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Woody species diversity, composition, structure and carbon storage of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania

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Abstract. *Mwakalukwa EE, Mwakisu A, Maliondo SMS. 2023. Woody species diversity, composition, structure and carbon storage of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania. Intl J Trop Drylands 7: 26-36.* The biodiversity status of flora and fauna of many forests found on small protruding and isolated hills in most parts of dry areas in Tanzania is largely less studied. Their contribution to climate mitigation options also remains largely unknown. This study assessed the woody species diversity, composition, structure and carbon stocks potential of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania. The vegetation data were collected from 23 concentric sample plots of 5m, 15m, and 20m radius laid systematically across the entire forest area of 6,100 ha. A total of 54 trees and shrubs species belonging to 29 families were identified. Diversity indices indicated the forest to have a high diversity of woody species. The most important species were *Cassipourea malosana, Diospyros abyssinica* and *Drypetes natalensis*. Stand structure comprised 288±173 stems ha^{-1}, basal area of 11.47±7.23 m^2ha^{-1} and standing volume of 27.3±16.3 m^3ha^{-1}. The mean above-ground and below-ground carbon stocks were 56.93±34.60 Mg C ha^{-1} and 34.71±19.72 Mg C ha^{-1}, respectively. The observed high species diversity and carbon density signify the importance of conservation efforts bestowed in this reserve. Quantification of other carbon pools for estimation of the total carbon stock potential of this forest is recommended.

Keywords: Biodiversity, climate change, humid forest, Monduli, REDD+

INTRODUCTION

The role of forest ecosystems in the conservation of soil, water and biodiversity and in mitigating climate change is well acknowledged (Burgess et al. 2007; Pan et al. 2011; Lewis et al. 2013; Ashagre et al. 2014; Spracklen and Righelato 2014; Apguaua et al. 2015; Kacholi et al. 2015; Mauya et al. 2019; Kendie et al. 2021; Biadgligne et al. 2022; Nugroho et al. 2022; Rawal and Subedi 2022). Forests contain most of the terrestrial biodiversity and are estimated to store about 289 Gt of biomass carbon (Apguaua et al. 2015; FAO 2022). The terrestrial vegetation alone is estimated to store approximately 450-650 Gt of carbon (Daba et al. 2022). Forests also support life of many living organisms on earth and are a source of livelihood for more than 1.4 billion people worldwide (Kendie et al. 2021). Dryland forests specifically, and other woodlands found in Africa are estimated to meet a large part of the needs of more than 320 million people (Haddad et al. 2021). According to Chidumayo and Marunda (2010), these requirements include rain-fed agricultural cultivation, animal farming, and the collection of timber and non-timber forest products, all of which boost regional enterprises.

Despite their potential, forest ecosystems are threatened by anthropogenic activities, mainly from deforestation and forest degradation (Hansen et al. 2013; Kideghesho 2015; Doggart et al. 2020; Biadgligne et al. 2022). Food and Agriculture Organisation (FAO) (2020) estimated that between 1990 and 2020, around 420 million ha of forest had been deforested and converted to other land uses. More specifically, about 10 million ha of forest were lost per year between 2015-2020. Studies have indicated that deforestation contributes to 18-20% of Anthropogenic Greenhouse Gases (GHGs) emissions globally (Baccini et al. 2012; Biadgligne et al. 2022). About 20% of GHGs emission is caused by deforestation from Africa (Leon et al. 2022). Although dryland ecosystems have been estimated to store about one-third of the global carbon stock, contributing significantly to land-based carbon sinks (Trumper et al. 2008; Lal 2019), the contribution of dry land forests, especially dry evergreen montane forests in Tanzania in carbon sinks is not well studied.

According to estimates, Tanzania loses between 372,816 and 469,420 ha of forest cover annually (MNRT 2015; URT 2017). This suggests that Tanzania's forest resources and biodiversity are in danger (Newmark and McNeally 2018), leading to higher GHG emissions. It is imperative to stop additional deforestation for this reason. According to Karki et al. (2017), deforestation prevention has been generally accepted as a promising mitigation strategy for mitigating climate change through carbon negotiation mechanisms like REDD+ (reduced emission from deforestation and forest degradation, plus forest conservation, sustainable forest management, and enhancement). REDD+ was devised under the United

Nations Framework Convention on Climate Change (UNFCCC) to combat CO_2 emissions (Houghton 2012; Daba et al. 2022). However, for a participating country to benefit from the carbon credit market, a precise and verifiable estimate of carbon stock data from the major carbon pools is necessary (Corbera and Schroeder 2011; Daba et al. 2022). Understanding available carbon stocks in different forest ecosystems is also important for estimating potential carbon losses through deforestation and forest degradation (Mauya et al. 2019; Manyanda et al. 2019).

Therefore, this study was intended to provide baseline data on species composition, diversity and structural attributes and carbon storage potential of a relatively undisturbed forest reserve of Essimingor Nature Forest Reserve (ENFR) in Tanzania. The isolated forest on top of a hill is part of broader distribution of dry evergreen montane forests surrounded by open savanna (forest-savanna mosaic) in Eastern Africa (Greenway 1973; White 1983). ENFR is among many forests found on small protruding and isolated hills in most parts of dry areas in Tanzania with high biodiversity values (Lovett and Pocs 1993; Sitati et al. 2014; Sitati et al. 2016; Kayombo et al. 2022) and carbon storage potential (Swai et al. 2014; Mwaluseke 2015) but is less studied. This information is important to aid the preparation of strategies for successful management of the forest reserve and planning for Ecotourism. Specifically, the study aimed to; (i) determine woody species composition and diversity of all trees and shrubs found in reserve, (ii) determine the structure of the forest (stem density, basal area and volume) of trees and shrubs with diameter > 5 cm in reserve, and (iii) estimate carbon stocks of the reserve in both above-ground and below-ground components.

MATERIALS AND METHODS

Study area

Essimingor Nature Forest Reserve (ENFR) is situated in the North East Tanzania between 36° 03’ to 36°08’E and 3° 21` to 3° 26`S. It is located 60 km from Monduli, 90 km from Arusha townships and 10 km from the Arusha to Dodoma Road (Lovett and Pocs 1993) (Figure 1). ENFR is owned by Central Government and was first declared as forest reserve in 1954. The forest reserve covers about 6,100 hectares with a boundary length of 28 km. Due to its high biodiversity value; it was upgraded to Nature Forest Reserve in 2020 by Government Notice No. 691 of 28/08/2020. The ENFR is characterized by ragged and steeply dissected Essimingor Mountain from an elevation range of 1520-2195 m.a.s.l. The soils are characterized by brown volcanic soils. Over volcanic rock occupy about 32% of the Monduli District (Lovett and Pocs 1993). The forest reserve is bordered by seven villages namely, Essimingor, Selela, Eslalei, Makuyuni, Mbuyuni, Mbaashi and Repruko. The main ethnic group in the locality is Masai who are mainly pastoralist. The major economic activities are extensive livestock keeping and agriculture (Lovett and Pocs 1993).

ENFR is dominated by orographic rainfall from the nearby Lake Manyara with continental temperatures. Rainfall ranges from 750-1000 mm/year on the lower slopes but higher than 1500 mm/year with mist effect on the higher altitudes on the upper slopes. Dry season is from June to October with temperatures of 15.4°C in December and 11.5°C in July at lower altitudes. According to Lovett and Pocs (1993), the vegetation distribution is clearly changes with elevation such that, in the lower slopes are dominated by grassland with scattered trees. On the upper slopes from 1675 to 2195 m, dry montane forest with fire-maintained grassland dominates. Closed forest is mostly concentrated at higher elevation with high humidity and dense canopy cover (Lovett and Pocs 1993; Holmes 1995). The forest is reserved as water catchment and contributes to ground water supplies below the mountain, and some are piped from the eastern side to farms on the lower slopes.

The forest has experienced minimal human disturbances that resulted into existence of wild animals such as Buffalo, Elephants and others. The ENFR alongside other forest reserves such as Burko and Monduli forest reserves serve as a corridor by linking movement of wild animals in three National Parks namely Tarangire, Manyara and Ngorongoro. The reserve is potentially a breeding site for Buffaloes. There is an increase in number of wild animals in ENFR during dry season due to favorable condition (fodder and water). Formerly it served as a hunting block under the Wildlife Division. The common genus of tree species found in the wooded grassland area include *Acacia* sp., *Combretum* sp., *Dombeya* sp., and *Euphorbia* sp. Tree species from dry montane forest area include *Albizia gummifera*, *Calodendrum capense*, *Cassipourea malosana*, *Catha edulis*, *Cussonia arborea*, *Ekerbergia capensis*, *Fagaropsis angolensis*, *Nuxia congesta* and *Olea capensis* (Lovett and Pocs 1993).

Data collection

In order to conduct the field survey, which took place in August and September 2014, a total of 23 concentric sample plots with a 5 m (0.0079 ha), 15 m (0.0707 ha), and 20 m (0.1257 ha) radius were strategically placed across the 6,100 hectare forest. Each of the 23 plots contained the following parameters: within a 5 m radius, all small trees and shrubs with Diameter at Breast Height (DBH) <1 cm was counted, and their species were recognized; medium-sized trees and shrubs with DBH ≥1 cm but <5 cm were identified, and their diameters were measured. All large trees and shrubs with DBH ≥5 cm within a 15 m radius had their species identified and their diameters measured. At 1.3 m above-ground, a diameter tape/caliper was used to measure the tree's DBH. In addition, three stems (with small, medium and large DBH) in a plot were selected and measured for height using Suunto hypsometer. Altitude was recorded at the plot center using GPS and slope was measured from the centre of the plot facing the direction of the slope using suunto clinometer.

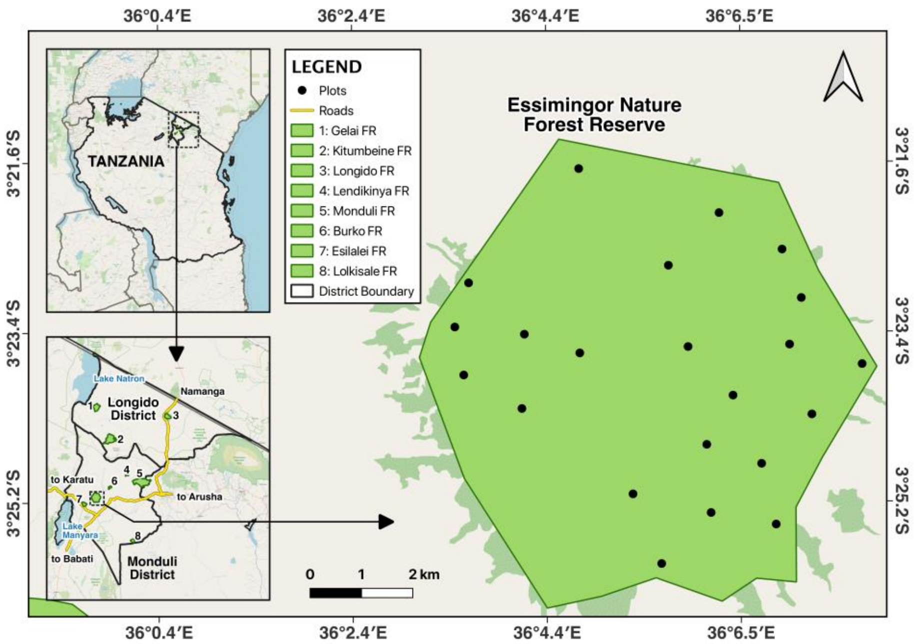

Figure 1. The map of Tanzania showing the location of Essimingor Nature Forest Reserve in the Monduli District and the surveyed sample plots

Data analysis

The collected data were analyzed for species richness, number of stems ha^{-1}, basal area ha^{-1}, volume ha^{-1} and biomass ha^{-1} (Kent 2012). Data on diameter at breast height (DBH) was used to estimate biomass using the developed equations and hence estimate of above-ground and below-ground carbon stocks potential of the forest. The models developed by Masota et al. (2016) for lowland and humid montane forests were used to estimate volume and biomass content (both for above-ground and below-ground) of the forest and after that converted to carbon content per ha of the forest:

Tree height (m) = $2.2936 \times DBH^{0.1225}$ ($n = 39$, RMSE = 0.434, $R^2 = 0.95$, DBH range 1.70-56.6 cm).
Total tree volume (m^3) = $g \times ht \times (1.414741-0.21174 \times \ln(DBH))$ ($n = 60$, RMSE (m^3) = 1.343, $R^2 = 0.91$, MPE (%) =-0.9).
Total tree above-ground biomass (kg) = $0.9635 \times DBH^{1.9440}$ ($n = 60$, RMSE (kg) = 1020.3, $R^2 = 0.80$, MPE (%) = 0.0).
Total tree below-ground biomass (kg) = $7.5811 \times DBH^{1.16801}$ ($n = 29$, RMSE (kg) = 312.7, R^2=0.71, MPE (%) = 2.0).

Where, g is the tree basal area (m^2), DBH is Diameter at Breast Height (cm), RMSE is root mean square error and R^2 is coefficient of determination. Carbon stock was estimated by multiplying with a conversion factor of 0.49 and presented per hectare (Mg C ha^{-1}) (Manyanda et al. 2020). All data were entered in Excel spreadsheet and analyzed using R (version 4.2.0).

RESULTS AND DISCUSSION

Species richness

Including all size categories (small individuals of DBH < 5 cm and large individuals of DBH ≥ 5 cm) a total of 54 species (29 plant families) of trees and shrubs were identified in the Essimingor Nature Forest Reserve (ENFR) (Table 1). Trees contributed 91% (26 plant families) and shrubs 9% (4 plant families) of the species. Generally, tree and shrub species from the family Euphorbiaceae contributed the most (11%) number of species, followed by those from the families Rutaceae (9%) Rubiaceae (6%) Oleaceae (6%), Meliaceae (6%) and Araliaceae (6%). For trees alone, the greatest number of species was found in Euphorbiaceae family (10) followed by Rutaceae family (10%), Araliaceae (6%), Meliaceae (6%), Oleaceae (6%) and Rubiaceae family (6%), whereas 40% of the shrub species were from the family Anacardiaceae.

Considering different size categories and including both trees and shrubs (small sizes, DBH<5cm and large sizes, DBH ≥ 5cm), a total of 46 species (25 families) were found among large sizes (DBH ≥ 5cm), with Euphorbiaceae (13%), Rutaceae (9%), Meliaceae (7%), Oleaceae (7%) and Rubiaceae (7%) being the most species-rich plant families, while among the small sizes (DBH < 5cm), a total of 25 species (17 families) were observed, with Euphorbiaceae (16%), Rutaceae (12%), Ebenaceae (8%), Malvaceae (8%) and Mimosoidea (8%) contributing the greatest number of species (Table 1). In general, the average number of species per plot was 4 species (range 0-9 species per plot). The species accumulation curve (Figure 2) indicates the rate of encountering new species. Species initially increased rapidly up to the 15th plot and increased slowly up to the 20th plot. However, since only 23 plots were sampled, the later result implies that any further increase in sample size might have included additional new species. The sample size was, considered sufficient to provide baseline information necessary in understanding the composition and diversity of the species in ENFR.

Table 1. Checklist of tree and shrub species identified in Essimingor Nature Forest Reserve (ENFR), Tanzania, showing frequency (%), density (mean±SE), basal area (mean±SE), Dispersion index (DI), Importance Value Index (IVI), stand volume (mean±SE), Above-ground Carbon (AGC) (mean±SE), and Below-ground Carbon (BGC) (mean±SE) for trees and shrubs with a minimum DBH 1 cm (plot size = 15 m radius)

Botanical name	Family	Habit /Life form	Frequency (%)	Density (Stems/ha)	Basal area (m^2/ha)	IVI	DI	Stand volume (m^3/ha)	AGC (Mg/ha)	BGC (Mg/ha)
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tree	52	52 ±17	2.35±0.77	35.6	8.83	5.73±1.87	11.74±3.85	7.29±2.35
Diospyros abyssinica (Hiern) F.White	Ebenaceae	Tree	30	34±13	1.30±0.55	18.1	8.28	3.21±1.34	6.50±2.73	4.35±1.75
Drypetes natalensis (Harv.) Hutch.	Euphorbiaceae	Tree	17	57±33	1.40±0.73	17.3	31.26	5.00±2.29	10.12±4.60	7.38±3.46
Combretum molle R.Br ex G. Don	Comretaceae	Tree	9	3±2	0.09±0.07	11.3	2.49	0.21±0.18	0.43±0.37	0.31±0.23
Dombeya krkii Mast.	Malvaceae	Tree	4	2±2	0.01±0.01	10.5	3.00	0.03±0.03	0.05±0.05	0.08±0.08
Steganotaenia araliace Hochst.	Araliaceae	Tree	4	1±1	0.02±0.02	10.5	1.00	0.06±0.06	0.12±0.12	0.09±0.09
Teclea nobilis Del.	Rutaceae	Tree	39	22±8	0.43±0.15	8.4	4.53	1.10±0.39	2.17±0.78	1.82±0.63
Drypetes gerrardii Hutch.	Euphorbiaceae	Tree	13	27±21	0.94±0.66	8.4	25.61	0.79±0.65	1.60±1.31	1.03±0.83
Albizia gummifera (J.F.Gmel.) C.A.Sm.	Mimosoidea	Tree	9	6±5	0.58±0.44	7.7	6.65	1.32±1.00	2.83±2.14	1.31±1.01
Ficus lutea Vahl	Moraceae	Tree	4	2±2	0.07±0.07	6.8	3.00	0.18±0.18	0.36±0.36	0.25±0.25
Fagaropsis angolensis (Engl.) H.M.Gardner	Rutaceae	Tree	4	1±1	0.46±0.46	6.0	2.00	0.85±0.85	2.14±2.14	0.57±0.57
Rhus vulgaris Meikle	Anacardiaceae	Shrub	4	3±3	0.02±0.02	5.8	5.00	0.05±0.05	0.09±0.09	0.13±0.13
Catha edulis Forssk.	Celasteraceae	Tree	9	2±2	0.45±0.42	4.8	2.43	0.91±0.84	2.14±1.99	0.73±0.64
Croton megalocarpus Hutch.	Euphorbiaceae	Tree	13	5±3	0.40±0.22	4.6	2.51	0.91±0.51	1.95±1.10	0.96±0.53
Calodendrum capense (L.f.) Thunb.	Rutaceae	Tree	13	9±6	0.42±0.25	4.1	5.79	1.01±0.60	2.10±1.24	1.25±0.75
Ekebergia capensis Sparrm.	Meliaceae	Tree	13	3±2	0.25±0.20	3.7	1.65	0.57±0.44	1.21±0.96	0.60±0.41
Dombeya rotundifolia (Hochst.) Planch.	Malvaceae	Tree	13	2±1	0.02±0.02	3.1	0.91	0.07±0.04	0.13±0.08	0.13±0.08
Olea europaea L.	Oleaceae	Tree	4	2±2	0.46±0.46	2.5	4.00	0.97±0.97	2.19±2.19	0.79±0.79
Celtis africana Burm.f.	Urmaceae	Tree	13	3±2	0.16±0.12	2.1	2.07	0.36±0.26	0.76±0.57	0.41±0.25
Commiphora africana (Rich.) Engl.	Burseraceae	Tree	4	1±1	0.02±0.02	2.1	1.00	0.05±0.05	0.10±0.10	0.08±0.08
Cussonia arborea Hochst. Ex A. Rich	Araliaceae	Tree	4	3±3	0.16±0.16	2.0	5.00	0.39±0.39	0.78±0.78	0.49±0.49
Maytenus senegalensis (Lam.) Exell	Celasteraceae	Tree	4	4±4	0.18±0.18	2.0	7.00	0.44±0.44	0.91±0.91	0.55±0.55
Mystroxylon aethiopicum (Thunb.) Loes	Melastomataceae	Tree	9	9±8	0.13±0.12	1.8	12.06	0.35±0.30	0.68±0.60	0.62±0.55
Clausena anisata (Willd.) Hook.f. ex Benth.	Rutaceae	Tree	4	2±2	0.01±0.01	1.5	4.00	0.02±0.02	0.05±0.05	0.08±0.08
Rhus natalensis Bernh.ex Krauss	Anacardiaceae	Shrub	4	1±1	0.00±0.00	1.5	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Acacia hockii De Wild.	Mimosoidea	Tree	4	1±1	0.00±0.00	1.4	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Lepidotrichilia volkensii (Gürke) Leroy	Euphorbiaceae	Tree	4	1±1	0.19±0.19	1.4	1.00	0.40±0.40	0.93±0.93	0.29±0.29
Pschotria sp.	Rubiaceae	Tree	9	5±4	0.04±0.04	1.4	6.17	0.12±0.11	0.23±0.22	0.26±0.24
Bersama abyssinica Fresen.	Melianthaceae	Tree	4	2±2	0.01±0.01	1.4	4.00	0.02±0.02	0.04±0.04	0.08±0.08
Ficus thonningii Blume	Moraceae	Tree	4	1±1	0.14±0.14	1.3	2.00	0.31±0.31	0.67±0.67	0.32±0.32
Turraea robusta Gürke	Meliaceae	Tree	4	1±1	0.20±0.20	1.2	1.00	0.41±0.41	0.95±0.95	0.30±0.30
Ilex mitis (L.) Radlk.	Aquifoliaceae	Tree	9	5±4	0.13±0.09	1.2	4.86	0.32±0.23	0.64±0.46	0.50±0.37
Denbolia borbonica Scheff.	Sapindaceae	Tree	13	3±2	0.03±0.02	1.1	2.07	0.08±0.06	0.16±0.11	0.18±0.12
Olea capensis L.	Oleaceae	Tree	4	3±3	0.05±0.05	1.1	5.00	0.14±0.14	0.26±0.26	0.25±0.25
Prunus africana (Hook.f.) Kalkman	Rosaceae	Tree	4	1±1	0.07±0.07	1.0	1.00	0.17±0.17	0.36±0.36	0.17±0.17
Senna sp.	Caesalpinioideae	Tree	9	1±1	0.05±0.04	0.7	0.95	0.11±0.09	0.23±0.19	0.15±0.12
Casearia battiscombei R.E.Fr.	Flacortiaceae	Tree	4	1±1	0.05±0.05	0.7	2.00	0.13±0.13	0.25±0.25	0.17±0.17
Vangueria infausta Burch.subsp.*infausta*	Rubiaceae	Tree	4	1±1	0.02±0.02	0.7	1.00	0.04±0.04	0.08±0.08	0.07±0.07

Schrebera alata (Hochst.) Welw.	Oleaceae	Tree	4	1±1	0.12±0.12	0.6	2.00	0.29±0.29	0.60±0.60	0.30±0.30
Memecylon sp.	Melastomataceae	Tree	4	1±1	0.03±0.03	0.5	2.00	0.08±0.08	0.15±0.15	0.12±0.12
Rinorea illicifolia (Welw. Ex Oliv.) Kuntze	Violaceae	Tree	9	1±1	0.01±0.01	0.4	0.95	0.03±0.02	0.05±0.04	0.06±0.05
Turraea holstii Gürke	Meliaceae	Tree	4	1±1	0.01±0.01	0.4	1.00	0.02±0.02	0.04±0.04	0.04±0.04
Xylopia sp.	Annonaceae	Tree	4	1±1	0.00±0.00	0.3	1.00	0.00±0.00	0.01±0.01	0.02±0.02
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	Tree	4	1±1	0.00±0.00	0.3	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Erythrococca sp.	Euphorbiaceae	Shrub	4	1±1	0.01±0.01	0.2	2.00	0.03±0.03	0.06±0.06	0.07±0.07
Vangueria sp.	Rubiaceae	Tree	4	1±1	0.00±0.00	0.1	1.00	0.00±0.00	0.01±0.01	0.02±0.02
Apodites dimidiata E.Mey. ex Arn.	Icacinaceae	Tree	+							
Commiphora schimperi (O.Berg) Engl.	Burseraceae	Tree	+							
Euclea divinorum Hiern	Ebenaceae	Tree	+							
Grewia similis K. Schum.	Tiliaceae	Shrub	+							
Harrisonia abyssinica Oliv.	Simaroubaceae	Shrub	+							
Premna sp.	Verbenaceae	Tree	+							
Schefflera volkensii (Engl.) Harms	Araliaceae	Tree	+							
Vepris simplicifolia (Verd.) Mziray	Rutaceae	Tree	+							
Total (all species			**417**	**288±173**	**11.47±7.23**	**200**		**27.29±16.32**	**56.93±34.60**	**34.71±19.72**

Note: +: Indicates species identified among smaller individuals within 5m radius plots (DBH<5cm), Mg/ha: Megagram per hectare

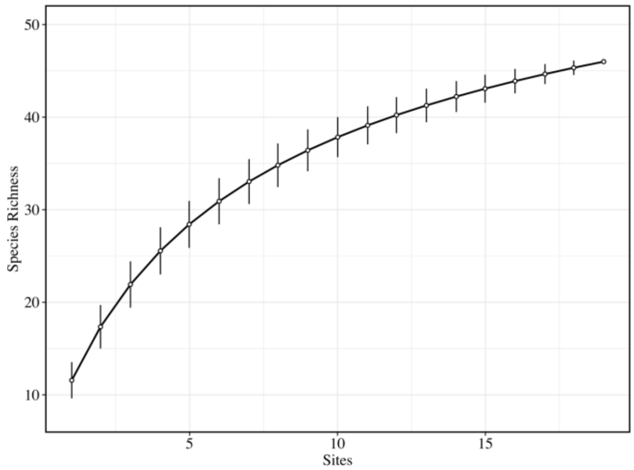

Figure 2. Species accumulation curve in Essimingor Nature Forest Reserve (ENFR), Tanzania

The species richness of 54 different trees and shrubs and 29 plant families reported in this study using 23 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 located in Longido District 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 Monduli District, 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 (0.04 ha) sample plots; Masresha and Melkamu (2022) reported 19 values of different species richness ranging from 55-122 tree species from dry evergreen Afromontane forest patches in Ethiopia; Erenso et al. (2014) found a total of 95 species from a dry evergreen forest in Ethiopia, and Daba et al. (2022) recorded a total of 68 tree and shrub species and 33 families from 100 plots of 20 m × 20 m from the moist Afromontane forest of South-western Ethiopia.

However, compared to other studies, the species richness of 54 was relatively higher despite the smaller sample size used in this study (23 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 located in Longido District in Tanzania; Masresha and Melkamu (2022) in Ethiopia reported seven different values of species richness ranging from 36-50 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; Sutomo and van Etten (2023) reported 20 tree species (in 19 genera and 13 families) from 25 sample plots of 0.25 ha in a seasonally dry tropical forest of Baluran National Park (BNP), located in the Situbondo Regency, East Java Province, in Indonesia 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 found 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). This shows that ENFR has a relatively large number of forest plant species, stressing the significance of its conservation. 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. For example, Erenso et al. (2014) apart from using 60 sample plots also conducted additional opportunistic sampling in selected microhabitats. However, the studies also included liana and epiphytes, but if liana and epiphytes are excluded, the total number of species is reduced to 76.

Species diversity

Shannon-Wiener diversity indices for large (DBH ≥5cm) and small (DBH <5cm) individuals were 2.70 and 2.93, respectively, and the Simpson index for large individuals was 0.13 and that of small individuals was 0.07. The following species were observed to have the greatest contribution to the Shannon-Wiener diversity index of large individuals (DBH ≥5cm): *Drypetes natalensis* (0.35), *C. malosana* (0.31), *Diospyros abyssinica* (0.25), *Teclea nobilis* (0.19), *C. capense* (0.10), *Mystroxylon aethiopicum* (0.10), and *Drypetes gerradii* (0.09). For smaller ones (DBH < 5cm), the greatest contributions were from *Pschotria* sp. (0.28), *Clausena anisata* (0.23), *A. gummifera* (0.19), *Combretum molle* (0.19), *Dombeya rotundifolia* (0.19), and *D. natalensis* (0.17). The index of dominance (1-D) for large individuals was 0.87 and for smaller individuals was 0.93; the index for evenness or equitability (J) for large individuals was 0.71 and for smaller individuals were 0.91.

In terms of frequency of occurrence for large sizes standing individuals, *C. malosana* was the most frequent species (52% of plots), followed by *T. nobilis* (39%) and *D. abyssinica* (30%), while for small sizes *C. anisate* (22%), *C. molle* (13%), and *D. natalensis* (13%) were the most frequent species. The Importance Value Index (IVI) for large individuals (DBH ≥ 5cm) shows that *C. malosana* (35.6), *D. abyssinica* (18.1), and *D. natalensis* (17.3) were the most important species. These tree species resemble those earlier reported from this forest (Lovett and Pocs 1993).

The values of the Shannon-Wiener index (*H´*= 2.70) for trees and shrubs in the present study are lower than those documented in other tropical forests. For instance, Sitati et al. (2014) reported a *H´* value of 2.848 from a dry evergreen forest of Gelai Forest Reserve in Tanzania; Mwaluseke (2015) reported a *H´* value of 3.46 from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania; Boz and Maryo (2020) from Ethiopia reported an average *H´* value of 3.38; Kacholi et al. (2015) found an overall *H´* value of 4.03 from the Uluguru forests in Tanzania; and Tynsong et al. (2022) reported a *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 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 a *H´* value of >1.5 from Tanzania, Sutomo and van Etten (2023) reported *H´* values ranging from 0.6-1.9 (mean 1.4) from seasonally dry tropical forest in Indonesia; Erenso et al. (2014) reported *H´* value of 1.79 and Dugilo (2009) reported *H´* value of 1.298. However, the *H´* value of 2.70 in this study falls in the range of *H´* value commonly found in other dry evergreen Afromontane forest patches as in Ethiopia where Masresha and Melkamu (2022) reported 18 different *H´* values ranging between 1.31-3.35 and in miombo woodland where values ranging from 1.05-4.27 were reported (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 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. Therefore, the value of 2.70 found in this study implies that the ENFR has high diversity in tree and shrub species. High diversity might be attributed to relatively low levels of disturbance experienced in the forest as there were no signs of tree cutting happening in the reserve as observed by Lovett and Pocs (1993) and during this study.

Spatial distribution

Table 1 lists the dispersion indices (DI) for each species. The values of the dispersion index range from 0.91, which indicates nearly complete spatial randomness or slight underdispersion, to 31.26, which indicate significant overdispersion and suggests a patchy or clustered distribution. Out of 46 species, 31 species (67%) had DI > 1, 12 species (26%) had DI = 1, and 3 species (7%) had DI <1, indicating that the majority of species have patchy distributions within the forest. The *D. rotundifolia* (0.91) had the species with the lowest estimated DI, and *D. natalensis* had the highest estimated DI (31.26). The most prevalent species are severely overdispersed, and these include *D. natalensis* (DI = 31.26), *C. malosana* (DI = 8.83), *D. abyssinica* (DI = 8.28), and *D. gerradii* (DI = 25.61).

Stand density

Large individuals with DBH ≥5cm had a total mean stem density of 288±173 stems ha^{-1}, while small individuals with DBH <5cm (including those with DBH 1cm) had a total mean stem density of 736±621 stems ha^{-1}. The *D. natalensis* (19.8% of 288 stems ha^{-1}) was the most prevalent species among large individuals, followed by *C. malosana* (17.9%), *D. abyssinica* (11.9%), and *D. gerradii* (9.4%). *Pschotria* sp. (14.3 of 736 stems ha^{-1}) was the species with the highest abundance among the smaller individuals, followed by *C. anisata* (9.8%), *A. gummifera* (7.5%), *C. molle* (7.5%), and *D. rotundifolia* (7.5%). The distribution of trees to size classes generally exhibited the typical reverse J shape (Figure 3).

The stem density of 288±173 stems ha^{-1} for the woody species with DBH ≥ 5 cm reported in this study is lower than that documented by Dugilo (2009) from dry evergreen forest of Selela village forest reserve in Tanzania who 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 Gebeyehu 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 288±173 stems ha^{-1} is ten times lower than those reported by Mialla (2002) from Monduli Forest Reserve a dry evergreen mountain forest in Tanzania, who reported a mean density of 1,822 stems ha^{-1}, Mwaluseke (2015) 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 1944 to 2100 trees ha^{-1} in the tropical evergreen forests of the North-East India.

However, mean stems density values of 288±173 stems ha^{-1} from this study fall in the range of density value found in miombo woodland of 281-1,521 stems ha^{-1} (Shirima et al. 2011; Mwakalukwa et al. 2014). This implies that ENFR is among the highly stocked dry evergreen montane forests in Tanzania and other forests in the tropical countries. The higher density reported in other studies might be attributed to the influence of microclimate which creates favorable conditions for the growth of more species. Presence of wildlife animals such as elephants could have affected the density of species in the ENFR. The density distribution (Figure 3) 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.

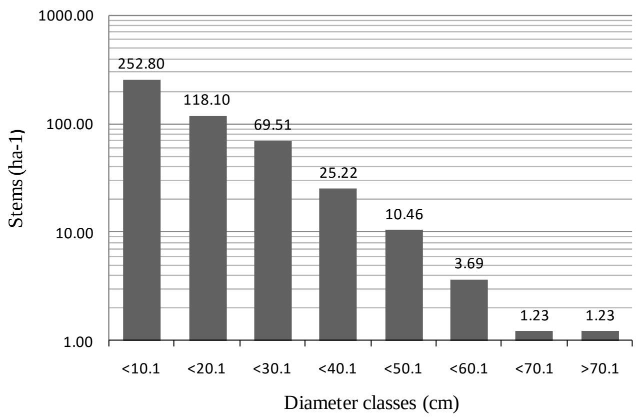

Figure 3. Density of trees ≥1cm DBH by diameter class in the Essimingor NFR (n = 23). NB: logarithmic scale on vertical axis

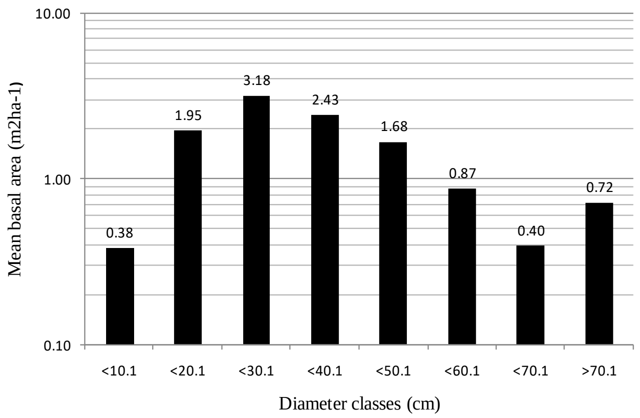

Figure 4. Distribution of basal area per hectare for trees ≥1cm DBH by diameter classes in the Essimingor NFR (n = 23). NB: logarithmic scale on vertical axis

Basal area

The mean basal areas for large (≥5cm DBH) and small individuals (<5cm DBH) found in Essimingor Nature Forest Reserve (ENFR) were 11.47±7.23 m^2ha^{-1} (Table 1, Figure 4) and 0.13±0.10 m^2ha^{-1}, respectively. The species contributing most to the basal area of large individuals were *C. malosana* (20.5%), *D. natalensis* (12.2%), *D. abyssinica* (11.3%), and *D. gerradii* (8.2%), while those contributing most to the basal area of smaller individuals were *C. anisate* (23.3%), *D. natalensis* (22.9%), *Erythrococca* sp. (19%), and *Margaritaria discoidea* (16.9%).

The mean basal area of 11.47±7.23 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} (Sitati et al. 2016). For instance, Sitati et al. (2014) reported a mean basal area of 26.87 $m^2ha^{-1}$from a dry evergreen forest of Gelai Forest Reserve in Tanzania; Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in 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 Monduli dry evergreen mountain forest in 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 a 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. However, the mean basal area reported in this study is higher than 11.42±5.41 m^2ha^{-1} reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania.

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} (Backeus et al. 2006; Dugilo 2009; Mwakalukwa et al. 2014). The low basal area obtained in this study could be due to 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 other forests.

Stand volume

The mean standing volume per hectare for individuals with diameter (≥5cm DBH) found in the ENFR was 27.3±16.3 m^3ha^{-1} (Table 1, Figure 5). The species contributing most to the standing volume of large individuals were *C. malosana* (21% = 5.73±1.87 m^3ha^{-1}), *D. natalensis* (18.3%), *D. abyssinica* (11.7%), *A. gummifera* (4.8%), and *T. nobilis* (4.0%). Their diameter classes distribution is presented in Figure 5. In general, the distribution of standing trees with diameter ranging from 20.1-50.1 cm contributed most to the mean total standing volume in the forest.

The total mean volume of 27.3±16.3 m^3ha^{-1} reported in this study for trees and shrubs with DBH ≥ 5 cm was considered lower than 40.03±11.21 m^3ha^{-1} reported by Dugilo (2009) 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) while 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. However, the volume reported in this study is within the range of 16.7 to 92.17±39.0 m^3ha^{-1} commonly reported in other forests including miombo woodland (Mwakalukwa et al. 2014; and at least two recent reports e.g., Chamshama et al. 2004 [76.1m^3ha^{-1}]; Maliondo et al. 2005 [54.0 m^3ha^{-1}]; Sawe et al. 2014 [32.6 m^3ha^{-1}]). The lower volume reported by this study might be caused by the presence of many small-sized trees and shrubs in the forest which contributed less to the total volume since large size woody plants were few. The scarcity of large trees in this study was attributed to microclimate condition (Sitati et al. 2016) and presence of wild animals like elephants which limit the growth of trees to large diameter classes.

Biomass and carbon storage

The mean above-ground biomass and potential carbon stocks of the forest reserve for trees and shrubs with diameter ≥5cm were 116.19±70.61 Mg ha^{-1} and 56.93±34.60 Mg C ha^{-1} respectively, while the mean below-ground biomass and potential carbon stocks of the forest reserve for trees and shrubs with diameter ≥5cm were 70.84±40.24 Mg ha^{-1} and 34.71±19.72 Mg C ha^{-1}, respectively (Table 1, Figure 6). Tree species which had high contribution to the observed above-ground carbon density were *C. malosana* (11.74±3.85 Mg C ha^{-1}), *D. natalensis* (10.12±4.60 Mg C ha^{-1}), *D. abyssinica* (6.50±2.73 Mg C ha^{-1}), *A. gummifera* (2.83±2.14 Mg C ha^{-1}), *Olea europaea* (2.19±2.19 Mg C ha^{-1}), *T. nobilis* (2.17±0.78 Mg C ha^{-1}), *C. edulis* (2.14±1.99 Mg C ha^{-1}), *F. angolensis* (2.14±2.14 Mg C ha^{-1}) and *C. capense* (2.10±1.24 Mg C ha^{-1}). On the other hand, species with high contribution to the observed below-ground carbon density were *D. natalensis* (7.38±3.46 Mg C ha^{-1}), *C. malosana* (7.29±2.35 Mg C ha^{-1}), *D. abyssinica* (4.35±1.75 Mg C ha^{-1}), *T. nobilis* (1.82±0.63 Mg C ha^{-1}), *A. gummifera* (1.31±1.01 Mg C ha^{-1}), *C. capense* (1.25±0.75 Mg C ha^{-1}), and *D. gerradii* (1.03±0.83 Mg C ha^{-1}).

The total mean aboveground carbon stocks of the trees and shrubs with DBH ≥ 5 cm of 56.93±34.60 Mg C ha^{-1} determined in this study is lower than that documented from other tropical forests. For instance, 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; Mauya and Madundo 2021 reported a range of 88.5 Mg C ha^{-1} to 436 Mg C ha^{-1} with an overall average of 175.54 Mg C ha^{-1} from mountain forests in Tanzania; Wondimu et al. (2021) reported a value of 332.69±37.42 t C ha^{-1} from a dry evergreen Afromontane forest 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 and Daba et al. (2022) reported a value of 203.80±12.38 t·C ha^{-1} from moist Afromontane forest in Ethiopia. From a tropical dry forest in India, Naveenkumar et al. (2017) reported a range of 99 to 216 t·C ha^{-1}, and Rawal and Subedi (2022) reported a value of mean carbon stock of 59.55 t C ha^{-1} from one of the community forests in Nepal.

In contrast, the total mean aboveground carbon stocks found in this study is higher than that reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania who reported a value of 16.04±7.7 t C ha^{-1}; Biadgligne et al. (2022) 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; Solomon et al. (2017) who reported a mean carbon stock of 40.99±0.40 t·C ha^{-1} from dry forests in Ethiopia; Biadgligne et al. (2022) from Ethiopia reported a mean carbon stock density of 43.72±3.79 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; Shirima et al. (2015) reported a value of 54.30±5.84 Mg C ha^{-1} from several montane sites in Tanzania and Jew et al. (2016) reported a mean carbon density of 14.6 t C ha^{-1}. from one site of miombo vegetation in Tanzania. Elsewhere, Rawal and Subedi (2022) reported a value of mean carbon stock of 51.86 t C ha^{-1} from one of the community forests in Nepal. However, very few studies have reported estimates of below-ground carbon density (MNRT 2015; Mauya et al. 2019).

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 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 different study sites.

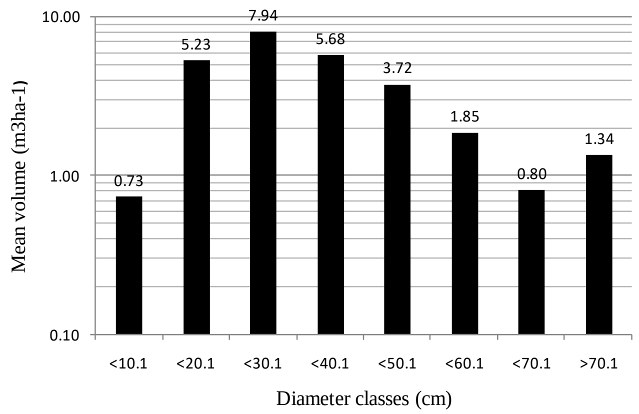

Figure 5. Distribution of mean volume per hectare for trees ≥5cm DBH by diameter classes in the Essimingor NFR, Tanzania (n = 23). NB: logarithmic scale on vertical axis

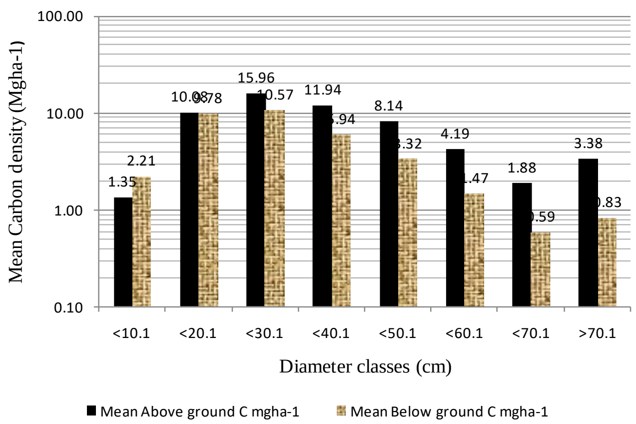

Figure 6. Distribution of both above-ground and below-ground mean carbon density of tree species with diameter ≥ 5cm by diameter classes in the Essimingor NFR, Tanzania (n = 23). NB: logarithmic scale on vertical axis

In this study we used models developed for lowland and humid montane forests (Masota et al. 2016) to estimate volume and biomass content (both for above-ground and below-ground) of the forest as there were no models developed specific for these vegetation types (Holmes 1995). These models were selected due to the fact that the climatic conditions of the area where the models were developed resemble with the condition of the study site especially on the amount of rainfall received in the study area. According to Lovett and Pocs (1993) rainfall in ENFR ranges from 750-1000 mm/year on the lower slopes but higher than 1,500 mm/year with mist effect on the higher altitudes on the upper slopes. According to Masota et al. (2016) their study site receives an annual rainfall ranging between 1,800 and 2,200 mm. The slight differences in the amount of rainfall could have slightly affected the total observed estimates.

In conclusion, the results showed that ENFR has relatively rich diversity of woody species (54 species), and high species diversity values (H'=2.70) as compared to many of dry evergreen montane forests of Tanzania and other tropical forests. Tree density and basal area are lower in our studied area as compared to other tropical forests. The above-ground carbon stock was relatively lower compared to those reported in other studies from dry evergreen montane forests. However, this study is among the few studies to report estimates on below-ground carbon density from dry evergreen montane forests in Tanzania and elsewhere. These data on carbon stock obtained provides baseline data for the possibility of future payment schemes on 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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