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Woody Species Composition, Structure, Regeneration Status and Carbon Storage of Mkulazi Forest Reserve in Tanzania

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Abstract

Little is known about the status of forest condition and carbon storage potential of Mkulazi forest reserve (MFR) located in Morogoro District, Tanzania. This study was conducted to assess i) woody species composition, richness and diversity, ii) stand structure, iii) regeneration status and iv) carbon storage. Data collection for vegetation involved establishment of 100 concentric circular sample plots in the forest area of 65,710 ha. A total of 54 plant species for trees and shrubs with DBH ≥ 5 cm that belongs to 20 plant families were identified. The diversity of woody species was high (*H'* = 3.11), while Stem density was 336 ± 126 stems ha^{-1}, basal area was 9.48 ± 2.88 m^2ha^{-1} and stand volume was 96.22 ± 32.51 m^3ha^{-1}. For the regeneration with DBH < 5 cm, a total of 26 plant species belonging to 11 plant families were identified. The diversity of woody species was also high (*H'* = 3.14) and stem density was 1,198 ± 847 stems ha^{-1}. The mean carbon stocks above ground for trees and shrubs with DBH ≥ 5 cm were 32.13 ± 10.91 Mg C ha^{-1} and that of below ground were 11.84 ± 3.58 Mg C ha^{-1}. The observed high diversity of woody species, regeneration status and relatively high carbon storage potential signifies the importance of continuing protecting this reserve.

Keywords: Diversity, human activities, forest condition, Morogoro, wet miombo woodlands.

Introduction

Miombo woodland is an ecosystem dominated by trees in the genera *Brachystegia*, *Julbernadia* and *Isoberlinia* of the family Fabaceae and sub-family Caesalpinioideae (Frost 1996, Chidumayo 1997). Dry and Wet Miombo woodlands contribute 19% and 35% of the total Miombo woodland area in Tanzania, respectively (Chamshama and Vyamana 2010, Mwakalukwa 2014a, MNRT 2015). In the dry Miombo areas, vegetation is floristically impoverished, and the canopy height is less than 15 m (Frost 1996). The species most found are *Brachystegia spiciformis*, and *B. boehmii*. In wet Miombo areas, the vegetation is floristically rich and the canopy height is greater than 15 m (Frost 1996). The vegetation includes all the characteristic Miombo species.

Studies have reported that where Miombo woodlands dominate they suffer annual losses of about 1.4 million ha through deforestation and forest degradation (Jew et al. 2016, Doggart et al. 2020). These losses raise concerns on the future capacity of these forests to provide the expected ecosystem services such as biodiversity conservation, provision of water services, regulation of the microclimate and carbon storage/sequestration (Mwakalukwa 2014a). Studies conducted in dry miombo woodlands have documented ecological conditions of the forests and threats from anthropogenic activities on species composition, richness, diversity, and forest structure (Luoga et al. 2002, Banda et al. 2006, Backéus et al. 2006, Giliba et al. 2011, Munishi et al. 2011, Mwakalukwa et al. 2014b, Jew et al. 2016) and on carbon storage potential (Chamshama et al. 2004, Williams et al. 2008, Munishi et al. 2010, Sawe et al. 2014, Jew et al. 2016). However, few studies have documented ecological conditions of wet miombo woodlands i.e. structure, composition and carbon storage (Shirima et al. 2011), floristic composition, species diversity and carbon storage (Kalaba et al. 2013), diversity, structure and aboveground carbon stock (Mwampashi 2013), species diversity (Shirima et al. 2015) and structure and aboveground carbon stock (Katani et al. 2016).

Mkulazi Forest Reserve (MFR) is the biggest forest reserve located in Morogoro District, Tanzania (Lovett and Pocs 1993, John 2018, TFS 2022). MFR was gazzetted in 1955 as productive forest due to its high potential timber values. It is dominated by woodlands and receives estimated rainfall of 1,000 - 1,500 mm annually (Lovett and Pocs 1993). Since gazettement in 1955, there has been no detailed vegetation survey that have been conducted in terms of floristic composition, diversity, structure and regeneration status apart from the study by Malimbwi et al. (2005) which reported the harvestable wood volume available in the reserve. With the increasing incidences of human activities in the forest reserve (Lovett and Pocs 1993, Malimbwi et al. 2005, John 2018, TFS 2022), information about floristic composition, structure and regeneration potential is critical for sound management and conservation strategies of the reserve. This will facilitate conservation of the remaining biodiversity which is potential for climate change mitigation and for livelihood of the adjacent communities (Godoy et al. 2011). The reported human activities taking place inside the forest reserve such as pit sawing, harvesting of building poles, firewood and medicinal plants, wildfires, charcoal making, livestock grazing and cultivation, is suspected to have affected the condition of the forest including species composition and structure (Lovett and Pocs 1993, Malimbwi et al. 2005, John 2018, TFS 2022).

This study therefore was geared to enhance understanding on the current conditions of MFR in terms of woody species composition, richness, diversity, structure, regeneration status and carbon stocks potential. The results from this study will provide baseline information to be used for improving management plans and conservation strategies of the reserve. The quantification of carbon storage potential of the reserve will contribute to the existing knowledge about the capacity of wet Miombo woodlands in sequestering carbon from the atmosphere. The information will provide basis for inclusion of wet Miombo woodlands in the emerging carbon credit market mechanism through the Reducing Emission from Deforestation and Forest Degradation (REDD+) scheme. The objectives of the study was therefore to assess i) woody species composition, richness and diversity, ii) stand structure in terms of stem density/ha, basal area/ha, volume of trees/ha and size class distributions, iii) regeneration status and iv) carbon stock potential of MFR.

Materials and Methods

Study area

MFR is located about 180 km from Morogoro town, with coordinates ranging from 37.9612°E, 7.2884°S in the southeast to 38.2170°E, 6.9244°S in the northwest (Figure 1). MFR is owned by the Central government under the Tanzania Forest Services Agency (TFS) of the Ministry of Natural Resources and Tourism (MNRT). MFR is surrounded by 14 villages namely Mkulazi, Chanyumbu, Kidunda, Millingwa, Dete, Kisanga Stand, Lulongwe, Matuli, Diguzi, Kwaba, Kiganila, Bwila juu, Bwila chini and Kiburumo (John 2018, TFS 2022). It covers an area of about 65,710 ha (John 2018). Altitude ranges from 100 to 800 m above mean sea level and the topography of the forest is flat (Malimbwi et al. 2005). The area receives estimated rainfall of 1,000 - 1,500 mm annually and estimated high temperature of 28 °C in December and low temperature of 24 °C in July (Lovett and Pocs 1993). The dry season is from June to October. The vegetation of MFR can be described as wet miombo woodland (White 1983). Dominant tree species in terms of stand volume are *Brachystegia boehmii*, *Julbernardia globiflora* and *Brachystegia speciformis* (Malimbwi et al. 2005). The reserve has catchment importance and is the source of the Lulongwe and Mkulazi rivers (Lovett and Pocs 1993). MFR is a major crossing point in which large herbivores such as Elephants, Buffalos, Wildebeests, Hartebeests, Zebras and Giraffes path through from Wami mbiki Game reserve to Nyerere National Park (TFS 2022). MFR suffered from frequent forest fires, livestock grazing, charcoal burning and tree cutting for poles and timber (TFS 2022).

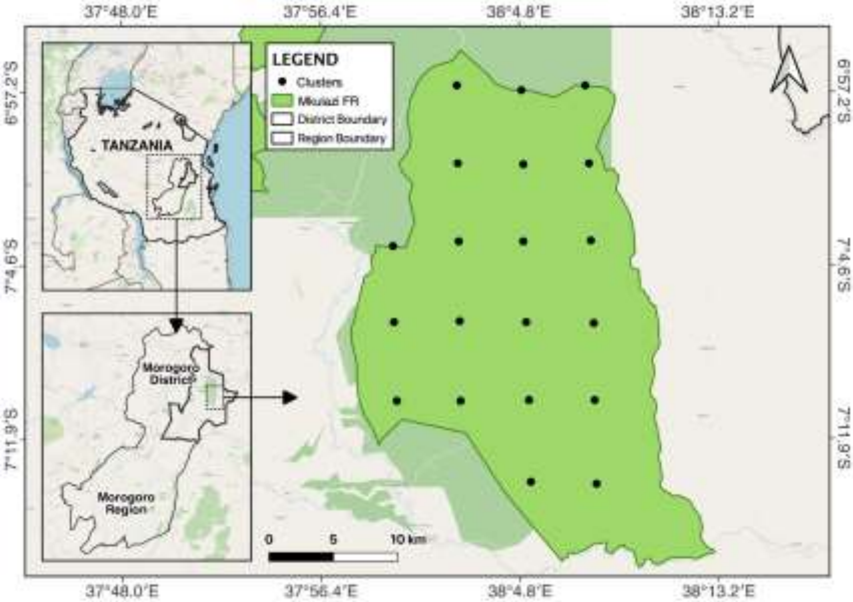

Figure 1: The map of Morogoro District, Tanzania, showing the location of Mkulazi Forest Reserve (MFR) and layout of clusters of plots in the reserve.

Data collection

The field survey was conducted in October 2016 and involved establishment of 100 concentric circular plots of radius 2 m, 5 m, 10 m and 15 m in 20 clusters of 5 plots each (MNRT 2015). These plots were distributed along the four transect lines with varying distance based on the forest shape, established parallel to one another across the entire forest area of 65,710 ha (Figure 1). The distance between transects was 6.2 km, distance between clusters was 5.2 km and the distance between plots within the cluster was 250 m (Malimbwi et al. 2005, MNRT 2015). The starting and ending points of cluster were Georeferenced using GPS. This study adopted a sampling intensity of 0.01% which is equivalent to 100 plots in order to cover variation of vegetation types across the entire forest area. Other reasons include time constraints and resource availability (Malimbwi et al. 2005, Giliba et al. 2011). In each sub-plot the following measurements were taken: Within 2 m radius all trees and shrubs with DBH < 5 cm were identified and counted at species level, within 5 m radius all trees and shrubs with DBH ≥ 5 - < 10 cm were identified and measured for DBH at species level, Within 10 m radius all trees and shrubs with DBH ≥ 10 - < 20 cm were identified and measured for DBH at species level, and within 15 m radius all trees and shrubs with DBH ≥ 20 cm were identified and measured for DBH at species level (Malimbwi et al. 2000, Giliba et al. 2011, MNRT 2015). This design was adopted because each individual have an equal chance of being included in a sample under study

(MNRT 2015). Identification of species was carried out by local person and a botanist. For those species that were difficult to identify in the field, voucher specimens were collected for proper identification in the Tanzania Forestry Research Institute (TAFORI) herbarium located in Lushoto District, Tanga region.

Data analysis

Species richness was expressed by the total number of observed species in the forest (Kacholi 2014), whereas Species diversity was computed using the Shannon-wiener diversity index (*H'*) (Kent 2012):

$$H' = -\sum_{i=1}^{n} p_i \cdot \ln(p_i)$$

Where, *n* = number of species in a community and *pi* = proportion of individuals of the species expressed as a proportion of total abundance in the sample, and ln = log $base_n$. The dominance of species was calculated using the Importance value index (IVI). The IVI was determined as the sum of relative frequency, relative density and relative dominance (basal area) and expressed in percent (Kent 2012). The species accumulation curve was constructed based on pooled species richness and combination of sites in order to show how the number of species increases with increasing individuals and sample size (Kindt and Coe 2005). The forest structure was described in terms of tree density (stems ha^{-1}), basal area for species (m^2 ha^{-1}), stand volume (m^3 ha^{-1}) and size class distributions (Kacholi 2014). The tree density was calculated using the number of individuals divided by sample area while the basal area was equal to 0.00007854 x DBH^2 divided by sample area (Kacholi 2014). Volume of a tree was estimated using the developed equation for miombo woodlands by Mauya et al. (2014): Volume (m^3 $tree^{-1}$) = 0.00016 x $DBH^{2.46300}$ (n = 158, RMSE -Root Mean Square Error (%) = 48.0, R^2 = 0.87, MPE -Mean Prediction Error (%) = -0.5). The biomass of tree above ground and below ground were estimated using equations for miombo woodlands developed by Mugasha et al. (2013): Above Ground Biomass (kg $tree^{-1}$) = 0.1027 x $DBH^{2.4798}$ (n = 167, RMSE (kg) = 411.5, R^2 = 0.95, MPE (%) = 1.6), and Below Ground Biomass (kg $tree^{-1}$) = 0.2113 x $DBH^{1.9838}$ (n = 80, RMSE (kg) = 107.5, R^2 = 0.92, MPE (%) = 2.6). Carbon stock (Mg C ha^{-1}) was estimated by multiplying biomass with a conversion factor of 0.49 (Manyanda et al. 2020). All data analyses were performed using Excel spread sheet and R version 4.2.0.

Results and Discussion

Species richness, composition and diversity of trees and shrubs with DBH ≥ 5 cm

A total of 54 tree and shrub species with DBH ≥ 5 cm to ≤ 132.5 cm in 20 plant families were identified in the MFR (Table 1). Trees contributed 61% (14 plant families) and shrubs 39% (10 plant families) of the species. The family Fabaceae contributed the most (39%) to the total number of species, followed by family Combretaceae (11%), Phyllanthaceae (6%) and Rubiaceae (6%). However, when all categories were combined (DBH < 5 cm and ≥ 5 cm), a total of 57 plant species in 21 plant families were identified (results not shown). Trees contributed 60% (14 plant families) and shrubs 40% (11 plant families) of the species. Of all recorded species, *Brachystegia boehmii* and *Combretum molle* were the most frequent and abundant species (Table 1). *B. boehmii* was the species with highest IVI value of 45.3, followed by *C. molle* (36.1), *Pteleopsis myrtifolia* (23.4), and *Diplorhynchus condylocarpon* (22.6) while the remaining 50 species had IVI of less than 20.0 (Table 1). The top four species accounted for 42% of the overall IVI.

The species richness of 54 different trees and shrubs in 20 plant families reported in this study from 100 sample plots of 0.071 ha is lower than that of Kalaba et al. (2013) who reported a total of 83 species belonging to 53 families from Zambia using 24 sample plots of 0.25ha (50 m x 50 m). The higher species richness observed by Kalaba et al. (2013) could be due to minimum human disturbances that were observed in their study area. The area had not experienced any major human or natural disturbances (undisturbed miombo site). However, species richness of 54 was higher compared to study by

Mwampashi (2013) from Iwuma forest reserve in Mbozi District, Tanzania who reported 11 species using 37 rectangular plots measuring 20 m x 40 m (0.08 ha) each, and Shirima et al. (2011) surveyed Nyanganje Forest Reserve in Tanzania who recorded 35 tree species using four 1-ha sample plots. The high species richness in the study area might be attributed to the presence of the riverine forest and groundwater (high water table) which favors the growth of many species. Several other factors such as sizes of the plots, sampling methodology, geographical variation, study area characteristics and temporal variation could contribute to the observed discrepancy (Kindt and Coe 2005, Kacholi 2014). The species accumulation curve (Figure 2) indicates that the sample size used in this study appears to be sufficient as the graph reaches the asymptote indicating that further increase in sample size would be unlikely to add many additional species. The average number of species per plot in this study was 5 species (range 1 - 10 species per plot).

The species richness in this study falls within the range of species commonly found in miombo woodland (both wet and dry) of 11 - 229 species (Mwampashi 2013, Mwakalukwa et al. 2014b, Shirima et al. 2015, Jew et al. 2016) stressing the importance of conserving this reserve. The dominance of *Brachystegia boehmii* and *Combretum molle* in terms of IVI agreed well with common patterns of wet miombo woodlands (Frost 1996, Timberlake et al. 2010).

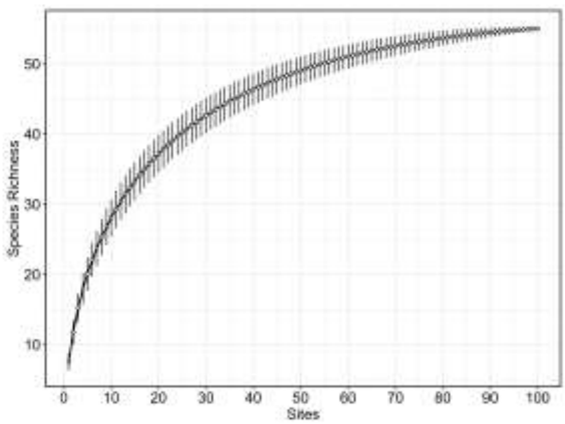

Figure 2: Species accumulation curve of tree species in Mkulazi Forest Reserve (MFR), Morogoro District in Tanzania. The curve depicts the expected number of species as a function of sampled area, with the upper and lower bounds representing the 95% confidence intervals.

Table 1. Checklist of tree and shrub species with a minimum DBH of 5 cm sorted by IVI identified in Mkulazi Forest Reserve (MFR), Morogoro District, Tanzania.

No.	Botanical name	Plant Family	Habit	Frequency (%)	*Rf (%)	RDe (%)	RDo (%)	IVI	*H'*	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Stand Volume (m^{3}ha^{-1})	AGC (Mgha^{-1})	BGC (Mgha^{-1})
1	*Brachystegia boehmii* Taub.	Fabaceae	Tree	58	12.1	14.4	18.8	45.3	0.30	41 ± 6	1.88 ± 0.24	20.16 ± 2.78	6.74 ± 0.93	2.34 ± 0.30
2	*Combretum molle* R.Br. ex G.Don	Combretaceae	Tree	52	11.4	13.1	11.7	36.1	0.26	38 ± 7	0.87 ± 0.11	7.40 ± 0.98	2.45 ± 0.32	1.10 ± 0.14
3	*Pteleopsis myrtifolia* (M.A.Lawson) Engl. & Diels	Combretaceae	Shrub/ tree	26	9.6	8.4	5.4	23.4	0.16	32 ± 9	0.48 ± 0.11	4.40 ± 1.22	1.46 ± 0.41	0.60 ± 0.14
4	*Diplorhynchus condylocarpon* (Müll.Arg.)	Apocynaceae	Shrub/ tree	26	8.9	7.9	5.7	22.6	0.20	30 ± 7	0.51 ± 0.10	4.04 ± 0.79	1.33 ± 0.26	0.64 ± 0.13
5	*Pseudolachnostylis glauca* (Hiern) Hutch.	Phyllanthaceae	Shrub/ tree	38	4.9	5.5	7.9	18.3	0.21	16 ± 3	0.88 ± 0.16	9.01 ± 1.66	3.01 ± 0.55	1.09 ± 0.19
6	*Combretum zeyheri* Sond.	Combretaceae	Shrub/ tree	27	4.8	5.8	4.5	15.2	0.16	16 ± 4	0.37 ± 0.08	3.08 ± 0.68	1.02 ± 0.23	0.47 ± 0.10
8	*Vachellia robusta* Burch.	Fabaceae	Tree	19	5.5	3.9	5.2	14.6	0.15	18 ± 7	0.45 ± 0.12	4.37 ± 1.25	1.46 ± 0.42	0.56 ± 0.15
7	*Xeroderris stuhlmannii* (Taub.) Mendonça & E.P.Sousa	Fabaceae	Tree	26	3.8	4.1	5.5	13.4	0.14	13 ± 4	0.66 ± 0.16	7.67 ± 2.00	2.57 ± 0.67	0.82 ± 0.20
9	*Annona senegalensis* Pers.	Annonaceae	Shrub/ tree	13	3.7	4.0	2.5	10.2	0.09	12 ± 5	0.19 ± 0.06	1.58 ± 0.57	0.52 ± 0.19	0.24 ± 0.08
11	*Bridelia cathartica* Bertol.	Phyllanthaceae	Shrub/ tree	12	3.2	3.3	1.7	8.2	0.08	11 ± 4	0.14 ± 0.05	1.00 ± 0.34	0.33 ± 0.11	0.17 ± 0.06
10	*Vachellia nilotica* (L.) Willd. ex Delile	Fabaceae	Tree	14	2.2	3.1	2.6	7.9	0.09	7 ± 2	0.16 ± 0.05	1.29 ± 0.36	0.43 ± 0.12	0.20 ± 0.06
12	*Sclerocarya birrea* (A.Rich.) Hochst.	Anacardiaceae	Tree	12	0.7	0.9	3.9	5.6	0.07	2 ± 1	0.45 ± 0.13	5.85 ± 1.82	1.97 ± 0.61	0.55 ± 0.16
14	*Lonchocarpus bussei* Harms	Fabaceae	Tree	10	2.3	2.3	1.0	5.6	0.07	8 ± 4	0.10 ± 0.04	0.80 ± 0.28	0.27 ± 0.09	0.13 ± 0.05
15	*Commiphora africana* (A.Rich.)	Burseraceae	Shrub/ tree	9	2.4	2.4	0.8	5.5	0.05	8 ± 3	0.06 ± 0.02	0.38 ± 0.14	0.12 ± 0.05	0.08 ± 0.03

No.	Botanical name	Plant Family	Habit	Frequency (%)	*Rf (%)	RDe (%)	RDo (%)	IVI	*H'*	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Stand Volume (m^3ha^{-1})	AGC ($Mgha^{-1}$)	BGC ($Mgha^{-1}$)
	Engl.													
13	*Boscia salicifolia* Oliv.	Capparaceae	Tree	12	1.4	2.2	1.8	5.4	0.08	5 ± 2	0.13 ± 0.05	1.03 ± 0.40	0.34 ± 0.13	0.16 ± 0.06
21	*Mystroxylon aethiopicum* (Thunb.) Loes.	Celastraceae	Tree	3	2.7	1.2	0.7	4.5	0.04	9 ± 6	0.04 ± 0.03	0.22 ± 0.14	0.07 ± 0.05	0.05 ± 0.03
16	*Pterocarpus angolensis* DC.	Fabaceae	Tree	12	0.9	1.2	1.5	3.6	0.07	3 ± 1	0.16 ± 0.06	1.65 ± 0.60	0.55 ± 0.20	0.20 ± 0.07
25	*Spirostachys africana* Sond.	Euphorbiaceae	Tree	2	2.1	0.8	0.6	3.5	0.04	7 ± 5	0.03 ± 0.03	0.19 ± 0.14	0.06 ± 0.05	0.04 ± 0.03
18	*Dalbergia melanoxylon* Guill. & Perr.	Fabaceae	Tree	10	1.2	0.9	1.3	3.5	0.06	4 ± 2	0.14 ± 0.05	1.39 ± 0.56	0.46 ± 0.19	0.17 ± 0.06
19	*Terminalia sericea* Burch. ex DC.	Combretaceae	Shrub/ tree	6	1.2	1.0	1.1	3.3	0.04	4 ± 3	0.07 ± 0.03	0.58 ± 0.24	0.19 ± 0.08	0.08 ± 0.03
20	*Ochna macrocalyx* Oliv.	Ochnaceae	Shrub	9	1.3	1.0	0.9	3.2	0.05	4 ± 3	0.09 ± 0.04	0.83 ± 0.42	0.28 ± 0.14	0.11 ± 0.05
17	*Diospyros mollis* (Kurz) Gürke	Ebenaceae	Tree	4	0.9	0.6	1.8	3.2	0.05	3 ± 2	0.16 ± 0.09	1.74 ± 0.99	0.58 ± 0.33	0.20 ± 0.11
37	*Terminalia brownii* Fresen.	Combretaceae	Tree	1	1.9	0.6	0.2	2.7	0.03	6 ± 6	0.02 ± 0.02	0.08 ± 0.08	0.03 ± 0.03	0.02 ± 0.02
22	*Combretum collinum* Fresen.	Combretaceae	Shrub/ tree	4	0.7	0.8	0.9	2.4	0.03	2 ± 1	0.03 ± 0.02	0.21 ± 0.11	0.07 ± 0.04	0.04 ± 0.02
23	*Acacia nigrescens* Oliv.	Fabaceae	Tree	9	0.6	0.8	1.0	2.3	0.05	2 ± 1	0.09 ± 0.03	0.84 ± 0.29	0.28 ± 0.10	0.12 ± 0.04
26	*Burkea africana* Hook.	Fabaceae	Tree	7	0.6	0.6	0.8	2.0	0.05	2 ± 1	0.10 ± 0.04	0.92 ± 0.39	0.31 ± 0.13	0.12 ± 0.05
38	*Vitex keniensis* Turrill	Lamiaceae	Tree	4	1.1	0.5	0.2	1.8	0.03	4 ± 3	0.03 ± 0.02	0.23 ± 0.12	0.08 ± 0.04	0.04 ± 0.02
24	*Erythrophleum africanum* (Benth.) Harms	Fabaceae	Tree	3	0.4	0.6	0.9	1.8	0.03	1 ± 1	0.10 ± 0.08	1.08 ± 0.95	0.36 ± 0.32	0.12 ± 0.10
27	*Julbernardia globiflora* (Benth.) Troupin	Fabaceae	Tree	3	0.2	0.2	1.2	1.6	0.02	1 ± 0	0.24 ± 0.20	4.33 ± 3.83	1.47 ± 1.31	0.29 ± 0.24
30	*Swartzia madagascariensis*	Fabaceae	Shrub	4	0.5	0.4	0.6	1.5	0.02	2 ± 1	0.04 ± 0.02	0.39 ± 0.21	0.13 ± 0.07	0.05 ± 0.03

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	Desv.													
34	*Monotes africanus* A.DC.	Dipterocarpaceae	Tree	2	0.6	0.5	0.3	1.4	0.02	2 ± 2	0.03 ± 0.02	0.26 ± 0.23	0.09 ± 0.08	0.04 ± 0.03
28	*Zanha africana* (Radlk.) Exell	Sapindaceae	Tree	2	0.3	0.3	0.8	1.4	0.03	1 ± 1	0.08 ± 0.06	0.91 ± 0.73	0.31 ± 0.24	0.09 ± 0.07
44	*Vangueria madagascariensis* J.F.Gmel.	Rubiaceae	Shrub/ tree	1	0.8	0.5	0.1	1.3	0.01	3 ± 3	0.01 ± 0.01	0.08 ± 0.08	0.03 ± 0.03	0.02 ± 0.02
45	*Albizia petersiana* (Bolle) Oliv.	Fabaceae	Tree	1	0.8	0.4	0.1	1.3	0.01	3 ± 3	0.02 ± 0.02	0.09 ± 0.09	0.03 ± 0.03	0.02 ± 0.02
31	*Diospyros kirkii* Hiern	Ebenaceae	Tree	4	0.2	0.4	0.5	1.2	0.03	1 ± 0	0.05 ± 0.03	0.55 ± 0.34	0.18 ± 0.12	0.06 ± 0.04
32	*Albizia gummifera* (J.F.Gmel.) C.A.Sm.	Fabaceae	Tree	2	0.2	0.4	0.5	1.1	0.02	1 ± 0	0.05 ± 0.04	0.55 ± 0.48	0.19 ± 0.16	0.06 ± 0.05
33	*Suregada zanzibariensis* Baill.	Euphorbiaceae	Shrub	2	0.2	0.4	0.5	1.1	0.02	1 ± 1	0.03 ± 0.03	0.31 ± 0.28	0.10 ± 0.09	0.04 ± 0.04
36	*Elaeodendron buchananii* (Loes.) Loes.	Celastraceae	Tree	3	0.2	0.3	0.5	1.1	0.02	1 ± 0	0.05 ± 0.03	0.57 ± 0.39	0.19 ± 0.13	0.06 ± 0.04
39	*Afzelia quanzensis* Welw.	Fabaceae	Tree	2	0.4	0.4	0.4	1.1	0.01	1 ± 1	0.04 ± 0.03	0.42 ± 0.38	0.14 ± 0.13	0.05 ± 0.04
40	*Vepris nobilis* (Delile) Mziray	Rutaceae	Tree	1	0.4	0.6	0.1	1.1	0.01	1 ± 1	0.00 ± 0.00	0.02 ± 0.02	0.01 ± 0.01	0.01 ± 0.01
41	*Grewia similis* K.Schum.	Malvaceae	Tree	2	0.5	0.5	0.2	1.1	0.01	2 ± 1	0.01 ± 0.01	0.10 ± 0.07	0.03 ± 0.02	0.02 ± 0.01
29	*Manilkara sulcata* (Engl.) Dubard	Sapotaceae	Tree	1	0.1	0.3	0.7	1.1	0.01	0 ± 0	0.18 ± 0.18	3.02 ± 3.02	1.02 ± 1.02	0.23 ± 0.23
35	*Cassia* sp.	Fabaceae	Shrub	1	0.1	0.5	0.3	1.0	0.01	0 ± 0	0.02 ± 0.02	0.21 ± 0.21	0.07 ± 0.07	0.03 ± 0.03
46	*Gardenia ternifolia* Schumach. & Thonn.	Rubiaceae	Shrub/ tree	1	0.4	0.3	0.3	0.9	0.01	1 ± 1	0.01 ± 0.01	0.05 ± 0.05	0.02 ± 0.02	0.01 ± 0.01

No.	Botanical name	Plant Family	Habit	Frequency (%)	*Rf (%)	RDe (%)	RDo (%)	IVI	*H'*	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Stand Volume (m^{3}ha^{-1})	AGC (Mgha^{-1})	BGC (Mgha^{-1})
47	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	Shrub	1	0.4	0.3	0.1	0.9	0.01	1 ± 1	0.01 ± 0.01	0.08 ± 0.08	0.03 ± 0.03	0.02 ± 0.02
42	*Tarenna nigrescens* R.D.Good	Rubiaceae	Shrub	3	0.2	0.2	0.4	0.8	0.03	1 ± 0	0.05 ± 0.03	0.55 ± 0.36	0.18 ± 0.12	0.07 ± 0.04
43	*Albizia harveyi* E.Fourn.	Fabaceae	Tree	4	0.2	0.2	0.4	0.8	0.02	1 ± 0	0.04 ± 0.03	0.46 ± 0.29	0.15 ± 0.10	0.06 ± 0.03
48	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Fabaceae	Shrub/ tree	1	0.4	0.3	0.1	0.8	0.01	1 ± 1	0.01 ± 0.01	0.05 ± 0.05	0.02 ± 0.02	0.01 ± 0.01
50	*Turraea floribunda* Hochst.	Meliaceae	Tree	2	0.2	0.2	0.1	0.5	0.01	1 ± 0	0.01 ± 0.01	0.05 ± 0.03	0.02 ± 0.01	0.01 ± 0.01
51	*Dalbergia arbutifolia* Baker	Fabaceae	Shrub	2	0.2	0.2	0.1	0.5	0.01	1 ± 0	0.01 ± 0.01	0.10 ± 0.07	0.03 ± 0.02	0.02 ± 0.01
49	*Tamarindus indica* L.	Fabaceae	Tree	2	0.1	0.2	0.2	0.4	0.01	0 ± 0	0.04 ± 0.03	0.45 ± 0.34	0.15 ± 0.11	0.05 ± 0.04
52	*Margaritaria discoidea* (Baill.) G.L.Webster	Phyllanthaceae	Shrub/ tree	1	0.2	0.2	0.1	0.4	0.01	1 ± 1	0.01 ± 0.01	0.05 ± 0.05	0.02 ± 0.02	0.01 ± 0.01
53	*Lannea schweinfurthii* (Engl.) Engl.	Anacardiaceae	Tree	1	0.0	0.0	0.2	0.3	0.01	0 ± 0	0.03 ± 0.03	0.43 ± 0.43	0.15 ± 0.15	0.04 ± 0.04
54	*Zanthoxylum chalybeum* Engl.	Rutaceae	Shrub/ tree	2	0.1	0.1	0.1	0.3	0.01	0 ± 0	0.01 ± 0.01	0.12 ± 0.09	0.04 ± 0.03	0.02 ± 0.01
	Total			**479**	**100**	**100**	**100**	**300**	**3.11**	**336 ± 126**	**9.48 ± 2.88**	**96.22 ± 32.51**	**32.13 ± 10.91**	**11.84 ± 3.58**

Note: * Rf = Relative frequency, RDe = Relative density, RDo = Relative dominance (basal area), IVI = Importance Value Index, *H'* = Shannon-Wiener diversity index, AGC = Above Ground Carbon (mean ± SE), BGC = Below Ground Carbon (mean ± SE), Stem density, Basal area, and Stand volume results are in mean ± SE. Plot size = 15 m radius. SE = Standard error.

Species diversity of trees and shrubs with DBH ≥ 5 cm identified in MFR using Shannon-Wiener diversity index (*H'*) was 3.11 (Table 1). Species with the greatest contributions to Shannon-Wiener diversity index (*H'*) were: *B. boehmii*, *C. molle*, *P. glauca* and *D. condylocarpon*. The *H´* value of 3.11 reported in this study is higher than those from other wet miombo woodlands which also employed the diameter limit of ≥ 5 cm. For instance, Kalaba et al. (2013) from Zambia reported a *H´* value of 2.8; Mwampashi (2013) reported *H´* value of 1.3 and Shirima et al. (2011) reported two *H´* values of 1.9 and 2.2. Similarly, as for the richness, the same factors such as sizes of the plots, sampling methodology, geographical variation, study area characteristics and temporal variation could have contributed to the variation of the results (Kindt and Coe 2005, Kacholi 2014). The *H´* value of 3.11 in this study falls in the range of *H´* values commonly found in miombo woodland (both wet and dry) of 1.05 - 4.27 (Shirima et al. 2011, Mwakalukwa et al. 2014b, Jew et al. 2016). According to Magurran (2004), the larger the *H'* value, the greater the species diversity. Values of the index usually lie between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5 (Kent 2012). An ecosystem with *H'* value > 2 was regarded as medium to high diverse in terms of species (Barbour et al. 1999, Magurran 2004). Therefore, the *H'* value of 3.11 in this study implies that the MFR is a highly diverse forest.

Stand structure for trees and shrubs with DBH ≥ 5 cm

The results for stem density (stems ha^{-1}), basal area (m^2ha^{-1}), and stand volume (m^3ha^{-1}) for trees and shrubs with DBH ≥ 5 cm identified and measured in MFR are presented in Table 1. The total mean stem density was 336 ± 126 stems ha^{-1}, basal area was 9.48 ± 2.88 m^2ha^{-1} and stand volume was 96.22 ± 32.51 m^3ha^{-1} (Table 1). *B. boehmii* contributed the most to the stem density (41 ± 6 stems ha^{-1}), basal area (1.88 ± 0.24 m^2ha^{-1}) and stand volume (20.16 ± 2.78 m^3ha^{-1}). The distribution of trees to size classes for stem densities showed the reverse J shape (Figure 3), while in basal area and stand volume the distribution of trees to size classes showed that trees with diameter between 10.1 cm and 50.0 cm contributed to higher mean basal area and stand volume of the forest (Figure 4 for basal area, volume not shown).

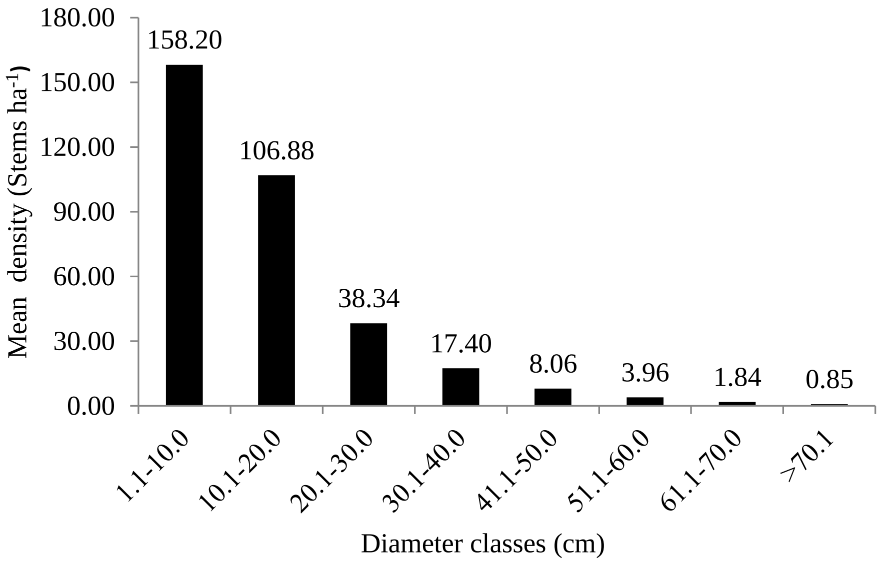

Figure 3: Density of trees and shrubs ≥ 5 cm DBH by diameter class in Mkulazi Forest Reserve (MFR), Morogoro District, Tanzania.

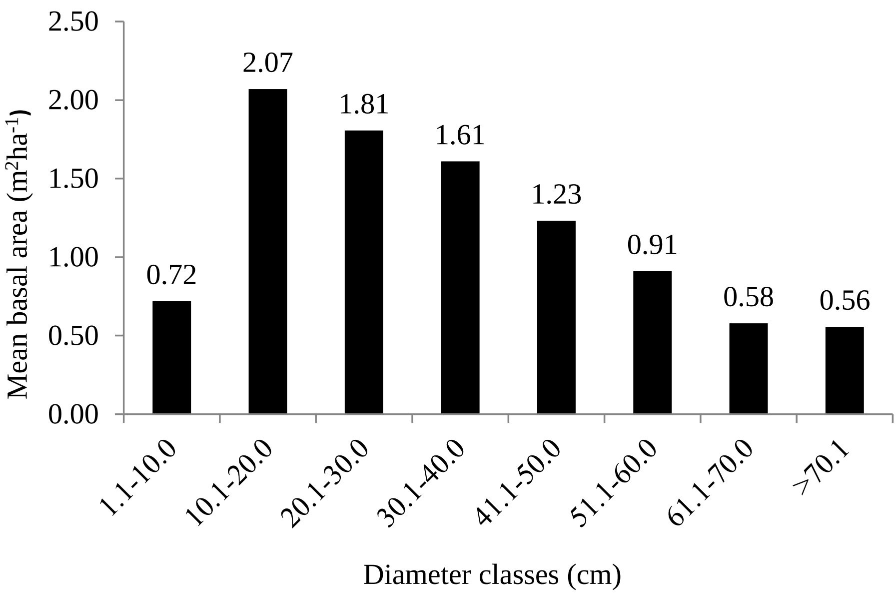

Figure 4: Distribution of basal area per hectare for trees and shrubs with ≥ 5 cm DBH by diameter class in Mkulazi Forest Reserve (MFR), Morogoro District, Tanzania.

The mean stem density of 336 ± 126 stems ha^{-1} for trees and shrubs with DBH ≥ 5 cm in this study is lower than the values reported by other scholars from wet miombo woodlands of Tanzania and Zambia. For instance, from Tanzania, Mwampashi (2013) reported a value of 553 stems ha^{-1}, Katani et al. (2016) reported a value of 658 ± 143 stems ha^{-1}, Shirima et al. (2011) reported two values of 382 stems ha^{-1} and 376 stems ha^{-1} and Malimbwi et al. (2005) reported a value of 827 ± 96 stems ha^{-1}. Kalaba et al. (2013)

from Zambia reported a value of 592 ± 28.01 stems ha^{-1}. The higher density reported by other studies might be attributed to higher presence of more stems due to lower disturbances. The effects of plot sizes could also contribute to the observed variations (Kindt and Coe 2005, Kacholi 2014). The mean stems density values in this study fall within the range found in miombo woodland (both wet and dry) of 232 - 1,988 stems ha^{-1} (Sawe et al. 2014, Mwakalukwa et al. 2014b, Katani et al. 2016). This implies that MFR is among the medium-stocked wet miombo woodland forests in Tanzania and elsewhere.

The observed mean basal area of 9.48 ± 2.88 m^2ha^{-1} in this study is lower than 14.34 ± 0.52 m^2ha^{-1} from Zambia (Kalaba et al. 2013). Corresponding values from Tanzania include 9.60 m^2ha^{-1} by Mwampashi (2013); 10.07 ± 1.68 m^2ha^{-1} by Katani et al. (2016); 12.3 m^2ha^{-1} and 13.3 m^2ha^{-1} by Shirima et al. (2011) and 18.78 ± 2.08 m^2ha^{-1} by Malimbwi et al. (2005). The observed lower basal area in this study might be due to low stem density observed due to ongoing human activities including illegal harvesting of key timber species in the reserve as in 2005 the basal area observed in the same forest was higher i.e 18.78 ± 2.08 m^2ha^{-1} (Lovett and Pocs1993, Malimbwi et al. 2005, John 2018). Other factors such as sampling methodology and sizes of the plots could also contribute to the observed variations (Kindt and Coe 2005, Kacholi 2014). However, the mean basal area in this study falls within the range of 3.9 - 18.78 ± 2.08 m^2ha^{-1} values commonly reported both in wet and dry miombo woodland (Backéus et al. 2006, Malimbwi et al. 2005, Mwakalukwa et al. 2014b, Masota et al. 2018).

The mean stand volume of 96.22 ± 32.51 m^3ha^{-1} reported in this study is higher than 60.29 m^3ha^{-1} reported by Mwampashi (2013) and 68.52 ± 18.84 m^3ha^{-1} by Katani et al. (2016) both from Tanzania, but lower than 171.9 ± 26 m^3ha^{-1} reported by Malimbwi et al. (2005) in the same area. The relatively higher stand volume recorded in this forest could be due to presence of relatively higher large-sized trees observed in the reserve. The mean stand volume reported in this study falls within the range of values commonly found in both wet and dry miombo woodland of 16.7 to 171.9 m^3ha^{-1} (Malimbwi et al. 2005, Mwakalukwa et al. 2014b, Masota et al. 2018).

Regeneration status for trees and shrubs with DBH < 5 cm

The results of species richness, diversity and density of regeneration (DBH < 5cm) identified in MFR are presented in Table 2. A total of 26 trees and shrubs species which belong to 11 plant families were identified. Tree and shrub species from the family Fabaceae contributed 42% of the total number of species, followed by those from the family Phyllanthaceae (15%), Combretaceae (8%) and Rutaceae (8%). The most frequent species were *B. boehmii* and *B. spiciformis*. The same species contributed the most to the Shannon-Wiener diversity index (*H'*) and stem density of the regenerants (Table 2). The high number of stems per hectare of regenerants in MFR indicates active regeneration and high rate of recruitment in the forest, an indication of sustainability of the woodland stock if not subjected to further anthropogenic disturbances (Giliba et al. 2011, John 2018, TFS 2022).

Table 2. Checklist of tree and shrub species of regenerants with DBH of < 5 cm identified in Mkulazi Forest Reserve (MFR), Morogoro District, Tanzania.

No.	Botanical name	Plant family	Habit	Frequency (%)	**H'*	Stem density (stems ha^{-1})
1	*Brachystegia boehmii* Taub.	Fabaceae	Tree	4	0.19	98 ± 50
2	*Brachystegia*	Fabaceae	Tree	4	0.22	107 ± 59

No.	Botanical name	Plant family	Habit	Frequency (%)	*H'	Stem density (stems ha^{-1})
	spiciformis Benth.					
3	*Vachellia nilotica* (L.) Willd. ex Delile	Fabaceae	Tree	3	0.16	74 ± 46
4	*Bridelia cathartica* Bertol.	Phyllanthaceae	Shrub /tree	3	0.16	57 ± 35
5	*Combretum molle* R.Br. ex G.Don	Combretaceae	Tree	3	0.16	66 ± 39
6	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	Shrub /tree	3	0.16	57 ± 33
7	*Pseudolachnostylis glauca* (Hiern) Hutch.	Phyllanthaceae	Shrub /tree	3	0.16	82 ± 48
8	*Annona senegalensis* Pers.	Annonaceae	Shrub /tree	2	0.12	57 ± 40
9	*Antidesma venosum* E.Mey. ex Tul.	Phyllanthaceae	Shrub /tree	2	0.12	33 ± 23
10	*Burkea africana* Hook.	Fabaceae	Tree	2	0.12	49 ± 34
11	*Dalbergia melanoxylon* Guill. & Perr.	Fabaceae	Tree	2	0.12	41 ± 33
12	*Diplorhynchus condylocarpon* (Müll.Arg.)	Apocynaceae	Shrub /tree	2	0.12	33 ± 23
13	*Lonchocarpus bussei* Harms	Fabaceae	Tree	2	0.12	41 ± 29
14	*Margaritaria discoidea* (Baill.) G.L.Webster	Phyllanthaceae	Shrub /tree	2	0.12	57 ± 40
15	*Pteleopsis myrtifolia* (M.A.Lawson) Engl. & Diels	Combretaceae	Shrub /tree	2	0.12	49 ± 36
16	*Turraea floribunda* Hochst.	Meliaceae	Tree	2	0.12	49 ± 36
17	*Acacia robusta* Burch.	Fabaceae	Tree	1	0.07	8 ± 8
18	*Albizia petersiana* (Bolle) Oliv.	Fabaceae	Shrub /tree	1	0.16	74 ± 73
19	*Dalbergia arbutifolia* Baker	Fabaceae	Shrub	1	0.07	25 ± 24
20	*Mystroxylon aethiopicum* (Thunb.) Loes.	Celastraceae	Tree	1	0.07	16 ± 16
21	*Ochna macrocalyx* Oliv.	Ochnaceae	Shrub	1	0.07	8 ± 8
22	*Pterocarpus angolensis* DC.	Fabaceae	Tree	1	0.07	33 ± 32

No.	Botanical name	Plant family	Habit	Frequency (%)	*H'*	Stem density (stems ha^{-1})
23	*Rourea orientalis* Baill.	Connaraceae	Shrub	1	0.07	25 ± 24
24	*Suregada zanzibariensis* Baill.	Euphorbiaceae	Shrub	1	0.07	33 ± 32
25	*Vepris nobilis* (Delile) Mziray	Rutaceae	Tree	1	0.07	16 ± 16
26	*Zanthoxylum chalybeum* Engl.	Rutaceae	Shrub /tree	1	0.07	8 ± 8
	Total			**51**	**3.14**	**1,198 ± 847**

Note: * Shannon-Wiener diversity index (*H*'), plot size = 2 m radius.

Biomass and Carbon storage for trees and shrubs with DBH ≥ 5 cm

The mean above ground biomass and carbon stocks potential of MFR for trees and shrubs with diameter ≥ 5 cm were 65.57 ± 22.26 Mg ha^{-1} and 32.13 ± 10.91 Mg C ha^{-1}, respectively, while the mean below ground biomass and carbon stocks potential of the same tree category were 24.16 ± 7.31 Mg ha^{-1} and 11.84 ± 3.58 Mg C ha^{-1}, respectively (Table 1, Figure 5). *B. boehmii* contributed most to the observed above ground carbon density of 6.74 ± 0.93 Mg C ha^{-1} by 21% and below ground carbon density of 2.34 ± 0.30 Mg C ha^{-1} by 20% (Table 1, Figure 5). The biomass and carbon distribution in different diameter classes indicated that trees with diameter between 10.1 cm and 60.0cm contributed most to the mean biomass and carbon stocks of the forest (Figure 5).

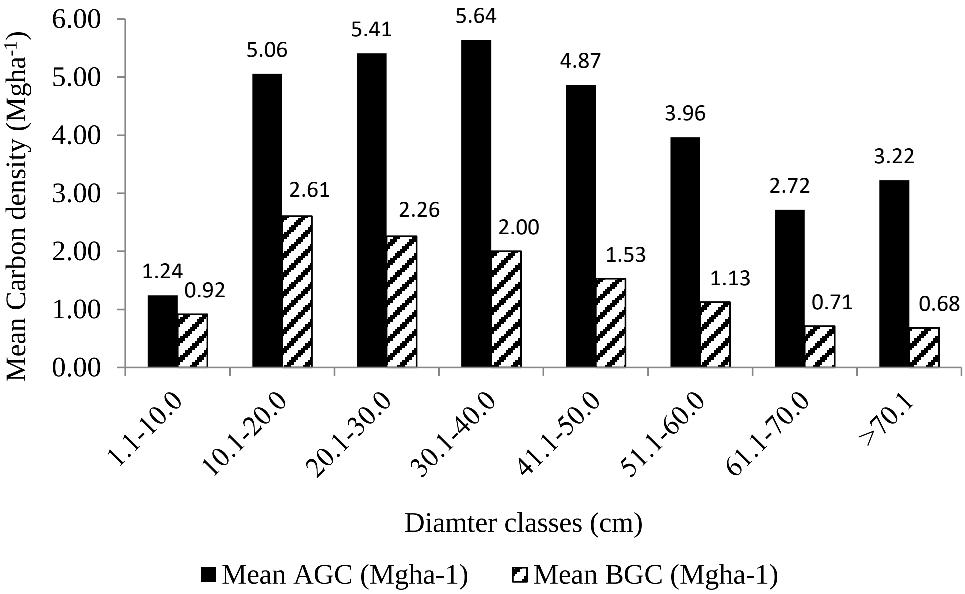

Figure 5: Distribution of both above ground and below ground mean carbon density for trees and shrubs ≥ 5 cm DBH by diameter classes in Mkulazi Forest Reserve (MFR), Morogoro District, Tanzania.

The total mean aboveground carbon stocks of the trees and shrubs with DBH ≥ 5 cm of 32.13 ± 10.91 Mg C ha^{-1} determined in this study is lower than 39.46 Mg C ha^{-1} reported by Mwampashi (2013) in Tanzania and 39.6 ± 1.5 Mg C ha^{-1} reported by Kalaba et al. (2013) in Zambia. The low value reported in this study could be due to presence of lower number of stem density and few trees of bigger diameter sizes contributing less to the total mean carbon density of the forest as compared to other studies. However, the values in this study are higher than 27.3 ± 5.0 Mg C ha^{-1} and 29.8 ± 5.9 Mg C ha^{-1} determined by Shirima et al. (2011) and 16.79 Mg C ha^{-1} reported by Katani et al. (2016) both from Tanzania. Additionally, factors like study area and stand characteristics, sampling methodology, level of disturbance, geographical variation and temporal variation may contribute to the variability in results.

Conclusion

Our results showed that MFR has relatively high species richness of woody species (54 species), and species diversity (*H'* = 3.11) as compared to other wet miombo woodlands forests of Tanzania except from Zambia (with 83 species). Tree density and basal area are lower, indicating that the forest has been subjected to anthropogenic activities such as illegal harvesting of trees, overgrazing, and unplanned fires which raise a need of further investigation. The findings of this study provide baseline information about species composition and structure which could be used during the review of the existing management plan of MFR. Conservation measures like intensifying number of patrols and involving adjacent communities in the management of forest reserve through Joint Forest Management arrangement is recommended. The carbon stock was relatively lower than those reported from other wet miombo woodlands forests. However, these estimates provide baseline data for the possibility of future payment schemes for REDD+ project implementation in Tanzania.

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