Woody Species Diversity, Composition, Structure and Carbon Storage of Esilalei Village Land Forest Reserve in North - Eastern Tanzania

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ABSTRACT

The biodiversity status of most forests found in village land area is lacking. This creates challenges in planning for sustainable management of these forests. This study therefore assessed woody species diversity, composition, structure and carbon stocks of Esilalei Village Land Forest Reserve located in Monduli district in the North-Eastern Tanzania. Vegetation data was collected from 20 concentric sample plots of 5m, 15m, and 20m radius laid out systematically in the forest of 2,800 ha. A total of 29 plant species were identified. Diversity indices indicated the forest to have moderate diversity of woody species. Stand structure comprised 77 ± 52 stems ha^{-1}, basal area of 1.82 ± 1.42 $m^2ha^{-1}$and volume of 8.42 ± 6.96 m^3ha^{-1} while the mean above ground and below ground carbon stocks were 9.71 ± 8.03 Mg C ha^{-1} and 0.98 ± 0.79 Mg C ha^{-1} respectively. Despite the observed low structural attributes including carbon density, it is very important to legally protect this area as village land forest reserve to serve as a corridor and dispersal area for wild animals when moving between the surrounding national parks. Quantification of other carbon pools such as soil, dead wood and surface litter should be considered.

Keywords: *Acacia-Commifora* woodlands - Community forest - Climate change - REDD+ - Monduli district - Overgrazing - Wildlife corridors.

INTRODUCTION

The importance of biodiversity conservation in livelihood improvement and well being of people is well acknowledged (Burgess *et al*. 1998, Onyango *et al*. 2004, URT 2014, URT 2015). Biodiversity conservation takes different forms including creation of various types of protected areas (IUCN 1978, EUROPARC and IUCN 2000, Dudley 2008). The creation of these protected areas has yielded significant results in biodiversity conservation worldwide (Watson *et al*. 2014, Bebber and Butt 2017, Miller and Nakamura 2018, Wade *et al*. 2020, CBD 2020, Wolf *et al*. 2021). In Tanzania protected areas are classified into different categories (URT 2015). This includes National parks, Game reserves, Nature forest reserves, Forest reserves, Marine parks and reserves and Plantation forest reserves (URT 2014, URT 2015, MNRT 2015, URT 2021a). Other areas outside the central government mandates include Wildlife Management Areas (WMA) and Village Land Forest Reserves (VLFR) managed through Participatory

Forest Management (PFM) arrangements (URT 1998, URT 2002, Ngaga *et al*. 2013, URT 2021a, MNRT 2022a). In general, the total protected area under the central government mandates is estimated to cover about 307,800 km^2, equivalent to 32.5% of the total land area (MNRT 2015, URT 2021a).

Participatory Forest Management (PFM) is mainly implemented using Joint Forest Management (JFM) and Community Based Forest Management (CBFM) (Ngaga *et al*. 2013, MNRT 2022a). Community-Based Forest Management (CBFM) is one of PFM approaches that take place on village land, on forests that are owned or managed by village councils on behalf of the village assembly (MNRT 2022a). This leads to the establishment of Village Land Forest Reserves (VLFR), Community Forest Reserves (CFR) or Private Forest Reserves (PFR) (URT 2002, Ngaga *et al*. 2013, Treue *et al*. 2014, Lusambo *et al*. 2016). These forest reserves can be established for different purposes such as strict protection as catchment forest reserves, biodiversity conservation, and for sustainable use of forest products to generate revenues to be used jointly by the communities (Vyamana 2009, Ngaga *et al*. 2013, Treue *et al*. 2014, Tadesse *et al*. 2017, Ali and Bachano 2020, Lusambo *et al*. 2021, Abebe 2021, Mawa *et al*. 2022, MNRT 2022a). All these are done with the aim of reducing forest degradation and deforestation of important areas, hence preserving the biodiversity found in these areas.

In Tanzania, recent statistics show that there are 734 declared CBFM forest reserves with a total area of 1,445,878 ha and 133 gazetted CBFM forest reserves with a total area of 471,345 ha (MNRT 2022a). A total of 258 villages are in various stages/processes of establishing CBFM forest reserves in the country (MNRT 2022a). The impacts of these CBFM forest reserves in the improvement of forest condition, biodiversity conservation, and biomass for Carbon stock in Tanzania have been well acknowledged (Kajembe *et al*. 2005, Zahabu 2008, Blomley *et al*. 2008, Lund and Treue 2008, Blomley and Iddi 2009, Mbwambo *et al*. 2012, Ngaga *et al*. 2013, Treue *et al*. 2014, Lund *et al*. 2015, Lupala *et al*. 2015, Lusambo *et al*. 2016, Lusambo *et al*. 2021) and elsewhere in Africa (e.g., Gobeze *et al*. 2009, Mtambo and Missanjo 2015, Tadesse *et al*. 2016, Ameha *et al*. 2016, Duguma *et al*. 2018, Tebkew and Atinkut 2022, Girma *et al*. 2023). Since the village land harbour big chunks of land areas and most of it is rapidly being converted into different land uses like agriculture leading to massive loss to biodiversity (Doggart *et al*. 2020), the government of Tanzania set plans to strategically conserve part of these areas for the well-being of people (MNRT 2022b). According to URT (2021b), it is targeted that by 2031 the country should have protected or in different stages of protection of about 16 million ha found in village land areas. It is estimated that this action will help to reduce the deforestation rate by 70% by 2031. For an area to be legally protected, some surveys must be conducted to document the available resources and demarcate the boundaries of those resources (URT 2002). Thus far, several forests are in different stages of being either declared or gazetted (MNRT 2022a).

Esilalei Village Land Forest Reserve (EVLFR) is located in Monduli district, North-Eastern part of Tanzania. The forest reserve is not yet declared or gazetted but is officially known by the village government as a village land forest reserve. The area is used by the local communities for various activities including grazing by their livestock, harvesting trees for firewood and construction purposes, and other non-timber forest products (NTFPs). This form of uncontrolled use of the reserve is feared to have caused massive loss of biodiversity and deterioration of the condition of the reserve. However, the area has been mostly used as dispersal area and a corridor for wild animals moving between the surrounding National parks of Manyara, Tarangire and Ngorongoro Conservation Area. To this effect, the area warrants some kind of strict/legal protection to safeguard the existing biodiversity. However, no biodiversity assessment has ever been conducted in this area. This study therefore aimed to assess the status of woody species diversity, composition, structure, and the carbon storage potential of the forest. Specifically, the study aimed to: (i) assess the status of woody species diversity, composition, and structure in the EVLFR, (ii) determine the effects of anthropogenic activities in the condition of the EVLFR, and (iii) assess the potential of the EVLFR in carbon storage.

MATERIALS AND METHODS

Description of the study site

The Esilalei Village Land Forest Reserve (EVLFR) is located within Esilalei village, and Esilalei ward in Monduli District about 110 km from Arusha town along the road leading to Lake Manyara National Park (Figure 1). The village is bordered by Oltukai and Losililwa villages, and Lake Manyara National Park. Land uses in Esilalei village include livestock keeping, farming, forest reserve, settlement, infrastructures e.g., roads, and social services e.g., dam, school etc. Esilalei VLFR is owned by the village government although the reserve is not yet gazetted. Esilalei VLFR covers about 2,800 hectares. Elevation ranges from 1029 - 1540 m.a.s.l (mean 1211 ± 35). Monduli District where the EVLFR is found is generally semi-arid with an average rainfall ranging 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 6-47% (mean 22.5 ± 3%). The vegetation is described as dry *Acacia* - *Commiphora* woodlands.

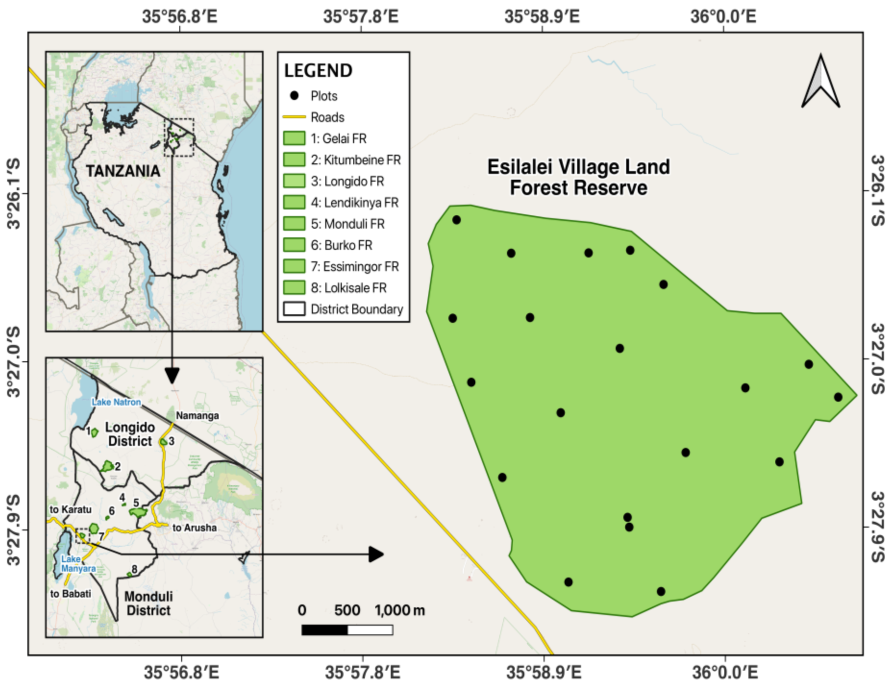

Figure 1: The map showing location of Esilalei VLFR and sample plots layout in the reserve
(**Source**: *The map was generated using QGIS, version 3.24 (*QGIS Development Team, 2022).

Data collection

The field survey was conducted in August and September 2014 and involved the establishment of a total of 20 concentric sample plots of 5m, 15m, and 20m radius systematically across the entire forest reserve of 2,800 ha (Figure 2). A total of five (5) transects were laid out across the forest at a bearing of 45° from North. The distance between transects was around 900 m, while the inter-plot distance within each transect was also around 900 m.

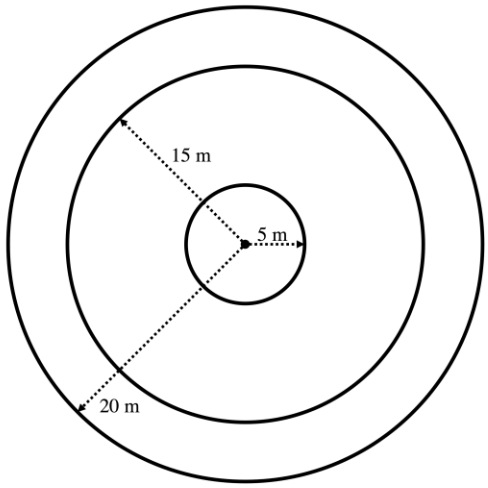

Figure 2: A diagram showing the shape and size of sample plots used for collection of vegetation data in Esilalei VLFR.

The following parameters were recorded within each of the 20 plots: within the 5 m radius, all small trees and shrubs with Dbh <1 cm was counted, and their species identified; and medium-size trees and shrubs (≥1 cm Dbh but <5 cm Dbh) were identified and measured for diameter. Within the 15 m radius subplot, the species were identified and the diameter measured for all large trees and shrubs with Dbh ≥5 cm. 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 at 1.3 m above ground using diameter tape/calliper. 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 centre using GPS, and the slope was measured from the centre of the plot facing the direction of the slope using the Suunto clinometer.

Data analysis

The collected data were analysed for species richness, diversity, number of stems/ha, basal area/ha (Kent 2012) as well as volume/ha, and biomass/ha. Sample tree data for height was used to develop a model to estimate the total tree height for the rest of sampled tree and shrub species in the reserve. Data on diameter at breast height (Dbh) was used to estimate biomass using the developed equations and hence estimates of the potential above-ground and below-ground carbon stocks of the forest. The models developed by Mugasha *et al*. (2016) for *Acacia - Commiphora* woodlands were used to estimate the volume and biomass content of the forest and thereafter converted to carbon content per ha of the forest:

Total tree volume (m^3) = 0.000142 x $dbh^{2.3008}$ (n = 110, RMSE (m^3) = 0.1, R^2 = 0.98, MPE (%) = 8.0.

Total Above ground biomass (kg) = 0.3154 x $dbh^{2.3189}$ (n = 110, RMSE (kg) = 72.4, R^2 = 0.97, MPE (% = -5.4).

Total Below ground biomass (kg) = 0.0915 x $dbh^{1.9820}$ (n = 110, RMSE (kg) = 23.2, R^2 = 0.92, MPE (%) = 10.9.

Where dbh is the diameter at breast height (cm), RMSE is the root mean square error and R^2 is the coefficient of determination. Carbon stock was estimated by multiplying with a conversion factor of 0.49 (Manyanda *et al*. 2020) and presented per hectare (Mg C ha^{-1}). All data analyses were performed using Excel spreadsheet.

RESULTS AND DISCUSSION

Species richness

A total of 29 species in 11 plant families of trees and shrubs were identified as species richness in Esilalei VLFR (Table 1). Trees contributed 90% (9 plant families) and shrubs 10% (3 plant families) of all species. Generally, tree and shrub species from the Mimosoidea family contributed the most (28%) to the total number of species, followed by those from the families Anacardiaceae (17%) and Combretaceae (14%). For trees alone, the greatest number of species were found in Mimosoidea family (27%) followed by Anacardiaceae family (19%) and Combretaceae family (15%). For shrub species alone, the three families of Mimosoidea, Rubiaceae and Tiliaceae shared equally number of species (33%).

When considering different size categories and including both trees and shrubs (small sizes, Dbh < 5cm and large sizes, Dbh ≥ 5cm), a total of 21 species (9 families) were found among large sizes, with Anacardiaceae (24%), Mimosoidea (24%) and Combretaceae (19%), being the most species-rich plant families, while among small sizes, a total of 17 species (7 families) were observed, with Mimosoidea (29%), Burseraceae (18%), Combretaceae (18%), and Papilionoidea (18%) contributing the greatest number of species (Table 1). In general, the average number of species per plot was found to be 2 species (range 0 - 5 species per plot). The species accumulation curve (Figure 3) indicates the rate of encountering new species, showing that species initially increased rapidly up to the 15th plot but increased slowly up to the 20th 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 (Attua and Pabi 2013, Gatti *et al*, 2022). The sample size was, considered sufficient to provide baseline information necessary in understanding the composition and diversity of the species in EVLFR.

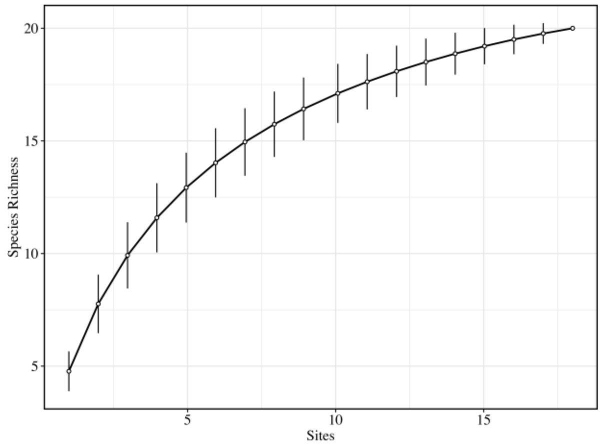

Figure 3: Species accumulation curve for Esilalei Village Land Forest Reserve, Tanzania

The species richness of 29 different trees and shrubs and 11 plant families reported in this study using 20 sample plots of 0.071 ha is much lower than what has been documented in other dry forests/woodlands which normally range between 34 - 229 species (Anderson *et al*. 2012p. 9, Mwakalukwa *et al*. 2014, Jew *et al*. 2016, Lemessa *et al*. 2017, Girmay *et al*.2020, Masresha and Melkamu 2022). For instance, Anderson *et al*. (2012) from *Acacia-Commiphora* woodland in the Yaeda Valley, Northern Tanzania reported species richness of 48 trees and shrubs species from 70 sample plots of 0.785 ha. Lemessa *et al*. (2017) reported species richness of 66 woody species of shrubs and trees that belonged to 26 families from 40 quadrates (size: 50 × 50 m each = 0.25 ha) from *Acacia-Commiphora* woodland in Ethiopia. Girmay *et al*. (2020) reported species richness of 171 including lianas and herbs belonged to 58 families with woody species of shrubs and trees comprising of 82 species from 80 quadrates (size: 25 × 25 m each = 0.06 ha) from *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia;

Table 1: Checklist of tree and shrub species identified in the Esilalei VLFR

S/No.	Species/botanical name	Family	Habit (Tree/shrub)	Frequency (%)	Density Stems/ha	Basal area (m^2/ha)	IVI	Stand volume (m^3/ha)	AGC (Mg/ha)	BGC (Mg/ha)
1	*Combretum zeyheri*	Combretaceae	Tree	35	18±7	0.24±0.09	49.1	0.95±0.37	1.09±0.42	0.13±0.05
2	*Combretum molle*	Combretaceae	Tree	20	12±7	0.24±0.20	17.4	1.08±0.94	1.24±1.09	0.13±0.11
3	*Lannea schweinfurthii*	Anacardiaceae	Tree	10	4±2	0.29±0.23	14.5	0.37±0.37	0.43±0.43	0.04±0.04
4	*Commiphora africana*	Burseraceae	Tree	15	6±4	0.18±0.14	12.5	0.83±0.64	0.95±0.74	0.10±0.08
5	*Balanites aegyptiaca*	Balanitaceae	Tree	10	4±3	0.15±0.13	12.3	0.73±0.62	0.84±0.72	0.08±0.07
6	*Acacia seyal*	Mimosoideae	Tree	5	3±3	0.02±0.02	11.1	0.07±0.07	0.08±0.08	0.01±0.01
7	*Acacia tomasii*	Mimosoideae	Tree	5	1±1	0.04±0.04	11.1	0.16±0.16	0.18±0.18	0.02±0.02
8	*Acacia tortilis*	Mimosoideae	Tree	5	4±4	0.14±0.14	11.1	0.67±0.67	0.77±0.77	0.08±0.08
9	*Dalbergia melanoxylon*	Papilionoidea	Tree	5	1±1	0.01±0.01	11.1	0.04±0.04	0.04±0.04	0.01±0.01
10	*Acacia mellifera*	Mimosoideae	Tree	10	6±5	0.06±0.04	10.9	0.21±0.15	0.24±0.17	0.03±0.02
11	*Acacia nilotica*	Mimosoideae	Tree	15	2±1	0.04±0.02	9.0	0.16±0.11	0.19±0.12	0.02±0.01
12	*Commiphora schimperi*	Burseraceae	Tree	25	4±1	0.08±0.04	7.2	0.38±0.21	0.43±0.24	0.04±0.02
13	*Gardenia ternifolia*	Rubiaceae	Shrub	5	4±4	0.03±0.03	5.3	0.11±0.11	0.13±0.13	0.02±0.02
14	*Sclerocarya birrea*	Anacardiaceae	Tree	10	1±1	0.06±0.04	3.9	0.27±0.20	0.31±0.23	0.03±0.02
15	*Terminalia kilimandscharica*	Combretaceae	Tree	5	1±1	0.13±0.13	3.1	0.71±0.71	0.83±0.83	0.07±0.07
16	*Lannea trifila*	Anacardiaceae	Tree	5	1±1	0.02±0.02	2.7	0.10±0.10	0.11±0.11	0.01±0.01
17	*Lannea schimperi*	Anacardiaceae	Tree	5	1±1	0.02±0.02	2.5	1.29±1.21	1.51±1.41	0.13±0.12
18	*Ziziphus mucronata*	Rhamnaceae	Tree	5	1±1	0.00±0.00	2.0	0.01±0.01	0.01±0.01	0.00±0.00
19	*Ozoroa insignis*	Anacardiaceae	Tree	5	1±1	0.04±0.04	1.5	0.15±0.15	0.18±0.18	0.02±0.02
20	*Cussonia spicata*	Araliaceae	Tree	5	1±1	0.01±0.01	0.9	0.02±0.02	0.02±0.02	0.00±0.00
21	*Terminalia brownii*	Combretaceae	Tree	5	1±1	0.02±0.02	0.8	0.10±0.10	0.12±0.12	0.01±0.01
22	*Acacia brevispica*	Mimosoideae	Tree	+						
23	*Acacia drepanolobium*	Mimosoideae	Tree	+						
24	*Commiphora mosambicensis*	Burseraceae	Tree	+						
25	*Dalbergia nitidula*	Papilionoidea	Tree	+						
26	*Dichrostachys cinerea*	Mimosoideae	Shrub	+						
27	*Grewia tembensis*	Tiliaceae	Shrub	+						
28	*Lonchocarpus eriocalyx*	Papilionoidea	Tree	+						
29	*Ormocarpum kirkii*	Papilionaceae	Tree	+						
	Total (all species)			**210**	**77 ± 52**	**1.82 ±1.42**	**200**	**8.42 ±6.96**	**9.71 ±8.03**	**0.98 ±0.79**

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

Birhane *et al*. (2020) reported species richness of 41 woody plant species from 45 sample quadrants (size: 20 × 20 m each = 0.04 ha) from *A. senegal* Woodland in Ethiopia;

Demie (2019) reported 48 woody species representing 23 families from 90 quadrants (size: 20 × 20 m each = 0.04 ha) from a desert and semi desert vegetation including *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia; Mialla (2002) reported species richness of 42 trees and shrubs from 48 sample plots of 0.071 ha from dry evergreen forest of Monduli Mountain Forest Reserve in Tanzania and Dugilo (2009) reported species richness of 42 species from 28 sample plots of 0.071 ha from dry evergreen forest of Selela village forest reserve in Tanzania.

Furthermore, 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. 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 (2015) 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. Erenso *et al*. (2014) found a total of 95 species from a dry evergreen forest in Ethiopia and Masresha and Melkamu (2022) reported 27 values of different species richness ranging from 34-122 tree species from dry evergreen Afromontane Forest patches in Ethiopia. This shows that EVLFR has a relatively lower number of plant species compared to other forests in the region. The higher values found elsewhere could be attributed to greater sampling effort (total area, number of sample plots, and sizes) employed by other studies as compared to this study.

Species diversity

The Shannon-Wiener diversity indices for large (Dbh ≥5cm) and small (Dbh <5cm) individuals were 2.60 and 2.53, respectively, and the Simpson index for large individuals was 0.11 and that of small individuals was 0.11. The following species had the greatest contribution to the Shannon-Wiener diversity index of large individuals (Dbh ≥5cm): *Combretum zeyheri* (0.34), *Combretum molle* (0.29), *Acacia mellifera* (0.21), *Commiphora africana* (0.21) and *Gardenia ternifolia* (0.16). Meanwhile, for smaller ones (Dbh <5cm) the greatest contributions were found for *Combretum zeyheri* (0.33), *Combretum molle* (0.31), *Acacia nilotica* (0.17), *Dalbergia melanoxylon* (0.17), *Grewia tembensis* (0.17) and *Ormocarpum kirkii* (0.17). The Index of dominance (1-D) for large individuals was 0.89 and for smaller individuals was 0.89, while index for evenness or equitability (J) were 0.85 for large individuals and 0.89.for smaller individuals.

In terms of frequency of occurrence for standing individuals (large sizes) in the Esilalei VLFR, *Combretum zeyheri* was the most frequent species (35% of plots), followed by *Commiphora schimperi* (25%), *Combretum molle* (20%), *Acacia nilotica* (15%) and *Commiphora africana* (15%), while for small sizes *Combretum molle* (20%), *Combretum zeyheri* (15%), *Dalbergia melanoxylon* (10%), *Grewia tembensis* (10%) and *Ormocarpum kirkii* (10%) were the most frequent species (Table 1). The Importance Value Index (IVI) for large individuals (Dbh ≥ 5cm) shows that *Combretum zeyheri* (49.10), *Combretum molle* (17.45), *Lannea schweinfurthii* (14.52), *Commiphora africana* (12.49) and *Balanites aegyptiaca* (12.32) were the most important species among standing individuals (Table 1).

The values of the Shannon-Wiener index (*H´*= 2.60) for trees and shrubs in the present study are lower than those reported by Girmay *et al.* (2020) who reported five different *H´* values ranging from 3.25-4.21 with a mean value of 3.86 from *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia; Demie (2019) who reported an *H´* value of 3.47 from a desert and semi desert vegetation including *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia; Mwaluseke (2015) who reported an *H´* value of 3.46 from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania and Sitati *et al*. (2014) who reported an *H´* value of 2.848 from a dry evergreen forest of Gelai Forest Reserve in Tanzania. However, *H´* values in this study are much higher than those documented by Birhane *et al.* (2020) from *A. senegal* (L.) Willd Woodland in Ethiopia who reported three *H´* values of 1.58, 2.12, and 2.24 with a mean value of 1.98; Sitati *et al.* (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania (*H´* value of 2.3616); Kayombo *et al*. (2022) reported an *H´* value of >1.5 from Tanzania; Erenso *et al*. (2014) reported *H´* value of 1.79. However, values lower than 1.298 reported by Dugilo (2009); Masresha and Melkamu (2022) reported 16 different *H´* values ranging between 2.78-3.35 from dry evergreen Afromontane forest patches in Ethiopia. However, the *H´* value of 2.60 in this study falls in the range of *H´* value commonly found in miombo woodland ranging from 1.05 - 4.27 (Shirima *et al*. 2011, Mwakalukwa *et al*. 2014, Jew *et al*. 2016). The *H´* values normally vary between 1.5 and 4.5 but rarely exceed 5. A threshold value of 2 has been cited to be the minimum value, above which an ecosystem can be regarded as medium to highly diverse (Magurran 2004, Kent 2012, Mwakalukwa *et al.* 2014). Therefore, the value of 2.60 found in this study implies that the EVLFR has medium diversity in tree and shrub species.

Stand density

The mean stem density for large individuals with Dbh ≥5cm in the Esilalei VLFR was 77 ± 52 stems ha^{-1} (Table 1) and that of small individuals with Dbh <5cm (including individuals with Dbh <1cm) was 516 ± 438 stems ha^{-1}. Among large individuals, the most abundant species were *Combretum zeyheri* (22.9% of 77 stems ha^{-1}), *Combretum molle* (15.6%), *Acacia mellifera* (8.3%), and *Commiphora africana* (8.3%). Among the small individuals, the most abundant species were *Dalbergia melanoxylon* (18.5% of 516 stems ha^{-1}) followed by *Acacia brevispica* (17.3%), *Combretum zeyheri* (14.8%), *Combretum molle* (13.6%) and *Dichrostachys cinerea* (11.1%). Generally, the distribution of trees to size classes showed the usual reverse J shape (Figure 4).

The stem density of 77 ± 52 stems ha^{-1} for the woody species with Dbh ≥ 5 cm reported in this study is lower than that documented by Luganga (2015) who reported a mean density of 971 stems ha^{-1}, from *Acacia-Commiphora* woodlands in Kimana Village in Kiteto District, Tanzania; Girmay *et al.* (2020) who reported a mean density of 528.4 stems ha^{-1} from *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia; Birhane *et al*. (2020) from *A. senegal* Woodland in Ethiopia who reported three values of 535 stems ha^{-1}, 950 stems ha^{-1} and 1013 stems ha^{-1} with a mean value of 832.8 stems ha^{-1}; Demie (2019) from a desert and semi desert vegetation including *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia reported a mean density of 538 stems ha^{-1} including seedlings; Dugilo (2009) who reported a mean density of 310 stems ha^{-1} from dry evergreen lowland forest of Selela village forest reserve in Tanzania; Sitati *et al.* (2014) reported a mean density of 377 stems ha^{-1} from a dry evergreen forest of Gelai Forest Reserve in Tanzania;

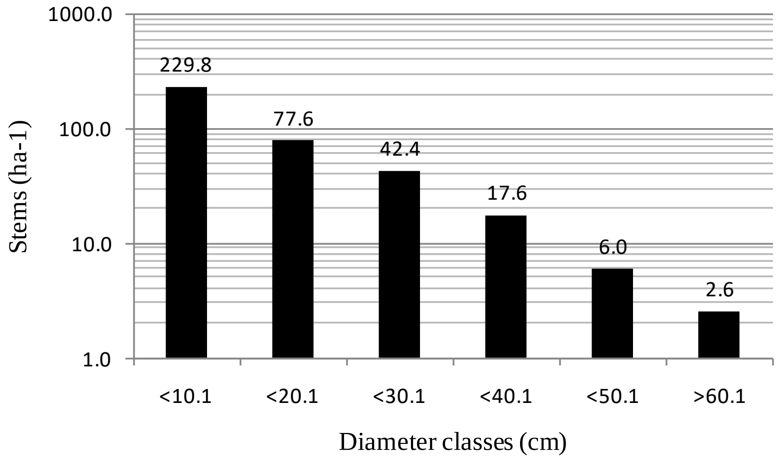

Figure 4: Density of trees ≥1cm Dbh by diameter class in the Esilalei VLFR (n = 20). NB: logarithmic scale on vertical axis.

and Sitati *et al*. (2016) reported a mean density of 435 stems ha^{-1} from a dry evergreen forest of Ketumbeine Forest Reserve also in Tanzania. Gebeyehu *et al*. (2019) reported a range of 365.6 - 664.1 stems ha^{-1} with a mean of 636.5 stems ha^{-1} from five forests in Ethiopia. The stem density of 77 ± 52 stems ha^{-1} found in this study is ten times lower than a mean density of 1,822 stems ha^{-1} reported by Mialla (2002) from Monduli Forest Reserve a dry evergreen mountain forest in Tanzania, and a mean density of 1,398 ± 679 stems ha^{-1} reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania and mean of 281-1,521 stems ha^{-1} reported by Shirima *et al*. (2011) and, Mwakalukwa *et al*. (2014). Atomsa and Dibbisa (2019) reported a mean density of 1,453 stems ha^{-1} from Ethiopia. This implies that EVLFR is among the lowest stocked dry forests/woodlands in Tanzania and other forests in tropical countries. The higher density reported in other studies might be attributed to the influence of microclimate which creates favourable conditions for the growth of more species. Overgrazing and the presence of wildlife animals such as Elephants could also have affected the density of species in the EVLFR. The density distribution (Figure 4) 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.

Basal area

The mean basal area for large (≥ 5cm Dbh) and small individuals (<5cm Dbh) were 1.82 ± 1.42 m^{2}ha^{-1} (Table 1, Figure 5) and 0.06 ± 0.05 m^{2}ha^{-1}, respectively. The species contributing most to the basal area of large individuals were *Lannea schweinfurthii* (16.1%), *Combretum zeyheri* (13.1%), *Combretum molle* (13.0%), and *Commiphora africana* (10.1%). Those contributing most to the basal area of smaller individuals were *Combretum molle* (24.0%), *Combretum zeyheri* (21.8%), *Gardenia ternifolia* (19.1%) and *Acacia drepanolobium* (15.9%).

The mean basal area of 1.82 ± 1.42 m^{2}ha^{-1} in this study is much lower than that documented in other dry forests/woodlands which normally range between 3.9 – 17.51 m^{2}ha^{-1} (Backeus *et al*. 2006, Dugilo 2009, Mwakalukwa *et al*. 2014, Masota *et al*. 2016, Demie 2019, Girmay *et al*. 2020, Birhane *et al*. 2020). For instance, Demie (2019) from a desert and semi desert vegetation including *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia reported a mean basal ares of 17.51

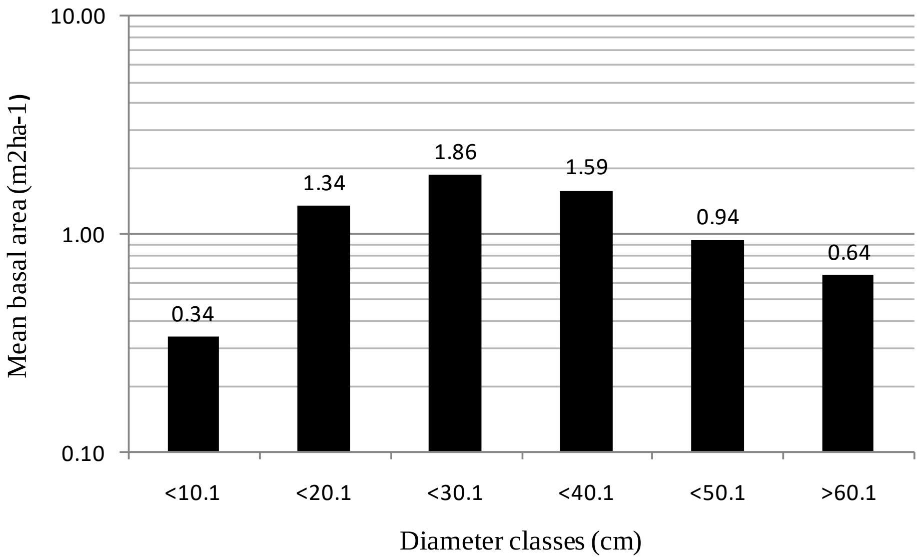

Figure 5: Distribution of basal area per hectare for trees ≥1cm Dbh by diameter classes in the Esilalei VLFR (n = 20). NB: logarithmic scale on the vertical axis.

m^2ha^{-1}; Girmay *et al.* (2020) reported a mean basal area of 14 m^2ha^{-1} from *Acacia-Commiphora* and *Combretum-Terminalia* woodland in Ethiopia; Birhane *et al*. (2020) from *A. senegal* Woodland in Ethiopia reported three values of 2.63 m^2ha^{-1}, 8.7 m^2ha^{-1} and 11.44 m^2ha^{-1} with a mean value of 7.7 m^2ha^{-1} and Masota *et al*. (2016) from two sites of *Acacia-Commiphora* woodlands in Tanzania reported two values of 5.7±3.0 m^2ha^{-1} (in Same) and 8.9±5.1 m^2ha^{-1} (in Kiteto). Mwaluseke (2015) reported a mean basal area of 11.42 ± 5.41 m^2ha^{-1} whereas, Sitati *et al*. (2014) reported a mean basal area of 26.87 m^2ha^{-} and Sitati *et al*. (2016) reported a mean basal area of 30.49 ± 2.3 m^2ha^{-1} and Mialla (2002) reported a mean basal area of 69.3 ± 1.6 m^2ha^{-1}, all from Tanzania. The low basal area obtained in this study could be due to the low stem density observed in the reserve. The higher basal area observed in other studies could be associated with the presence of high stem density of individuals in the higher Dbh classes as compared to this forest.

Harvested stems

The overall mean stem density ha^{-1} for stumps was 21 ± 10 stems ha^{-1}. The most harvested species were *Balanites aegyptiaca* (5 ± 4 stems ha^{-1}), *Zanthoxylum chalybeum* (2 ± 2 stems ha^{-1}), *Acacia mellifera* (2 ± 2 stems ha^{-1}), *Acacia tortilis* (2 ± 1 stems ha^{-1}), *Ziziphus mucronata* (2 ± 2 stems ha^{-1}), and *Grewia bicolor* (2 ± 1 stems ha^{-1}). In terms of the harvested stems, the mean basal area ha^{-1} for stumps in Esilalei VLFR was 0.18 ± 0.07 m^2ha^{-1}. The most harvested species with high basal area were *Acacia tomasii* (0.06 ± 0.06 m^2ha^{-1}), *Balanites aegyptiaca* (0.03 ± 0.02 m^2ha^{-1}), and *Acacia mellifera* (0.02 ± 0.02 m^2ha^{-1}). Their distribution per diameter and basal area classes are presented in Figures 6a & b, respectively.

The mean stems ha^{-1} for stumps of 21 ± 10 stems ha^{-1} is lower than that reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania who reported a value of 63 ± 37 stems ha^{-1}. According to Mwaluseke (2015) stumps distribution showed the expected reversed "J" shape with higher stem density in Dbh class ≤ 10 cm but no stumps with Dbh > 50 cm were found. In the case of basal area, the mean basal area ha^{-1} for stumps of 0.18 ± 0.07 m^2ha^{-1}found in EVLFR was also lower than that reported by Mwaluseke (2015) who reported a value of 1.12 ± 0.63 m^2ha^{-1}.

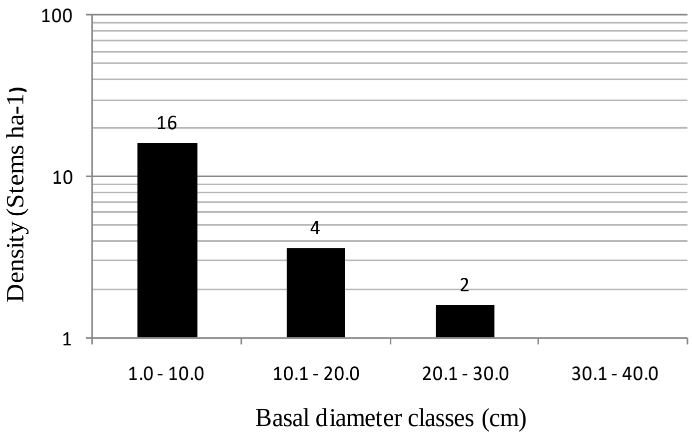

Figure 6a: Distribution of harvested stems per hectare (stems ha^{-1}) by basal diameter classes in the Esilalei VLFR (n = 20). NB: logarithmic scale on vertical axis.

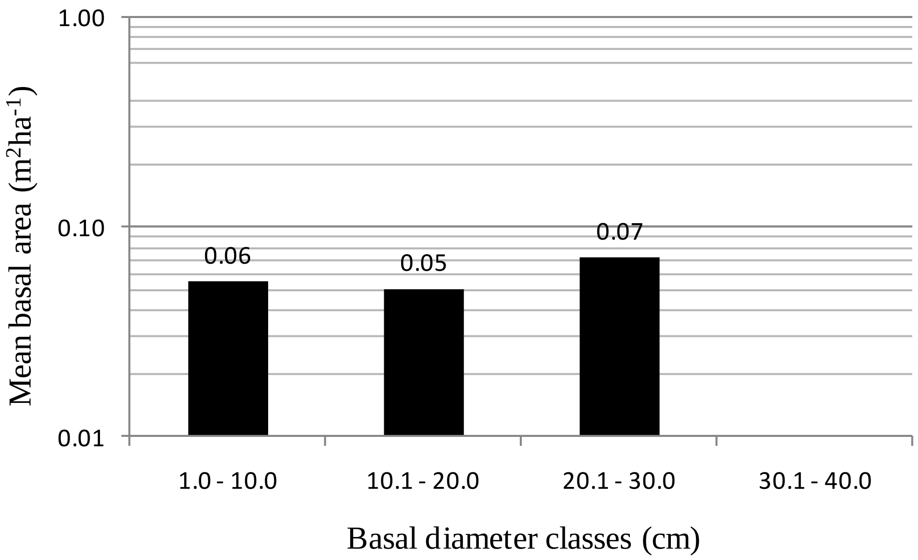

Figure 6b: Distribution of basal area per hectare for harvested stems by basal diameter classes in the Esilalei VLFR (n = 20). NB: logarithmic scale on vertical axis.

This is true due to the fact that there were no large stumps that were observed in the EVLFR. This means that trees harvested were within a diameter size class (≤10 cm) unlike those reported by Mwaluseke (2015) which they were within a diameter size class (≤10 to 50 cm), implying that larger size trees were overexploited in Lendikinya Forest Reserve

Stand volume

The mean standing volume ha^{-1} for individuals with a diameter (≥5cm Dbh) was 8.42 ± 6.96 m^{3}ha^{-1} (Table 1, Figure 7). The species contributing most to the standing volume of large individuals were *Lannea schimperi* (15.4% = 1.29 ± 1.21 m^{3}ha^{-1}), *Combretum molle* (12.8%), *Combretum zeyheri* (11.3%), *Commiphora africana* (9.8%), *Balanites aegyptiaca* (8.7%) and *Terminalia kilimandscharica* (8.5%). Their distribution in terms of diameter classes is presented in Figure 5. In general, the distribution of standing trees to size classes showed that trees with diameter 20.1- 40.1 cm contributed more to the mean total standing volume in the forest.

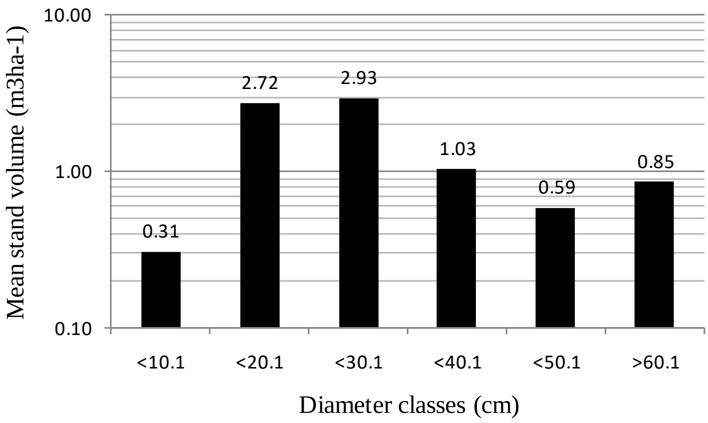

Figure 7. Distribution of mean volume per hectare for trees ≥5cm Dbh by diameter classes in the Esilalei VLFR (n = 20). NB: logarithmic scale on the vertical axis.

The total mean volume of 8.42 ± 6.96 m^3ha^{-1} reported in this study for trees and shrubs with Dbh ≥ 5 cm was considered much lower than that documented in other dry forests/woodlands which normally range between 16.7 to 155.9 m^3ha^{-1} (Mwakalukwa *et al*. 2014, Masota *et al*. 2016). For instance, values of 21.9 m^3ha^{-1} and 38.0 m^3ha^{-1} were reported by Masota *et al*. (2016) from two *Acacia*-*Commiphora* woodland sites in Kiteto District and Same District both respectively, in Tanzania. Dugilo (2009) reported a value of 40.03 ± 11.21 m^3ha^{-1} from Selela village forest reserve and a value of 54.47 ± 24.1 m^3ha^{-1} from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania (Mwaluseke (2015). Sitati *et al*. (2016) reported a much higher value of 395.07 ± 14 m^3ha^{-1} from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania. The lower volume reported by this study might be caused by the presence of fewer large-sized trees which normally are the ones that contribute higher to the total volume. The scarcity of large trees in this study could be attributed to microclimate conditions (Sitati *et al*. 2016) and overgrazing in the area and the presence of wild animals which limit the growth of trees to large diameter classes.

Biomass and Carbon storage

The mean above-ground biomass and carbon stocks potential of the forest reserve for tree individuals with diameter ≥ 5cm were 19.81 ± 16.40 Mg ha^{-1} and 9.71 ± 8.03 Mg C ha^{-1} respectively, while the mean below-ground biomass and carbon stocks potential of the forest reserve for tree individuals with diameter ≥ 5cm were 2.01 ± 1.61 Mg ha^{-1} and 0.98 ± 0.79 Mg C ha^{-1}, respectively (Table 1, Figure 8). Tree species that had high contribution to the observed above-ground carbon density were *Lannea schimperi* (1.51±1.41 Mg C ha^{-1}), *Combretum molle* (1.24±1.09 Mg C ha^{-1}), *Combretum zeyheri* (1.09±0.42 Mg C ha^{-1}), *Commiphora africana* (0.95±0.74 Mg C ha^{-1}), *Balanites aegyptiaca* (0.84± 0.72 Mg C ha^{-1}) and *Terminalia kilimandscharica* (0.83 ± 0.83 Mg C ha^{-1}). On the other hand, species that had high contribution to the observed below-ground carbon density were *Combretum zeyheri* (0.13 ± 0.05 Mg C ha^{-1}), *Combretum molle* (0.13 ± 0.11 Mg C ha^{-1}), *Lannea schimperi* (0.13 ± 0.12 Mg C ha^{-1}), *Commiphora africana* (0.10 ± 0.08 Mg C ha^{-1}), *Balanites aegyptiaca* (0.08 ± 0.07 Mg C ha^{-1}), *Acacia tortilis* (0.08 ± 0.08 Mg C ha^{-1}) and *Terminalia kilimandscharica* (0.07 ± 0.07 Mg C ha^{-1}).

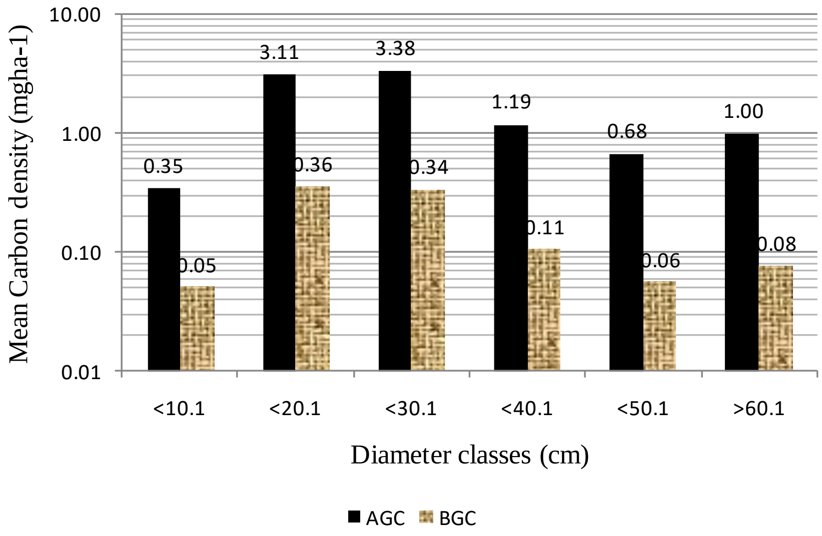

Figure 8: Distribution of both above ground and below ground mean carbon density of tree species with diameter ≥ 5cm by diameter classes in the Esilalei VLFR (n = 20). NB: logarithmic scale on vertical axis.

The total mean aboveground biomass of trees and shrubs with Dbh ≥ 5 cm of 19.81 ± 16.40 Mg ha^{-1} and below-ground biomass of 2.01 ± 1.61 Mg ha^{-1} determined in this study is lower than that reported by Masota *et al.* (2016) from one site of *Acacia-Commiphora* woodland located in Kiteto district in Tanzania where a value of 48.8 t ha^{-1} has been reported and corresponding belowground biomass of 18.6 t ha^{-1}. However, above-ground biomass of the trees and shrubs with Dbh ≥ 5 cm of 19.81 ± 16.40 Mg ha^{-1} reported in this study is considered higher than the value of 17.4 t ha^{-1} for aboveground biomass reported by Masota *et al.* (2016) from a site located in Same district Tanzania; the corresponding belowground biomass of 5.8 t ha^{-1} was however higher than that reported in this study.

Using a conversion factor of 0.49 (Manyanda *et al.* 2020), the equivalent total aboveground mean carbon stocks of trees and shrubs from Kiteto district was estimated to be 23.91 t C ha^{-1} and 9.11 t C ha^{-1} for total belowground mean carbon stocks. In Same district, the estimated equivalent total aboveground mean carbon stocks of trees and shrubs was 8.53 t C ha^{-1} and 2.84 t C ha^{-1} for total belowground mean carbon stocks. Thus, carbon stocks of the trees and shrubs with Dbh ≥ 5 cm of 9.71 ± 8.03 Mg C ha^{-1} determined in this study are lower than 23.91 t C ha^{-1} reported by Masota *et al.* (2016) from Kiteto district in Tanzania and 22.6±19.9 t C ha^{-1} reported by Anderson *et al.* (2012) a value from *Acacia-Commiphora* woodland in the Yaeda Valley, Northern Tanzania. Furthermore, Birhane *et al.* (2020) from *A. senegal* Woodland in Ethiopia reported two values of 10.43 ± 0.69 t C ha^{-1} and 12.69 ± 0.65 t C ha^{-1}; Swai *et al.* (2014) reported a mean carbon stock of 48.4 ± 8.0 t C ha^{-1} from Hanang mountain forest in Tanzania; Mwaluseke (2015) reported a value of 16.04 ± 7.7 t C ha^{-1} from a dry evergreen forest in Tanzania; Jew *et al.* (2016) reported a mean carbon density of 14.6 t C ha$^{-1.}$ from one site of miombo vegetation in Tanzania and Masota *et al.* (2016) reported a range of values from miombo vegetation between 11.86-49.69 t C ha^{-1} (for aboveground Carbon density) and 9.31-19.11 t C ha^{-1}. From Ethiopia, Solomon *et al.* (2017) reported a mean carbon stock of 40.99 ± 0.40 t·C ha^{-1} from dry forests, and Biadgligne *et al.* (2022) reported two values of 43.72 ± 3.79 t C ha^{-1} and 14.84 ± 1.27 t C ha^{-1} from two community forests also from Ethiopia.

Furthermore, 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) reported a range of 99 to 216 t·C ha^{-1} from a tropical dry forest in India. However, few studies have reported estimates of below-ground carbon density for *Acacia-Commiphora* woodlands (Anderson *et al*. 2012p. 11 [10.8 ± 4.29 t C ha^{-1}], Masota *et al*. 2016p.121) and other vegetation types found in Tanzania and elsewhere (MNRT 2015, Mauya *et al*. 2019, Birhane *et al*. 2020). Interestingly, the total mean aboveground carbon stocks found in this study is higher than 8.53 t C ha^{-1} reported by Masota *et al*. (2016) from Same district in Tanzania and 8.77 t C ha^{-1} for Itigi thickets in Manyoni district in Tanzania. Biadgligne *et al*. (2022) reported a value of 3.49 ± 0.66 t C ha^{-1} from one of the community forests in Ethiopia and Birhane *et al*. (2020) from *A. senegal* Woodland in Ethiopia who reported a value of 5.29 ± 0.46 t C ha^{-1}. The high value reported by several authors could be due to differences in climatic conditions of these sites in terms of rainfall received and the presence of many large trees which had a significant contribution to the total mean carbon density than the presence of many small trees reported in this study (Mauya and Madundo 2021).

According to Mauya and Madundo (2021) climate, topography as well as estimation methods particularly the selection of allometric models is also key factors when it comes to accurate estimation of AGB and AGC in the moist montane forests in West Usambara. In this study, we used models developed for *Acacia-Commiphora* woodlands (Mugasha *et al*. 2016), the common vegetation type found in the EVLFR to estimate volume and both above-ground and below-ground biomass content. These models were selected because the climatic conditions of the area and major vegetation types where the models were developed resemble the condition of the study site. The Monduli district where EVLFR belongs receives an average rainfall ranging between 400 and 900 mm per annum. According to Mugasha *et al*. (2016), their study sites receive an annual rainfall ranging between 400 to 600 mm in the Same District site; and a mean annual rainfall of up to 800 mm in Kiteto District site.

In conclusion, the results showed that EVLFR is relatively rich in woody species (29 species), and moderately high species diversity (*H*'=2.60) as compared to many dry forests/woodlands of Tanzania and other tropical forests. Tree density, basal area, stand volume, and above and below-ground carbon stock was relatively lower than those reported in other studies from dry forests/woodlands. However, this study is among the few studies to report on the status of woody species and estimates on above and below-ground carbon density from dry *Acacia-Commiphora* woodlands in Tanzania and elsewhere. The data on carbon stock obtained provides baseline data for the possibility of future carbon offset payment schemes in REDD+ project implementation in Tanzania. Quantification of other carbon pools such as in soil, dead wood and surface litter should be considered for estimation of the total carbon stocks potential of this forest.

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