported a value of 553 stems ha^{-1} and Shirima et al. (2011) from Nyanganje Forest Reserve in Tanzania reported two values of 382 stems ha^{-1} and 376 stems ha^{-1}. The mean stem density values in this study fall within the range of density values found in Miombo woodland of 232–1,988 stems ha^{-1} (Sawe et al., 2014; Mwakalukwa et al., 2014; Katani et al., 2016). This implies that LVLFR is among the high-stocked wet Miombo woodland forests in Tanzania and elsewhere. The higher density reported in this study might be attributed to good weather conditions (high rainfall) and the presence of two adjacent rivers (Liwolelu and Mchuchuma Rivers draining their waters into Lake Nyasa), which creates favourable conditions for trees and shrubs to grow and flourish. The usual reverse J-shaped curve noted in this study indicates a steady and expanding population.

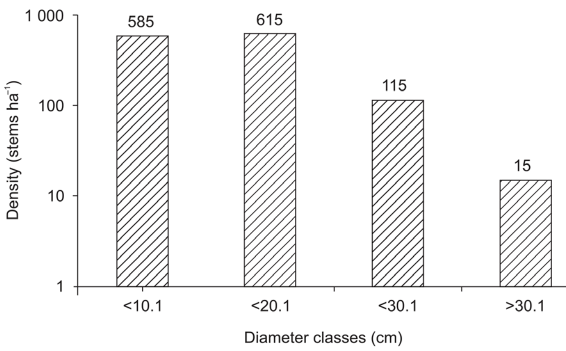

Fig. 3. Density of woody plant species with DBH ≥ 5 cm by diameter classes in Litwang'ata village forest reserve Southwest Tanzania (n = 20, y-axis is on the logarithmic scale).

Woody plants basal area

The mean basal areas for trees and shrubs with DBH ≥ 5 cm was 18.97 ± 6.81 m^2 ha^{-1} (Table 1, Fig. 4). Among the most abundant species were *Brachystegia spiciformis* (40% of 18.97 ± 6.81 m2 ha^{-1}), *Brachystegia boehmii* (14%), *Acacia amythethophylla* (8%), *Uapaca kirkiana* (7%) and *Faurea saligna* (7%). Generally, the distribution of trees to size classes showed a normal distribution shape (Fig. 4) with trees with diameters >10.1 cm and <30.1 cm contributing higher to the overall mean basal area of the forest.

The mean basal area of 18.97 ± 6.81 m^2 ha^{-1} obtained in this study is higher than those documented in other wet Miombo woodland. For instance, Kalaba et al. (2013) from wet Miombo woodland of Copperbelt Province in Zambia reported a value of 14.34 ± 0.52 m^2 ha^{-1}.

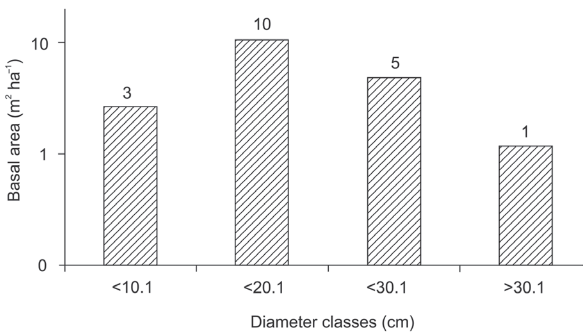

Fig. 4. Distribution of basal area per hectare for woody plant species with DBH ≥ 5 cm by diameter classes in Litwang'ata village forest reserve, Southwest Tanzania (n = 20, y-axis is on the logarithmic scale).

Shirima et al. (2011) reported two values of mean basal area i.e. 12.3 m^2 ha^{-1} and 13.3 m^2 ha^{-1} in Nyanganje Forest Reserve in Tanzania, and Katani et al. (2016) reported a value of 10.07 ± 1.68 m^2 ha^{-1} in wet Miombo woodland of Angai Village Land Forest Reserve, Tanzania. Also, Mwampashi (2013) reported a value of 9.60 m^2 ha^{-1} for wet Miombo woodland of the Iwuma Forest Reserve in Mbozi District, Tanzania. The mean basal area found in this study falls beyond the range of values commonly found in Miombo woodland (both wet and dry) of 3.9–16.7 m^2 ha^{-1} (Backéus et al., 2006; Mwakalukwa et al., 2014; Masota et al., 2018). The higher basal area obtained in this study could likely be due to the comparatively higher stem density observed in the Litwang'ata VLFR.

Woody plant species volume

The mean stand volume for trees and shrubs with DBH ≥ 5 cm in LVLFR was 142.36 ± 52.17 m^3 ha^{-1} (Table 1, Fig. 5). The species contributing most to the volume were *Brachystegia spiciformis* (57.69 ± 10.70 m^3 ha^{-1}), *Brachystegia boehmii* (21.32 ± 7.73 m^3 ha^{-1}), *Acacia amythethophylla* (11.94 ± 6.75 m^3 ha^{-1}) and *Faurea saligna* (10.46 ± 4.88 m^3 ha^{-1}). In general, the distribution for trees and shrubs with DBH ≥ 5 cm to size classes showed that trees with diameters between >10.1 cm and <30.1 cm contributed higher to the mean total standing volume in the forest (Fig. 5).

The mean stand volume of 142.36 ± 52.17 m^3 ha^{-1} reported in this study for trees and shrubs with DBH ≥ 5 cm was considered higher than other values reported by Mwampashi (2013) from wet Miombo woodland of Iwuma Forest Reserve in Mbozi District, Tanzania who reported a value of 60.29 m^3 ha^{-1} and Katani et al. (2016) from wet Miombo woodland of Angai Village Land Forest

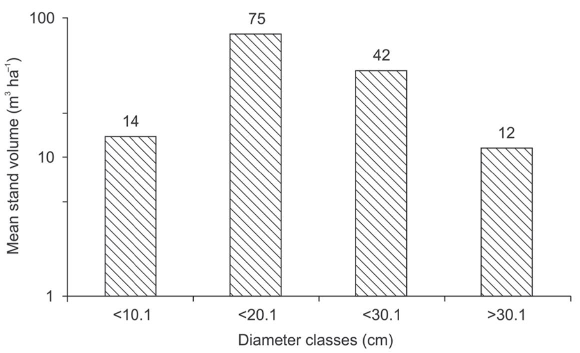

Fig. 5. Distribution of mean stand volume per hectare for trees and shrubs ≥ 5 cm DBH by diameter classes in Litwang'ata village land forest reserve Southwest Tanzania (n = 20, y-axis is on the logarithmic scale).

Reserve, Tanzania who reported a value of 68.52 ± 18.84 m^3 ha^{-1}. Generally, the mean volume reported in this study falls within the range of values commonly found in Miombo woodland of 16.7 to 155.9 m^3 ha^{-1} (Mwakalukwa et al., 2014; Masota et al., 2018). The relatively higher volume reported by this study might be caused by presence of large-sized trees in the forest contributing higher to the total volume.

Biomass and carbon storage

The mean aboveground biomass and carbon stocks of LVLFR for studied woody plants with diameter ≥ 5 cm were 95.86 ± 35.16 Mg ha^{-1} and 46.97 ± 17.23 Mg ha^{-1}, respectively. The mean belowground biomass and carbon stocks of the forest reserve were 48.78 ± 17.52 Mg ha^{-1} and 23.90 ± 8.58 Mg ha^{-1}, respectively (Table 1, Fig. 6). Tree species which made a high contribution to the observed aboveground carbon were *Brachystegia spiciformis* (19.04 ± 3.54 Mg ha^{-1}), *Brachystegia boehmii* (7.06 ± 2.56 Mg ha^{-1}), *Acacia amythethophylla* (3.94 ± 2.23 Mg ha^{-1}), *Faurea saligna* (3.46 ± 1.62 Mg ha^{-1}) and *Uapaca kirkiana* (3.26 ± 1.58 Mg ha^{-1}). Species which made a high contribution to the observed belowground carbon density were *Brachystegia spiciformis* (9.65 ± 1.70 Mg ha^{-1}), *Brachystegia boehmii* (3.29 ± 1.18 Mg ha^{-1}), *Acacia amythethophylla* (1.93 ± 1.09 Mg ha^{-1}), *Uapaca kirkiana* (1.80 ± 0.84 Mg ha^{-1}) and *Faurea saligna* (1.68 ± 0.69 Mg ha^{-1}). The biomass and carbon distribution in different diameter classes indicated that trees with diameters between >10.1 cm and <30.1 cm contributed higher to the mean biomass and carbon stocks of the forest (Fig. 6).

The obtained total mean aboveground carbon

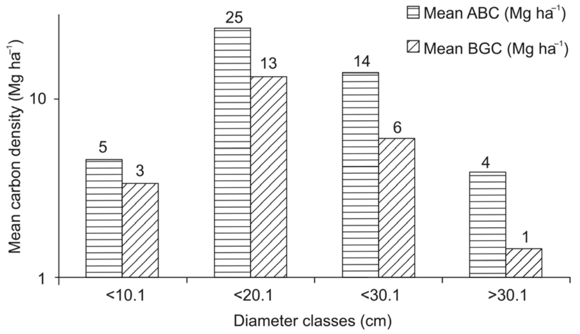

Fig. 6. Distribution of aboveground and belowground mean carbon density for trees and shrubs ≥ 5 cm DBH by diameter classes in Litwang'ata village land forest reserve Southwest Tanzania (n = 20, y-axis is on the logarithmic scale).

stocks of woody plants in this study (46.97 ± 17.23 Mg ha^{-1}) is higher than stocks reported elsewhere. Kalaba et al. (2013) reported a value of 39.6 ± 1.5 Mg ha^{-1}, Mwampashi (2013) reported a value of 39.46 Mg ha^{-1}, Shirima et al. (2011) reported two values of 27.3 ± 5.0 Mg ha^{-1} and 29.8 ± 5.9 Mg ha^{-1} and Katani et al. (2016) reported a value of 16.79 Mg ha^{-1}. The high value reported in this study could be due to the presence of a high number of stem densities in the reserve and trees with high DBH. This study is the first to report estimates of mean below-ground biomass and carbon stock potential of wet Miombo woodland in which if added to aboveground estimates LVLFR will have an even much higher contribution in terms of carbon density of the whole forest than other wet Miombo forests (i.e. 70.87 Mg ha^{-1}).

In conclusion, the results showed that LVLFR had low species richness of woody species (20 species) and medium species diversity (*H'* = 2.27; D = 0.18) as compared to other wet Miombo woodlands in Tanzania and elsewhere. However, tree density, basal area and stand volume were comparatively higher in our studied forest than other wet Miombo woodland indicating that the forest is still in good condition. These kinds of information are essential to inform baseline and for proper planning of management and conservation of LVLFR as well as for future monitoring. The carbon stocks were higher compared to those reported from another wet Miombo woodlands. This study is the first one to provide carbon stock estimates of both aboveground and belowground for wet Miombo woodland in Tanzania and elsewhere. These carbon estimates provide baseline data for the possibility of future payment schemes in Reduced Emissions from Deforestation and Forest Degradation (REDD+) project implementation in Tanzania. Quantification of other carbon pools, such as soil, dead wood and surface litter, should be considered for estimating the total carbon stocks potential of this recently declared village land forest reserve.

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