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Vegetation composition, diversity, stand structure, and carbon storage of Lolkisale Village Land Forest Reserve in the Northeastern part of Tanzania

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Abstract. *Mwakalukwa EE, Mwakisu A, Madundo S, Maliondo SMS. 2023. Vegetation composition, diversity, stand structure, and carbon storage of Lolkisale Village Land Forest Reserve in the Northeastern part of Tanzania. Nusantara Bioscience 15: 79-90.* Little is known about the effects of human activities on the condition of the Lolkisale Village land Forest reserve located in Monduli District, Arusha region, in the northeastern part of Tanzania. This study assessed the status of woody species diversity, composition, structure, and available potential of the forest on carbon storage. The vegetation data were collected from 33 concentric sample plots of 5 m, 15 m, and 20 m radius laid systematically across the forest area of 960 ha. A total of 58 plant species belonging to 30 families were identified. Diversity indices have indicated a high woody species diversity in the forest reserve. The most important species were *Commiphora schimperi* (O.Berg) Engl., *Dombeya rotundifolia* (Hochst.) Planch., *Acacia tortilis* (Forssk.) Hayne, and *Combretum molle* R.Br. ex G. Don. Stand structure comprises 190 ± 117 stems ha^{-1}, basal area of 7.68 ± 5.17m^2ha^{-1} and standing volume of 64.04 ± 45.85 m^3ha^{-1}, while the mean above-ground carbon stocks and the mean below-ground carbon stocks were 19.55 ± 13.38 Mg C ha^{-1} and 3.91 ± 2.68 Mg C ha^{-1} respectively. Generally, the reserve was found to be in good condition. The observed high diversity of woody species signifies the importance of legally protecting this area as a village land forest reserve. In addition, quantifying other carbon pools, such as soil, dead wood, and surface litter, should be considered for estimating this forest's total carbon stock potential. In this regard, measures to control the use of the forest as a grazing area would be useful to allow new regrowth and young trees to attain maturity stages without being interfered with by the livestock.

Keywords: Community forest, dry evergreen forest, game controlled area, human activities, montane forest, REDD+

INTRODUCTION

The effects of deforestation and forest degradation on the quality and condition of forest resources have been well studied (Foley et al. 2007; Kideghesho 2015; Newmark and McNeally 2018; Doggart et al. 2020; FAO 2020; FAO and UNEP 2020; Gizachew et al. 2020; Wade et al. 2020; Shapiro et al. 2021; Wolf et al. 2021; Fritz et al. 2022; Mammides et al. 2022). Deforestation reduces the ability of the forest to offer its various ecosystems services, including carbon sequestration, amelioration of climate for rainfall formation, conservation of watershed services, soil fertility, biodiversity, and habitats for other living organisms (Lele 2009; Betts et al. 2017; Karki et al. 2017; Houghton and Nassikas 2018; Popkin 2019; Qin et al. 2021; Njora and Yilmaz 2022). For example, FAO (2020) estimated that between 1990 and 2020, around 420 million ha of forest has been deforested worldwide and converted to other land uses. More specifically, about 10 million ha of forest were lost annually between 2015-2020. According to TEEB (2010), conserving forests could avoid greenhouse gas emissions worth US$ 3.7 trillion globally. This is the amount the world will save by avoiding deforestation.

According to FAO (2020), the rate of forest loss is greater in Africa than anywhere else in the world. For example, from 2010 to 2020, the African continent experienced a net forest loss of 3.9 million ha annually, compared to 2.6 in South America, 0.1 in North and Central America, and 0.0 in Asia (FAO 2020; Wolf et al. 2021). Burning and clearing land for agriculture are the most important causes of forest loss hence carbon emissions (Doggart et al. 2020; FAO 2020). Currently, Tanzania is losing 469,420 ha of forest area annually (URT 2017). Therefore, using a deforestation rate of 372,816 ha (MNRT 2015), and considering on other provisioning services apart from those which are usually reflected in the Gross Domestic Product (GDP) accounting, including non-timber forest products, regulating services such as water, and supporting services such as biodiversity, the present value of net economic losses from deforestation to the Tanzanian economy in 2013-2033 is estimated to be TSh 5,588 billion (US$ 3.5 billion) (UNEP 2015).

Different strategies have been suggested and practiced globally to help reduce or curb the effects of deforestation, such as establishing new protected areas, especially in areas found to be rich in biodiversity (Watson et al. 2014; Bebber and Butt 2017; Miller and Nakamura 2018; CBD 2020; Wade et al. 2020; Wolf et al. 2021; Daba et al. 2022). Recently, Tanzania has set strategies to bring about 16 million hectares of forests found in village land areas that have constantly been facing serious threats of deforestation (i.e., Doggart et al. 2020) to effective protection by 2031 as one way of reducing the effects of deforestation. (URT 2021; MNRT 2022a). In this case, Participatory Forest Management (PFM) through Community Based Forest Management (CBFM) approach has been implemented to assist villagers in conserving forests found within their reach. According to MNRT (2022b), the total area of declared and gazetted CBFM forests is estimated to be 1,917,224 ha out of the total area of 2,202,335 ha under CBFM in Tanzania mainland. Some villages are still under different stages of declaration or gazettement of their village forest area.

The Lolkisale Village Land Forest Reserve (LVLFR) is believed to harbor distinct diversity of micro-habitats. It is rich in flora and fauna, like any other isolated mountain with forest on top of hills found in northern Tanzania's Monduli District, Arusha region. LVLFR is known to preserve some water sources for the nearby villages and act as a corridor for animals migrating from nearby national parks. However, the forest has not been declared nor gazetted due to a lack of data on forest conditions for preparing management plans (URT 2002). LVLFR is also among the forest reserves that face various levels of human interference (Sitati et al. 2014; Sitati et al. 2016; Mwakalukwa et al. 2023a; Mwaluseke et al. 2023a). This uncontrolled use of forest resources could cause a massive biodiversity loss. However, the biodiversity assessment has not been conducted. This study, therefore, specifically aims to; (i) assess the status of woody species diversity, composition, and structure in the LVLFR, (ii) assess the effects of anthropogenic activities in the condition of the LVLFR, and (iii) assess the potential of the LVLFR in carbon storage.

MATERIALS AND METHODS

Study area

The Lolkisale Village Land Forest Reserve (LVLFR) is located within Lolkisale village in Lolkisale ward, Monduli District, about 50 km off the road from Arusha town along the road leading to Babati or Lake Manyara National Park, Tanzania (Figure 1). The Lolkisale village is bordered by seven other villages: Meserani, Nalalan, Lobosoi, Tukusi, Mbuyuni, Makuyuni, and Naitoliaa. Land uses in Lolkisale village include livestock keeping, farming, forest reserve, settlement, infrastructures, e.g., roads, and social services such as dams, schools, etc. The village government owns LVLFR, although the reserve is not yet gazetted. LVLFR covers about 960 hectares. Elevation ranges from 1,491 - 2,097 masl (mean 1,724 ± 32). The district where the LVLFR belongs is generally semi-arid with average rainfall between 400 and 900 mm per annum while the average temperature ranges from 11.5°C (July) to 29°C (December). The slope ranges from 14-75% (mean 39.1 ± 2.8%). The vegetation is described as dry evergreen montane forests.

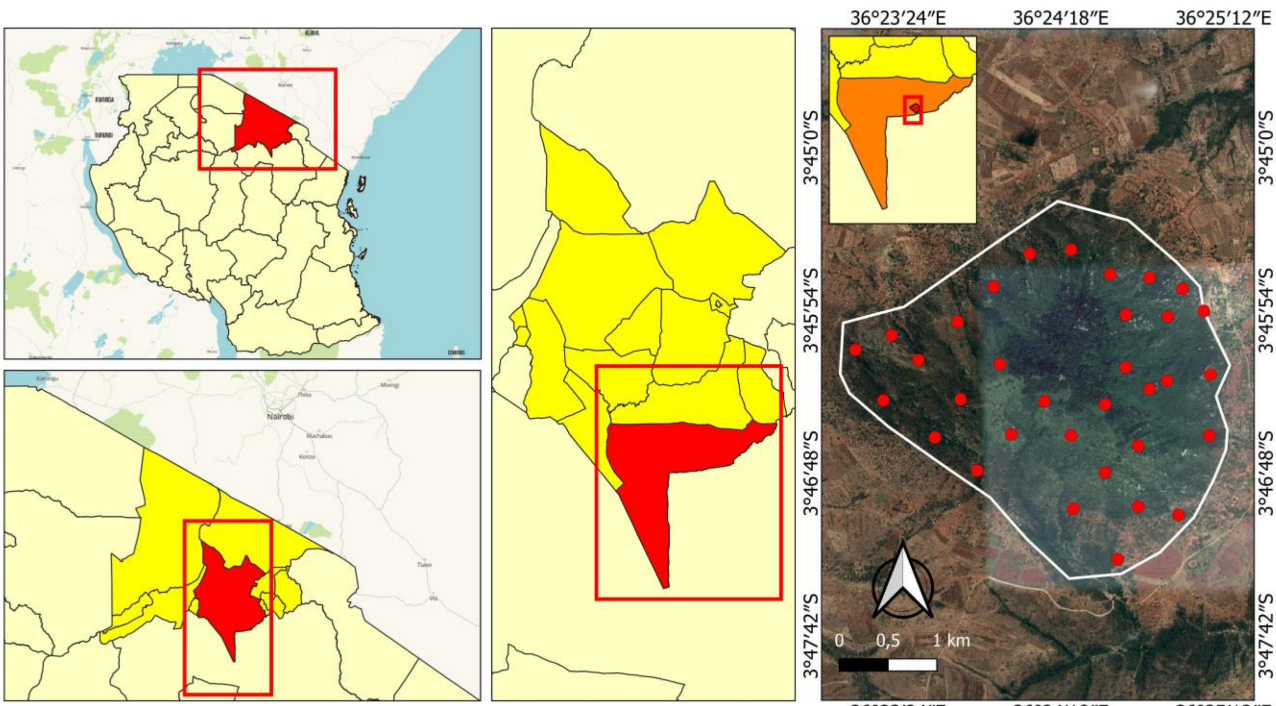

Figure 1. The map of Monduli District, Tanzania, showing the location of Lolkisale Village Land Forest Reserve (LVLFR) and sample plots layout in the reserve

Data collection

The field survey was conducted in August and September 2014 and involved systematically establishing 33 concentric sample plots of 5 m, 15 m, and 20 m radius across the LVLFR of 960 ha. The following parameters were recorded within each of the 33 plots: within the 5m radius, all small trees and shrubs with DBH < 1 cm were counted, and their species were identified, and medium-size trees and shrubs (≥ 1cm DBH but < 5cm DBH) were identified and measured concerning diameter. The species were identified within a 15 m radius, and the diameter was measured for all large trees and shrubs with DBH ≥ 5cm. Stumps of trees and shrubs were measured for Basal Diameter (BD) at 10 cm above ground within a 20 m radius plot. The Diameter at Breast Height (DBH) was measured 1.3 m above ground using diameter tape or caliper. In addition, three stems with small, medium, and large DBH in a plot were selected and measured for heights using a Suunto hypsometer. Altitude was recorded at the plot center using GPS, and the slope was measured from the plot's center facing the slope's direction using a Suunto clinometer.

Data analysis

The collected data were analyzed for species richness, the number of stems/ha, basal area/ha, volume/ha, and biomass/ha. Total species richness was computed as the total number of species across all 33 plots. Species diversity was computed using the Shannon-Wiener diversity (H′) index and Simpson's diversity index (D), whereas the Importance Value Index (IVI) was determined as the sum of relative density and dominance (basal area) and expressed in percent (Kent 2012; Mwakalukwa et al. 2014). Forest structure was expressed through stem density, basal area, and volume for species against diameter classes. Data on Diameter at Breast Height (DBH) and Height (Ht) were used to estimate volume and biomass using the developed equations and hence estimate the forest's stand volume, above-ground, and below-ground carbon stocks potential. The models developed by Mwaluseke et al. (2023b) for dry evergreen montane forests were used to estimate the volume and biomass content of the forest; after that converted to carbon content per ha of the forest. Below-ground biomass of each species was estimated as 20% of the total above-ground biomass:

$$\text{Height (m)} = 2.3249 + 6.6101/\text{DBH} + 0.2847\text{DBH} \; (R^2 = 0.78, \text{RMSE} = 1.79, \text{AIC} = 164.37).$$

$$\ln(\text{Volume, m}^3) = -9.845 + 1.915\ln(\text{DBH}) + 1.089\ln(\text{Ht}) \; (R^2 = 0.97, \text{RMSE} = 0.296, \text{AIC} = -144.18).$$

$$\ln(\text{Biomass, kg}) = -1.666 + 0.853\ln(\text{WD} \times \text{DBH}^2 \times \text{Ht}) \; (R^2 = 0.95, \text{RMSE} = 0.324, \text{AIC} = 224.13).$$

Where:

DBH	: Diameter at Breast Height (cm)
Ht	: total tree height (m)
WD	: basic Wood Density (g/cm^3)
RMSE	: Root Mean Square Error
AIC	: Akaike's Information Criterion
R^2	: coefficient of determination

Wood basic density values for each species were extracted from various sources (Bryce 1967; Goldsmith and Carter 1981; Drichi 1992; Brown 1997; Suzuki 1999; Ishengoma et al. 2000; Hamza et al. 2001; Mbwambo et al. 2006; Mwaluseke et al. 2023b). Carbon stock was estimated by multiplying with a conversion factor of 0.49 (Manyanda et al. 2020) and presented per hectare ($Mg\ Cha^{-1}$). All data analyses were performed using Excel spreadsheet and R (version 4.2.0).

RESULTS AND DISCUSSION

Species richness

The results for species richness of all size categories (small individuals of DBH< 5 cm and large individuals of DBH ≥ 5 cm) that were identified in the LVLFR are found in Table 1. A total of 58 species (30 plant families) of trees and shrubs were identified. Trees contributed 84% (26 plant families), and shrubs 16% (8 plant families) of the species. Generally, tree and shrub species from the family Mimosoideae contributed the most (17%) to the total number of species, followed by those from the families Anacardiaceae (10%) and Rutaceae (9%). For trees alone, the greatest number of species was found in Mimosoideae family (18%), followed by Rutaceae family (10%) and Anacardiaceae (8%), whereas for shrub species alone were from Anacardiaceae family (22%).

Therefore, a total of 49 species (28 families) were found among large sizes (DBH ≥ 5cm), with Mimosoideae (18%), Anacardiaceae (10%), Rutaceae (8%), and Burseraceae (6%) being the most species-rich plant families. While among small sizes (DBH < 5 cm), a total of 26 species (17 families) were observed, with Mimosoideae (16%), Rutaceae (16%), Anacardiaceae (16%), Oleaceae (16%), and Papilionoidea (16%) contributing most of the species (Table 1). Generally, the average number of species per plot was 4 species (range 1 - 8 per plot). The species accumulation curve indicates the rate of encountering new species (Figure 2). Species initially increased rapidly to the 20th plot and slowly up to the 33rd plot. However, since only 33 plots were sampled, the later result implies that any further increase in sample size might have included additional new species. Nevertheless, the sample size was sufficient to provide the baseline information necessary for understanding the composition and diversity of the species in LVLFR.

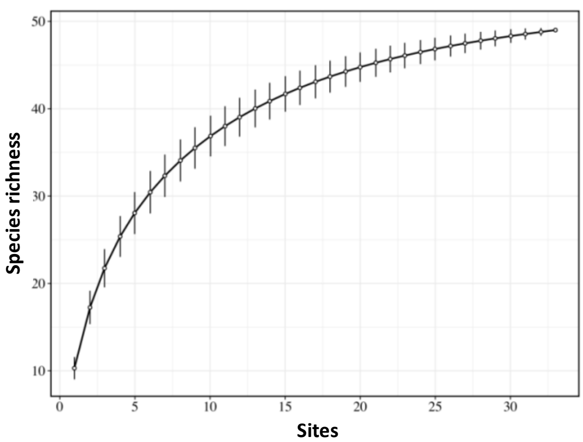

Figure 2. Species accumulation curve of tree species in Lolkisale Village Land Forest Reserve (LVLFR), Tanzania

The species richness of 58 different trees and shrubs and 30 plant families reported in this study using 33 sample plots of 0.071 ha is lower when compared to other studies from other tropical forests. For instance: Sitati et al. (2014) found a total of 75 tree and shrub species from 100 plots of 0.02 ha established in a dry evergreen forest of Gelai Forest Reserve in Tanzania; Mwaluseke et al. (2023a) found a total of 79 tree and shrub species from 56 concentric sample plots of 0.071 ha established in a dry evergreen forest of Lendikinya Forest Reserve in Tanzania; Kayombo et al. (2022) found a total of 84 tree species from 60 plots of 20 m × 20 m established in a dry evergreen forest of Monduli Mountain Forest Reserve in Tanzania; Boz and Maryo (2020) from Ethiopia reported a total of 76 woody species representing 40 families in a dry semi-evergreen Afromontane forest from 64 sample plots (0.04 ha); Masresha and Melkamu (2022) reported 13 values of different species richness ranging from 62-122 tree species from dry evergreen Afromontane forest patches in Ethiopia and Erenso et al. (2014) found a total of 95 species from a dry evergreen forest in Ethiopia.

However, compared to other studies, the species richness of 58 was relatively higher despite the smaller sample size used in this study (33 plots). For instance: Sitati et al. (2016) found a total of 43 tree and shrub species from 77 plots of 0.071 ha established in a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania; Mwakalukwa et al. (2023b) found a total of 54 tree and shrub species from 23 plots of 0.071 ha established in a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania; Masresha and Melkamu (2022) in Ethiopia reported 13 different values of species richness ranging from 34-57 tree species; Mialla (2002) reported species richness of 42 trees and shrubs from 48 sample plots of 0.071 ha; Dugilo (2009) reported species richness of 42 species from 28 sample plots of 0.071 ha; Feroz et al. (2016) reported 40 species (in 0.16 ha) in tropical wet evergreen forest in Bangladesh; and Kacholi et al. (2015) reported six different values of species richness ranging between 17 - 52 from seven individual tropical wet forests of Uluguru forests in Tanzania.

The species richness in this study falls within the range of species commonly found in miombo woodland of 40 - 229 species (Mwakalukwa et al. 2014; Jew et al. 2016). That shows LVLFR has a relatively large number of forest plant species, stressing the significance of its conservation. The higher values found in other studies could be attributed to greater sampling effort (total area, number of sample plots, and sizes) employed by other studies compared to this study.

Species diversity

The results for species diversity in the LVLFR according to Shannon-Wiener diversity indices for large (DBH ≥ 5 cm) and small (DBH < 5 cm) individuals were 3.41 and 2.78, respectively. Species of large individuals (DBH ≥ 5 cm) that were observed to have the greatest contributions were: *Commiphora schimperi* (O.Berg) Engl. (0.24), *Dombeya rotundifolia* (Hochst.) Planch. (0.18), *Acacia tortilis* (Forssk.) Hayne (0.17), *Dracaena usambarensis* Engl. (0.17), *Teclea nobilis* Del. (0.17), and *Combretum molle* R.Br. ex G.Don (0.16). While for smaller ones (DBH < 5 cm) were: *Albizia petersiana* (Bolle) Oliv. (0.32), *C. molle* (0.29), *D. rotundifolia* (0.22), *Grewia bicolor* Juss. (0.20), *Vepris simplicifolia* (Verd.) Mziray (0.18), *Cassipourea malosana* (Baker) Alston (0.13), and *T. nobilis* (0.13). According to the Simpson index, species diversity for large individuals was 0.04, and that of small individuals was 0.09. The index of dominance (1-D) for large individuals was 0.96, and for smaller individuals was 0.91, while the index for evenness or equitability (J) for large individuals was 0.88 and for smaller individuals was 0.85.

In terms of frequency of occurrence for standing individuals (DBH ≥ 5 cm) in the LVLFR, *C. schimperi* was the most frequent species (42% of plots), followed by *D. rotundifolia* (36%), *C. molle* (30%) and *Acacia nilotica* (L.) Willd. ex Delile (21%). In comparison, for small sizes (DBH < 5cm), *C. molle* (21%), *D. rotundifolia* (15%), and *A. petersiana* (12%) were the most frequent species (Table 1). The Importance Value Index (IVI) for large individuals (DBH ≥ 5 cm) shows that *C. schimperi* (30.77), *D. rotundifolia* (23.86), *A. tortilis* (14.49), and *C. molle* (13.72) were the most important species among standing individuals (Table 1).

The values of the Shannon-Wiener index (H'= 3.41) for trees and shrubs in the present study are lower than those reported by other researchers. For example, Mwaluseke et al. (2023a) reported an H' value of 3.46 from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania; Kacholi et al. (2015) found an overall H' value of 4.03 from the Uluguru forests in Tanzania, and Tynsong et al. (2022) reported an H' values ranging from 3.74 - 3.95 (mean 3.85 ± 0.06) from the tropical evergreen forests in India. However, H' values in this study are much higher than those documented by other researchers. For example, Masresha and Melkamu (2022) reported 18 different H' values ranging between 1.31- 3.35 from dry evergreen Afromontane forest patches in Ethiopia; Dugilo (2009) reported H' value of 1.30 from Tanzania; Kayombo et al. (2022) reported an H' value of >1.5 from Tanzania; Erenso et al. (2014) reported H' value of 1.79 from Ethiopia; Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania (H' value of 2.36); Mwakalukwa et al. (2023b) from a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania who reported an H' value of 2.70; Sitati et al. (2014) reported an H' value of 2.85 from a dry evergreen forest of Gelai Forest Reserve in Tanzania; and Boz and Maryo (2020) from Ethiopia reported an average H' value of 3.38. However, the H' value of 3.41 in this study falls in the *H'* value commonly found in miombo woodland, where values range from 1.05 - 4.27 (Shirima et al. 2011; Mwakalukwa et al. 2014; Jew et al. 2016). According to Magurran (2004) and Mwakalukwa et al. (2014), the H' values normally vary between 1.5 and 4.5 and rarely exceed 5. A threshold of 2 is the minimum value, above which an ecosystem can be regarded as medium to highly diverse. Therefore, the value of 3.41 found in this study implies that the LVLFR has high diversity in tree and shrub species. High diversity might be attributed to relatively low levels of disturbance experienced in the forest, as very few stumps were observed during the survey.

Table 1. Checklist of tree and shrub species identified in the Lolkisale Village Land Forest Reserve (LVLFR), Tanzania, showing frequency (%); density (mean ± SE); basal area (mean ± SE); Wood basic density; Importance Value Index (IVI); Stand volume (mean ± SE); Above-ground Carbon (mean ± SE); and Below-ground Carbon (mean ± SE) for trees and shrubs with a minimum DBH 1 cm (plot size = 15 m radius)

Species/botanical name	Family	Habit / Life form	Wood basic density (kg/m³)	Frequency (%)	Density (stems/ha)	Basal area (m²/ha)	IVI	Stand volume (m³/ha)	AGC (Mg/ha)	BGC (Mg/ha)
Commiphora schimperi (O.Berg) Engl.	Burseraceae	Tree	640	42	21±6	0.88±0.26	30.77	5.93±1.85	2.07±0.63	0.41±0.13
Dombeya rotundifolia (Hochst.) Planch.	Sterculiaceae	Tree	640	36	13±4	0.17±0.06	23.86	0.82±0.28	0.35±0.12	0.07±0.02
Acacia tortilis (Forssk.) Hayne	Mimosoideae	Tree	640	15	12±6	0.67±0.34	14.49	5.18±2.62	1.67±0.84	0.33±0.17
Combretum molle R.Br ex G. Don	Combretaceae	Tree	758	30	10±3	0.32±0.14	13.72	2.06±0.94	0.85±0.37	0.17±0.07
Lannea schimperi (Hochst.ex A. Rich.) Engl.	Anacardiaceae	Tree	640	9	2±1	0.09±0.05	8.07	0.61±0.35	0.21±0.12	0.04±0.02
Acacia nilotica (L.) Willd. ex Delile	Mimosoideae	Tree	797	21	8±4	0.11±0.06	7.68	0.55±0.27	0.28±0.14	0.06±0.03
Albizia gummifera (J.F.Gmel.) C.A.Sm.	Mimosoideae	Tree	640	9	8±4	0.87±0.51	6.40	9.12±5.78	2.52±1.55	0.50±0.31
Commiphora mossambicensis (Oliv.) Engl.	Burseraceae	Tree	370	9	9±6	0.18±0.12	6.38	0.94±0.61	0.24±0.16	0.05±0.03
Teclea nobilis Del.	Rutaceae	Tree	849	18	12±7	0.32±0.27	6.34	2.06±1.83	0.94±0.81	0.19±0.16
Albizia petersiana (Bolle) Oliv.	Mimosoideae	Tree	640	12	6±3	0.09±0.07	5.32	0.49±0.40	0.20±0.15	0.04±0.03
Nuxia congesta R.Br.ex Fresen.	Loganiaceae	Tree	640	9	7±5	1.35±1.07	5.08	15.59±12.52	4.12±3.28	0.82±0.66
Lannea triphylla (Hochst.ex A.Rich.) Engl.	Anacardiaceae	Tree	450	6	3±3	0.23±0.20	4.48	1.81±1.58	0.43±0.37	0.09±0.07
Calodendum capense (L.f.) Thunb.	Rutaceae	Tree	583	9	5±3	0.15±0.09	3.85	0.92±0.51	0.31±0.18	0.06±0.04
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tree	785	12	7±4	0.28±0.16	3.79	2.41±1.67	0.88±0.54	0.18±0.11
Olea europaea L.	Oleaceae	Tree	1169	3	1±1	0.10±0.10	3.69	0.84±0.84	0.06±0.06	0.01±0.01
Commiphora africana (A.Rich.) Engl.	Burseraceae	Tree	276	18	3±1	0.09±0.04	3.61	0.55±0.23	0.10±0.04	0.02±0.01
Acacia thomasii Harms	Mimosoideae	Tree	503	3	1±1	0.07±0.07	3.56	0.49±0.49	0.13±0.13	0.03±0.03
Acacia mellifera (Vahl) Bosc	Mimosoideae	Tree	947	9	5±3	0.09±0.06	3.51	0.53±0.39	0.29±0.20	0.06±0.04
Boscia angustifolia Harv.	Capparidaceae	Tree	640	6	3±3	0.09±0.07	3.11	0.72±0.59	0.23±0.18	0.05±0.04
Steganotaenia araliacea Hochst.	Araliaceae	Tree	370	9	3±2	0.01±0.01	2.89	0.04±0.03	0.01±0.01	0.00±0.00
Acacia hockii De Wild.	Mimosoideae	Tree	720	12	3±2	0.05±0.03	2.88	0.28±0.17	0.12±0.07	0.02±0.01
Erythrina abyssinica Lam. ex DC.	Papilionoidea	Tree	426	3	1±1	0.35±0.35	2.82	4.87±4.87	0.83±0.83	0.17±0.17
Cassipourea gummiflua Tul.	Rhizophoraceae	Tree	720	3	2±2	0.02±0.02	2.74	0.11±0.11	0.06±0.06	0.01±0.01
Cordia monoica Roxb.	Boraginaceae	Tree	830	9	4±3	0.03±0.02	2.55	0.17±0.13	0.09±0.06	0.02±0.01
Rhus natalensis Bernh.ex Krauss	Anacardiaceae	Shrub	606	3	2±2	0.01±0.01	2.48	0.02±0.02	0.01±0.01	0.00±0.00
Ormocarpum kirkii S.Moore	Papilionoidea	Tree	742	6	1±1	0.01±0.00	2.17	0.03±0.02	0.02±0.01	0.00±0.00
Obetia radula (Baker) Baker ex B.D.Jacks.	Urticaceae	Tree	640	6	2±1	0.08±0.07	2.09	0.74±0.69	0.22±0.20	0.04±0.04
Dracaena usambarensis Engl.	Agavaceae	Tree	640	3	12±12	0.19±0.19	2.01	0.95±0.95	0.39±0.39	0.08±0.08
Acacia gerrardii Benth.	Mimosoideae	Tree	816	6	1±1	0.04±0.03	1.92	0.21±0.18	0.10±0.08	0.02±0.02
Turraea robusta Gürke	Meliaceae	Tree	640	6	1±1	0.05±0.05	1.80	0.38±0.37	0.13±0.12	0.03±0.02
Lannea humilis (Oliv.) Engl.	Anacardiaceae	Tree	640	3	1±1	0.03±0.03	1.76	0.15±0.15	0.06±0.06	0.01±0.01
Drypetes gerrardii Hutch.	Ephorbiaceae	Tree	703	3	2±2	0.03±0.03	1.45	0.14±0.14	0.06±0.06	0.01±0.01
Terminalia brownii Fresen.	Combretaceae	Tree	640	6	1±1	0.06±0.06	1.45	0.54±0.51	0.16±0.15	0.03±0.03
Adenium obesum (Forssk.) Roem. & Schult.	Apocynaceae	Tree	881	3	1±1	0.04±0.04	1.40	0.29±0.29	0.13±0.13	0.03±0.03
Grewia bicolor Juss.	Tiliaceae	Shrub	670	9	2±1	0.01±0.00	1.32	0.02±0.01	0.01±0.01	0.00±0.00
Azanza garckeana (F.Hoffm.) Exell & Hillc.	Malvaceae	Tree	640	6	1±1	0.03±0.03	1.02	0.19±0.17	0.07±0.06	0.01±0.01

Fagaropsis angolensis (Engl.) H.M.Gardner	Rutaceae	Tree	689	3	0±0	0.05±0.05	1.00	0.42±0.42	0.14±0.14	0.03±0.03
Ozoroa insignis Delile	Anacardiaceae	Tree	529	3	1±1	0.02±0.02	0.87	0.08±0.08	0.03±0.03	0.01±0.01
Maesa lanceolata Forssk.	Myricinaceae	Tree	676	3	4±4	0.08±0.08	0.76	0.39±0.39	0.17±0.17	0.03±0.03
Rytigynia sp.	Rubiaceae	Shrub	689	3	3±3	0.14±0.14	0.69	1.03±1.03	0.36±0.36	0.07±0.07
Vepris simplicifolia (Verd.) Mziray	Rutaceae	Tree	800	3	3±3	0.03±0.03	0.67	0.15±0.15	0.08±0.08	0.02±0.02
Balanites aegyptiaca (L.) Delile	Balanitaceae	Tree	630	3	0±0	0.03±0.03	0.64	0.17±0.17	0.06±0.06	0.01±0.01
Pappea capensis Sond.	Sapindaceae	Tree	640	3	0±0	0.01±0.01	0.62	0.08±0.08	0.03±0.03	0.01±0.01
Ximenia americana L.	Olacaceae	Shrub	640	3	1±1	0.00±0.00	0.57	0.01±0.01	0.01±0.01	0.00±0.00
Ziziphus mucronata Willd.	Rhamnaceae	Tree	640	3	0±0	0.02±0.02	0.55	0.17±0.17	0.06±0.06	0.01±0.01
Ekebergia capensis Sparrm.	Meliaceae	Tree	609	3	0±0	0.06±0.06	0.41	0.55±0.55	0.16±0.16	0.03±0.03
Ochna sp.	Ochnaceae	Tree	640	3	1±1	0.02±0.02	0.37	0.12±0.12	0.05±0.05	0.01±0.01
Albizia amara (Roxb.)Boivin	Mimosoideae	Tree	677	3	0±0	0.01±0.01	0.32	0.04±0.04	0.02±0.02	0.00±0.00
Mytenus senegalensis (Lam.) loes.	Celasteraceae	Tree	685	3	0±0	0.01±0.01	0.09	0.08±0.08	0.03±0.03	0.01±0.01
Acacia brevispica Harms	Mimosoideae	Shrub	640	+						
Cadaba farinosa Forssk.	Capparidaceae	Shrub	640	+						
Claucena anisate (Willd.) Hook.f. ex Benth.	Rutaceae	Tree	704	+						
Croton scheffleri Pax	Euphorbiaceae	Tree	721	+						
Harissonia abyssinica Oliv.	Simaroubaceae	Shrub	640	+						
Lonchocarpus eliocalyx Harms	Papilionoidea	Tree	758	+						
Rhus vulgaris Meikle	Anacardiaceae	Shrub	760	+						
Schrebera alata (Hochst.) Welw.	Oleaceae	Shrub	607	+						
Schrebera trichoclada Welw.	Oleaceae	Tree	801	+						
Total (all species)				**415**	**190 ± 117**	**7.68 ± 5.17**	**200**	**64.04 ± 45.85**	**19.55 ± 13.38**	**3.91 ± 2.68**

Notes: + indicates species identified among smaller individuals within 5 m radius plots (DBH<5cm). Mg/ha = Megagram per hectare

Stand density

The total mean stem density for large individuals with DBH ≥ 5 cm in the LVLFR was 190 ± 117 stems ha^{-1} (Table 1, Figure 3), and that of small individuals with DBH < 5 cm (including individuals with DBH < 1 cm) was 486 ± 346 stems ha^{-1}. Among large individuals, the most abundant species were *C. schimperi* (10.8% of 190 stems ha^{-1}), *D. rotundifolia* (6.8%), *A. tortilis* (6.1%), *T. nobilis* (6.1%), and *D. usambarensis* (6.1%). Among small individuals, the most abundant species were *C. molle* (16.7% of 486 stems ha^{-1}), followed by *G. bicolor* (11.9%), *A. petersiana* (11.1%), *D. rotundifolia* (9.5%), and *A. tortilis* (9.5%). Generally, the distribution of trees to size classes showed the usual reverse J shape (Figure 3).

The stem density of 190 ± 117 stems ha^{-1} for the woody species with DBH ≥ 5 cm reported in this study is lower than that documented by Mwakalukwa et al. (2023b) from a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania, who reported a mean density of 288 ± 173 stems ha^{-1}; Dugilo (2009), from dry evergreen forest of Selela village forest reserve in Tanzania, reported a mean density of 310 stems ha^{-1}; Sitati et al. (2014), from a dry evergreen forest of Gelai Forest Reserve in Tanzania, reported a mean density of 377 stems ha^{-1}; Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania reported a mean density of 435 stems ha^{-1}; and Gebeyetu et al. (2019) from five forests in Ethiopia reported a range of 365.6 - 664.1 stems ha^{-1} with a mean of 636.5 stems ha^{-1}; Kacholi et al. (2015), from seven tropical wet forests in the Uluguru forests in Tanzania, reported an overall mean density of 390 stems ha^{-1}.

The stem density of 190 ± 117 stems ha^{-1} is ten times lower than those reported by Mialla (2002) from Monduli Forest Reserve, a dry evergreen mountain forest in Tanzania, reported a mean density of 1,822 stems ha^{-1}. Mwaluseke et al. (2023a) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania reported a mean density of 1,398 ± 679 stems ha^{-1}; Atomsa and Dibbisa (2019) reported a mean density of 1,453 stems ha^{-1} from Ethiopia; Boz and Maryo (2020) reported the total density of 1,745.3 stems ha^{-1} from Ethiopia. Whereas Tynsong et al. (2022) reported a mean density of 2,005 ± 48.01 trees ha^{-1} with a range from 1,944 to 2,100 trees ha^{-1} in the tropical evergreen forests of North-East India. Furthermore, the mean stems density values of 190 ± 117 stems ha^{-1} from this study are also lower than the density value range found in miombo woodland of 281-1,521 stems ha^{-1} (Shirima et al. 2011; Mwakalukwa et al. 2014). That implies LVLFR is among the lowest-stocked dry evergreen montane forests in Tanzania and other tropical countries. The higher density reported in other studies might be attributed to microclimate influence, which creates favorable conditions for the growth of more species. The presence of wildlife animals such as Elephants could have affected the density of species in the LVLFR. The density distribution indicated a dominance of small trees depicting the normal reversed "J" shape, which indicates strong regeneration status and recruitment of the forest, a tendency normally observed in the natural mixed species of different ages (Figure 3).

Basal area

The mean basal areas for large individuals (≥ 5 cm DBH) and small individuals (<5 cm DBH) were 7.68 ± 5.17 m^2ha^{-1} and 0.16 ± 0.12 m^2ha^{-1}, respectively (Table 1, Figure 4). The species contributing most to the basal area of large individuals were *Nuxia congesta* R.Br.ex Fresen. (17.6%), *C. schimperi* (11.5%), *Albizia gummifera* (J.F.Gmel.) C.A.Sm. (11.3%), and *A. tortilis* (8.7%). In comparison, those contributing most to the basal area of smaller individuals were *A. petersiana* (24.0%), *D. rotundifolia* (11.8%), *T. nobilis* (11.0%), *G. bicolor* (10.7%), and *C. molle* (10.0%).

The mean basal area of 7.68 ± 5.17 m^2ha^{-1} determined in this study is much lower than that documented in other mountain forests, which normally range between 20 - 60 m^2ha^{-1} (Burke 2005; Sitati et al. 2016). For instance, Mwaluseke et al. (2023a) from Tanzania reported a mean basal area of 11.42 ± 5.41 m^2ha^{-1}; Mwakalukwa et al. (2023b) from Tanzania reported a mean basal area of 11.47±7.23 m^2ha^{-1}; Sitati et al. (2014) reported a mean basal area of 26.87 $m^2ha^{-1}$from Tanzania; Sitati et al. (2016) from Tanzania reported a mean basal area of 30.49 ± 2.3; Mialla (2002) reported a mean basal area of 69.3 ± 1.6 $m^2ha^{-1}$from Tanzania; Kacholi et al. (2015) from Uluguru mountain forests reported a mean basal area of 24 m^2ha^{-1}; and Tynsong et al. (2022) reported a range from 52.26 to 68.05 m^2ha^{-1} (mean 61.72 ± 4.82 m^2ha^{-1}) in the tropical evergreen forests in India. The basal area determined in this study is ten times lower than the mean basal area of 114.64 m^2ha^{-1} reported by Erenso et al. (2014) from Ethiopia, and a mean basal area of 126.47 m^2ha^{-1} from lowland dry semi-evergreen forest in Ethiopia (Boz and Maryo 2020). Siraj and Zhang (2018) recorded a total basal area of 454.52 $m^2 \cdot ha^{-1}$ from a dry Afromontane forest in Ethiopia.

The mean basal area found in this study is within the range of values commonly found in other forests, including miombo woodland of 3.9 - 16.7 m^2ha^{-1} (Backéus et al. 2006; Dugilo 2009; Mwakalukwa et al. 2014). Therefore, the low basal area obtained in this study could be due to the low stem density observed in reserve. On the other hand, the higher basal area observed in other studies could be associated with the high stem density of individuals in the higher DBH classes compared to other forests.

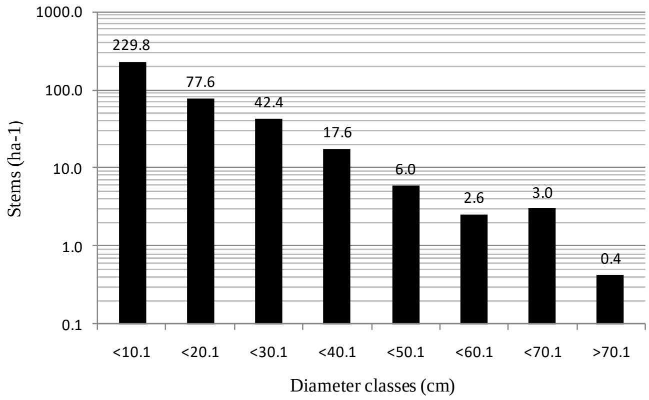

Figure 3. The density of trees ≥ 1 cm DBH by diameter class in the Lolkisale Village Land Forest Reserve, Tanzania (n = 33). NB: logarithmic scale on the vertical axis

Stand volume

The mean standing volume ha^{-1} for individuals with a diameter (≥ 5 cm DBH) was 64.04 ± 45.85 m^{3}ha^{-1} (Table 1, Figure 5). The species contributing most to the standing volume of large individuals were *N. congesta* (24.3% = 15.59 ± 12.52 m^{3}ha^{-1}), *A. gummifera* (14.2%), *C. schimperi* (9.3%), *A. tortilis* (8.1%), and *Erythrina abyssinica* Lam. ex DC. (7.6%). Their distribution in terms of diameter classes is presented in Figure 5 below. Generally, the distribution of standing trees to size classes showed that trees with a diameter of 20.1 - 70.1 cm contributed higher to the mean total standing volume in the forest.

The mean standing volume of 64.04 ± 45.85 m^{3}ha^{-1} reported in this study for trees and shrubs with DBH ≥ 5 cm was considered lower than 395.07 ± 14 m^{3}ha^{-1} reported by Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania. However, the mean standing volume of 64.04 ± 45.85 m^{3}ha^{-1} reported in this study is much higher than those reported by Mwaluseke et al. (2023a) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania with a value of 54.47 ± 24.1 m^{3}ha^{-1}; Mwakalukwa et al. (2023b), who reported a value of 27.3 ± 16.3 m^{3}ha^{-1} from a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania; and Dugilo (2009) who reported a value of 40.03 ± 11.21 m^{3}ha^{-1} from Selela village forest reserve in Tanzania. The volume reported in this study is within the range of 16.7 to 155.9 m^{3}ha^{-1}, commonly reported in other forests, including miombo woodland (Mwakalukwa et al. 2014; Masota et al. 2016). The relatively higher volume reported by this study might be caused by the few large-sized trees and shrubs in the forest, contributing higher to the total volume.

Harvested stems

The mean stems ha^{-1} for stumps in Lolkisale VLFR was found to be 3 ± 3 stems ha^{-1}. The most harvested tree species were *A. tortilis* (0.86 ± 0.86 stems ha^{-1}), *Cordia monoica* Roxb. (0.43 ± 0.30 stems ha^{-1}), *Commiphora africana* (A.Rich.) Engl. (0.43 ± 0.43 stems ha^{-1}), *C. schimperi* (0.43 ± 0.30 stems ha^{-1}), *A. nilotica* (0.22 ± 0.22 stems ha^{-1}), *Commiphora mossambicensis* (Oliv.) Engl. (0.22 ± 0.22 stems ha^{-1}), and *Lannea schimperi* (Hochst.ex A. Rich.) Engl. (0.22 ± 0.22 stems ha^{-1}). Regarding of basal area of the harvested stems, the mean basal area ha^{-1} was 0.06 ± 0.05 m^{2}ha^{-1}. Harvested tree species with the highest basal areas were *C. schimperi* (0.02 ± 0.01 m^{2}ha^{-1}), *C. africana* (0.01 ± 0.01 m^{2}ha^{-1}), *A. nilotica* (0.01 ± 0.01 m^{2}ha^{-1}), and *L. schimperi* (0.01 ± 0.01 m^{2}ha^{-1}). Their distribution per diameter class falls within one diameter class of 1.0-10.0.

The mean stems ha^{-1} for stumps of 3 ± 3 stems ha^{-1} is lower than that reported by Mwaluseke et al. (2023a) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania, who reported a value of 63 ± 37 stems ha^{-1} with *Diospyros abyssinica* subsp. *abyssinica* being the most contributing species (12.7% of the total), followed by *Teclea simplicifolia* (11.1%), while *Drypetes natalensis* (Harv.) Hutch. and *D. rotundifolia* contributed 9.5% each. According to Mwaluseke et al. (2023a), stumps distribution showed the expected reversed "J" shape with higher stem density in DBH class ≤ 10 cm, but no stumps with DBH > 50 cm was found. In the basal area, the mean basal area ha^{-1} for stumps of 0.06 ± 0.05 m^{2}ha^{-1} found in LVLFR was also lower than that reported by Mwaluseke et al. (2023a), who reported a value of 1.12 ± 0.63 m^{2}ha^{-1}. This is true because no large stumps were observed in the LVLFR. That means trees harvested were within a diameter size class (≤10 cm), unlike those reported by Mwaluseke et al. (2023a), which were within a diameter size class (≤ 10 to 50 cm), implying that larger size trees were overexploited in Lendikinya Forest Reserve.

Biomass and carbon storage

The mean above-ground biomass and carbon stocks potential of Lolkisale VLFR for tree individuals with a diameter ≥ 5 cm were 39.90 ± 27.30 Mg ha^{-1} and 19.55 ± 13.38 Mg C ha^{-1}, respectively. At the same time, the mean below-ground biomass and carbon stocks potential of the forest reserve for tree individuals with a diameter ≥ 5cm were 7.98 ± 5.46 Mg ha^{-1} and 3.91 ± 2.68 Mg C ha^{-1}, respectively (Table 1, Figure 6). Tree species that made a high contribution to the observed above-ground carbon density were *N. congesta* (21.1% = 4.12 ± 3.28 Mg C ha^{-1}), *A. gummifera* (12.9%), *C. schimperi* (10.6%), *A. tortilis* (8.5%) and *T. nobilis* (4.8%). On the other hand, species that made a high contribution to the observed below-ground carbon density were *N. congesta* (21.1% = 0.82 ± 0.66 Mg C ha^{-1}), *A. gummifera* (12.9%), *C. schimperi* (10.6%), *A. tortilis* (8.5%), and *T. nobilis* (4.8%).

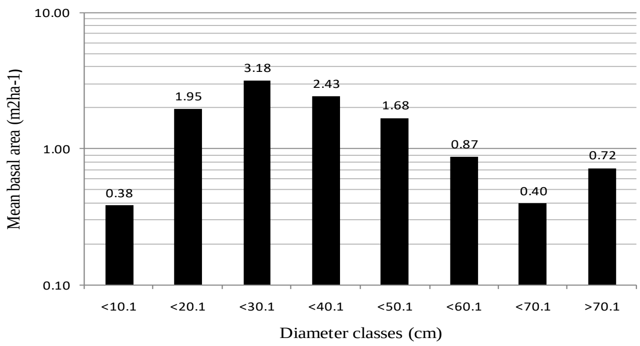

Figure 4. Distribution of basal area per hectare for trees ≥ 1 cm DBH by diameter classes in the Lolkisale VLFR, Tanzania (n = 33). NB: logarithmic scale on the vertical axis

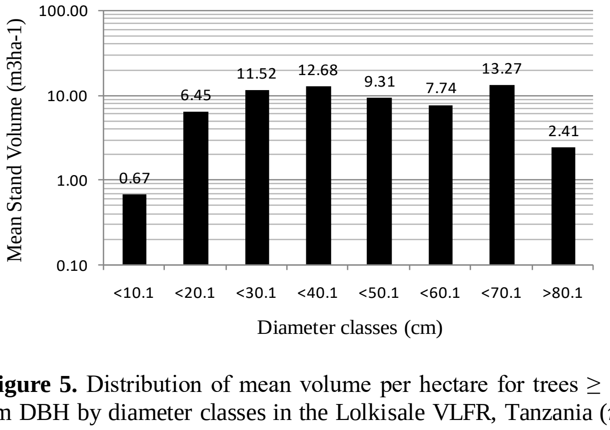

Figure 5. Distribution of mean volume per hectare for trees ≥ 5 cm DBH by diameter classes in the Lolkisale VLFR, Tanzania (n = 33). NB: logarithmic scale on the vertical axis

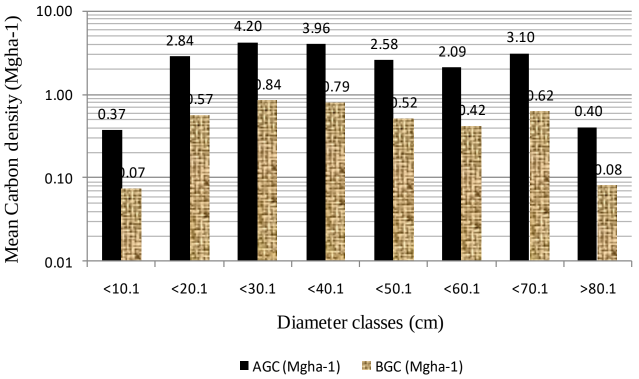

Figure 6. Distribution of both above-ground and below-ground mean carbon density of tree species with diameter ≥ 5 cm by diameter classes in the Lolkisale VLFR, Tanzania (n = 33). NB: logarithmic scale on the vertical axis

The mean above-ground carbon stocks of the trees and shrubs with DBH ≥ 5 cm of 19.55 ± 13.38 Mg C ha^{-1} determined in this study is lower than that documented from other tropical forests. For instance, Swai et al. (2014) reported a mean carbon stock of 48.4 ± 8.0 t C ha^{-1} from the Hanang mountain forest in Tanzania; Mwakalukwa et al. (2023b) reported a mean carbon stock of 56.93 ± 34.60 Mg C ha^{-1} from a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania; Asrat et al. (2022) reported two values of 180.18 ± 17.19 t·C ha^{-1} and 106.71 ± 7.64 t·C ha^{-1} from dry evergreen Afromontane forests in Ethiopia; Gebeyehu et al. (2019) reported a mean value of 191.6 ± 19.7 Mg C ha^{-1} from five different dry Afromontane forests in Ethiopia; Wondimu et al. (2021) reported a value of 332.69 ± 37.42 t C ha^{-1} from a dry evergreen Afromontane forest in Ethiopia; Rawal and Subedi (2022) reported two values of mean carbon stock of 51.86 t C ha^{-1} and 59.55 t C ha^{-1}from two community forests in Nepal; and Naveenkumar et al. (2017) from a tropical dry forest in India reported a range of 99 to 216 t C ha^{-1}. In contrast, the mean above-ground carbon stocks found in this study are higher than that reported by Mwaluseke et al. (2023a), from a dry evergreen forest in Tanzania reported a value of 16.04 ± 7.7 t C ha^{-1}; and Biadgligne et al. (2022) who reported two values of 14.84 ± 1.27 t C ha^{-1} and 3.49 ± 0.66 t C ha^{-1} from two community forests from Ethiopia. With regards to the below-ground carbon density, the value reported in this study of 3.91 ± 2.68 Mg C ha^{-1} is much lower than that reported by Mwakalukwa et al. (2023b) from a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania who reported a value of 34.71 ± 19.72 Mg C ha^{-1}.

The low value reported in this study could be due to many small and few large trees, which contributed less to the total mean carbon density than the presence of many large trees reported in other studies. On the other hand, the low value of below-ground carbon density could be due to a lack of allometric models for site-specific and dry Evergreen Mountain forests in Tanzania (Mwaluseke et al. (2023b). We used a ratio of 20% of above-ground carbon density to represent the below-ground components; this could not have been the best approach than using the site-specific allometric models.

In conclusion, the LVLFR has high species diversity (H'= 3.41) and is relatively rich in diversity of woody species (58 species) compared to many of the dry evergreen montane forests of Tanzania and other tropical forests. The mean stand volume is relatively higher, although tree density and basal area are lower than in other tropical forests. The above-ground and below-ground carbon stocks are also lower than those reported in other studies from dry areas. The reported data on carbon stock provides baseline data for the possibility of future payment schemes for REDD+ project implementation in Tanzania.

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