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Research Article

Human-Induced Changes in Woody Plant Diversity and Structure in Mbiwe Forest Reserve, Tanzania: Implications for Forest Quality and Conservation

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Abstract

The increasing demands for land and wood resources is threatening the existence of many species both flora and fauna, causing massive loss of biodiversity in many countries including Tanzania. This study assessed the effects of anthropogenic activities on woody species richness, diversity, and structure in Mbiwe forest reserve located in Chunya district, Tanzania. Specifically, the study i) compare species composition and diversity as well as ii) structural attributes between disturbed and undisturbed areas. Vegetation data for adult trees (Dbh ≥ 4 cm), saplings (Dbh 1< 4 cm), regenerants (Dbh < 1 cm), and stumps were collected from 50 rectangular sample plots (50 m ×20 m) established in the forest area of 49,147.7 ha. The results indicate that undisturbed areas exhibited higher values as compared to disturbed areas. In undisturbed areas, species richness was 71, H′ = 3.68, density = 868 ±588 stem/ha, basal area =8.75 ±4.95 m^2/ha, and volume = 73.61 ±44.68 m^3/ha. The area registered only 13 ±10 stem/ha for stumps unlike 263 ±88 stem/ha in the disturbed areas. Areas close to the town centers shows high rate of degradation than those found away from the centers. Law enforcement among other protection measures is recommended to safeguard the existing biodiversity in the reserve.

Keywords

Anthropogenic Activities, Biodiversity Loss, Miombo Woodland, Town Centers, Wood Volume Removal

1. Introduction

Tropical dry forests, particularly Miombo woodlands support diverse plant communities that have adapted to nutrient-poor soils, seasonal drought, and fire regimes [1]. The Miombo woodlands, covering about 92% of the forested land (44.7 million hectares), dominate Tanzania's landscape [2]. Dry and wet Miombo woodlands make up about 19% and 35% of Tanzania's Miombo woodland area, respectively [3]. These ecosystems play a vital role in sustaining biodiversity and providing ecosystem goods and services. However, increasing anthropogenic activities driven by population growth, livelihood demands, and weak enforcement of conservation policies have emerged as major threats to their existence [2, 4].

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Across southern and central Tanzania, Miombo woodlands have been increasingly subjected to disturbances such as fire, agricultural expansion, illegal logging, charcoal production and uncontrolled livestock grazing, leading to widespread ecological degradation [2, 5, 6]. These disturbances are reported to have significant effects on woody species richness, diversity, and forest structure by altering species composition and disrupting natural regeneration [6-9]. This degradation compromises the ecosystem's ability to provide essential services and weakens forest resilience against environmental stress and disturbances [10, 11].

Despite being gazetted as protected forest, many forest reserves in Tanzania continue to experience degradation due to insufficient on-ground management and enforcement [2, 12]. Mbiwe Forest Reserve (MFR), located in Chunya District of Mbeya Region, is one such case. The reserve serves both ecological and hydrological functions, yet faces pressure from activities like artisanal gold mining, charcoal production, illegal logging, and shifting cultivation [13]. A study by [13] provides evidence of a decline in woodland cover and carbon stocks, although it did not adequately examine the effects of anthropogenic activities on woody species composition, diversity and structure in the reserve.

This study hypothesises that anthropogenic activities significantly reduce woody species richness and diversity, alter species composition, and negatively affect forest structure attributes in Mbiwe Forest Reserve. For effective planning for conservation of biodiversity found in the reserve, assessment of the current situation is imperative. This study seeks to bridge that gap by assessing the condition of the forest both in undisturbed and disturbed areas so as to see to what extent these activities have affected the species composition, diversity and structural characteristics of Mbiwe Forest Reserve. This information will assist the Tanzania Forest Services Agency (TFS) who oversee the management of this reserve to take relevant action in curbing the ongoing illegal activities taking place in the reserve and safeguarding the existing biodiversity found in Mbiwe forest reserve.

2. Materials and Methods

2.1. Study Area Description

Mbiwe Forest Reserve is located in Chunya District, Mbeya Region, Tanzania. The reserve, managed by Tanzania Forest Services (TFS) Agency under the Ministry of Natural Resources and Tourism, was officially gazetted through Government Notice No. 598 of 1995. It covers an area of 49,147.7 hectares, situated between latitudes 8°24'36.84" to 8°39'44.27" S and longitudes 33°02'57.72" to 33°20'14.96" E (Figure 1). The reserve is found at an elevation ranging from 475 to 2,981 meters above sea level [14, 15].

Mbiwe Forest Reserve experiences a tropical climate, influenced by topography and altitude, with an average annual temperature ranging from 21 ℃ to 23 ℃. Rainfall varied between 600 mm and 1,000 mm per year, with the wettest months occurring between December and March [13]. The reserve's landscape is hilly, including Mbala Hills, and serves as a major catchment area for seasonal and permanent rivers, such as Mbala, Zira, Manyanya, Itete, and Lupa, which drain into Lake Rukwa [16]. The geology is primarily composed of sedimentary rocks, particularly sandstone, with shallow, stony, and low-fertility soils in woodland areas. Deeper soils included quartz-dominated sands, such as Albic Arenosols, Orthic Ferralsols, Ferralic Arenosols, and Ferralic Cambisols [13]. The dominant vegetation type is dry Miombo woodland consisting of species like *Brachystegia spiciformis*, *Brachystegia boehmii*, and *Pterocarpus angolensis*, alongside mixed dry forests, legume-dominated forests, and shrublands [17]. The reserve is surrounded by four town centers namely Matundasi, Makongorosi, Infwenkenya and Mkwajuni [13].

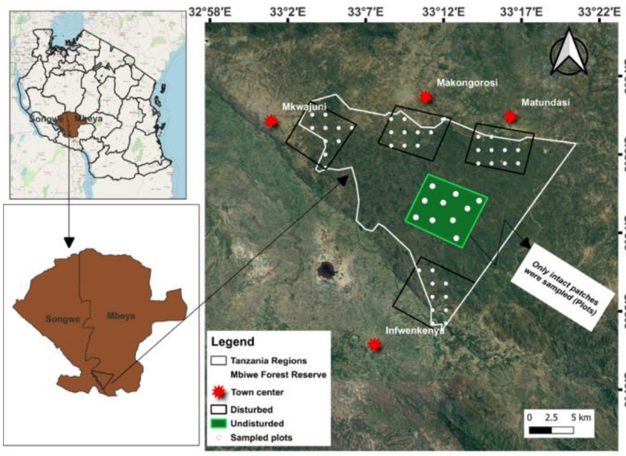


Figure 1. *A map of Tanzania showing the location and plot distribution (white circles) in Mbiwe forest reserve, Chunya district, Mbeya region.*

2.2. Sampling Design

Disturbance levels within Mbiwe Forest Reserve were classified based on proximity to surrounding town centers (Mkwajuni, Infwenkenya, Matundasi, and Makongorosi), which were assumed to experience higher human disturbances. Areas near these towns were categorized as disturbed, while those located deeper within the forest, with minimal or no visible human activities, were classified as undisturbed. A 1 km ^{2} cluster was established for each category, following the disturbance gradient approach described by [18]. In the disturbed cluster, a systematic random sampling design was used where by sampled plots were established at fixed intervals, with a randomly generated starting point determined using the 'Regular Points' tool in QGIS software [43], while a purposive sampling approach was used to establish plots in the undisturbed cluster (Figure 1). A total of 50 main plots (50 m × 20 m each) were distributed across five clusters, with four clusters in a disturbed part placed 500 meters from reserve boundary and one in an undisturbed part placed beyond 500 meters from the reserve boundary. Each cluster contained two north-south transects, with five plots per transect, spaced 100 meters apart, and 200 meters between adjacent transects. Within each main plot, 100 subplots (5 m × 5 m each) were arranged diagonally, while 100 sub-subplots (2 m × 2 m each) were positioned at the corners of the main plot (Figure 2). The total number of plots and their distance between them were calculated by formula (1) used by [19].

$$N = T_A \text{ X Si /Ps X100} \tag{1}$$

Where; N = number of sample plots, TA = Total area of the forest, Ps = Plot size and Si = Sampling intensity. The distance between plots was determined as per [19];

$$D = \sqrt{(Af + 10000)/N} \tag{2}$$

Where; D = inter plots distance (m), Af = Area of the forest (ha) and N = number of plots.

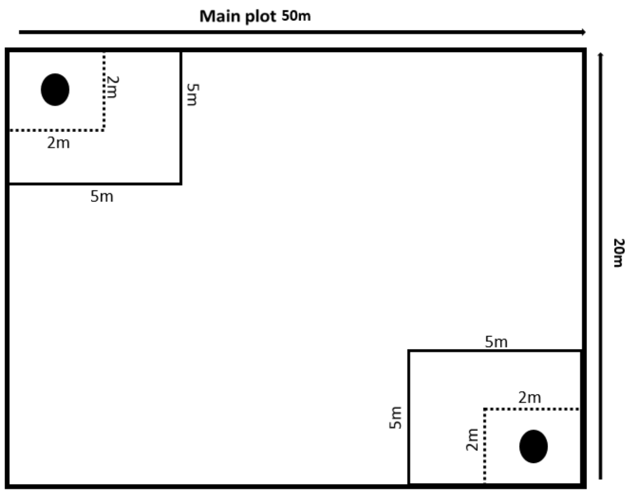


Figure 2. *The main plot showing layout of sub-plots used for vegetation data collection in disturbed and undisturbed parts of Mbiwe forest reserve, Tanzania.*

2.3. Vegetation Data Collection

Vegetation data were collected in November 2024 to assess woody species richness, diversity, and structure. Within each 50 m × 20 m main plot (Figure 2), all trees and shrubs with Dbh ≥4 cm were measured using a caliper, identified to species level, and recorded. Stumps encountered within these plots their diameters were measured at 20 cm above ground, identified to species level, and recorded. In each 5 m × 5 m subplot, all trees/shrubs with a diameter between 1 cm and 4 cm were similarly measured, identified to species level, and recorded. Meanwhile, in the 2 m × 2 m sub-subplots (Figure 2), all seedlings (diameter <1 cm) were counted, identified to species level, and recorded as regenerants. Based on dbh classifications, trees with Dbh ≥ 4 cm were categorised as large trees, while those between 1 cm and < 4 cm were classified as saplings.

Species identification was conducted by a botanist, and GPS devices were used for accurate navigation between plots, geographical location (UTM coordinates) and altitude (m). Human disturbance indicators were assessed through direct field observation, with their intensity levels recorded within each plot. These indicators included evidence of livestock dung, grazing signs, tree stumps, tree debarking, clearing, mining pits, and footpath trespassing. Observations were conducted within the main sample plots (50 m × 20 m). The severity of human disturbance was visually estimated and quantified using the Likert scale of 0 to 4, where 0 = absence of disturbance, 1 = low disturbance, 2 = moderate disturbance, 3 = high disturbance, and 4 = severe disturbance as used by [20].

A score of 4 indicated severe disturbance (≥ 75% of the plot affected), typically resulting from extensive logging, recurrent fires, or heavy grazing. Scores of 3 and 2 represented high (51–75%) and moderate (1–50%) disturbance, respectively, often caused by intensive or selective resource use. A score of 1 denoted low disturbance, such as the presence of a few stumps or evidence of light grazing. A score of 0 indicated the absence of disturbance, where plots maintained their original vegetation structure with no visible signs of human activities.

2.4. Data Analysis

Before actual analysis, all plots were grouped into two categories; disturbed (regardless of the levels of disturbances) and undisturbed (plots with no signs of disturbances). In each group, data were analysed for species richness, diversity, stem density, basal area, volume, and status of harvested stems. Species richness was computed as the total number of species across all plots sampled. Species importance value index (IVI) was computed as the summation of relative frequency, relative density and relative dominance as in [6];

$$\text{IVI}=\sum\text{Relative frequency} + \text{Relative density} + \text{Relative dominance} \tag{3}$$

Species diversity was assessed using the Shannon-Wiener Diversity Index (H’) as in [21];

$$\text{H}' = -\sum_{i=1}^{S} PiLnPi \tag{4}$$

Where; pi is the proportion of individuals belonging to the n^{th} species.

Stem density (number of stems per hectare) was calculated as;

$$N = \frac{n}{ps} \tag{5}$$

Where; ps = area of plot (ha), n = number of individual plants (count), and basal area (m ²per hectare) of the forest was calculated as;

$$G = \sum \left(\frac{Gi}{n}\right) \quad (6)$$

Where; *G*= Average basal area per hectare of the stand, *Gi*=basal area of the plot and *n* = number of sample plots.

Volume of standing trees was computed using developed allometric equation by [22];

$$\text{Volume } (m^3/\text{ tree}) = 0.00016 \times DBH^{2.46300} \quad (7)$$

Where that of stumps (harvested volume) was computed using the equation by [23];

$$Y = 0.000032 \times SD^{2.7992} \quad (8)$$

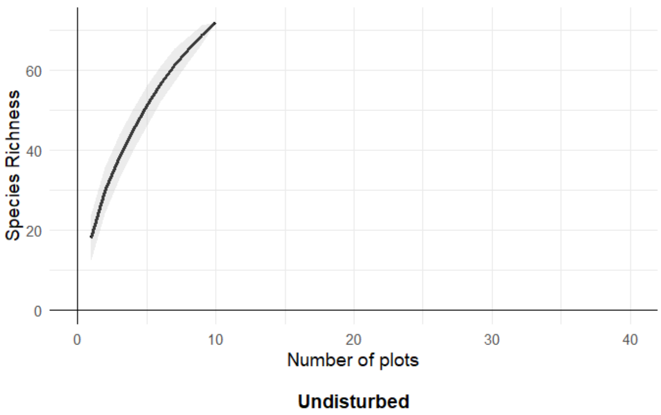
Where; Y (m3/ stump) = Volume of the stump and SD= Stump diameter

A species accumulation curve for all species observed in the studied forest parts was produced to assess the sufficiency of sampling intensity. Data summarization was done using MS Excel Spreadsheet 2010, and all statistical analyses and result visualization were conducted in R version 4.4.1 [24].

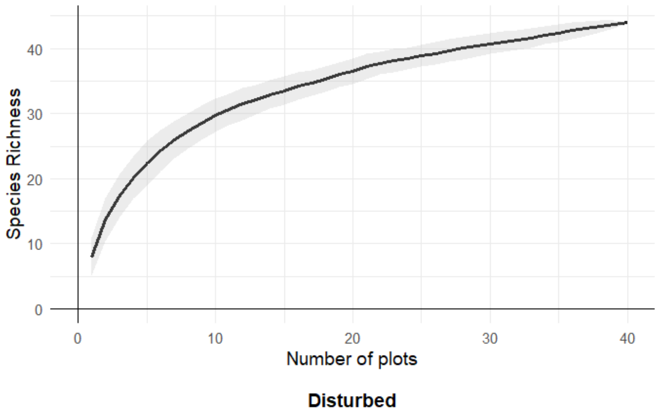
3. Results

3.1. Species Richness and Sampling Adequacy

A total of 50 sample plots measuring 0.1 ha were measured both in the disturbed (40 plots) and undisturbed (10 plots) areas of the forest reserve making total of 5 ha sampled area of the study. The sampling effort resulted into a total of 2,026 individuals ranging from 1 to 65 cm diameter at the breast height (DBH). The species accumulation curve for undisturbed stand (Figure 3a) significantly varied from the disturbed forest (Figure 3b).



a



b

Figure 3. *a. Species accumulation curve showing the relationship between the number of plots sampled and cumulative species richness in the undisturbed part; b. Species accumulation curve showing the relationship between the number of plots sampled and cumulative species richness in the disturbed parts.*

3.2. Woody Species Richness and Composition

A total of 2,026 individuals (with a maximum diameter of 65 cm and a minimum diameter of 1 cm) were recorded across the entire forest area of 49,147.7 ha within 50 plots. In the whole forest (50 plots), a total of 78 plant species which belongs to 56 genera and 21 plant families were identified, whereas in the undisturbed areas (10 plots) a total of 71 species which belongs to 51 genera and 20 plant families were identified and in the disturbed areas (40 plots) a total of 35 species which belongs to 35 genera and 15 plant families were identified. For the saplings with Dbh 1 cm to < 4 cm, in the whole forest (50 plots), a total of 44 plant species which belongs to 31 genera and 10 plant families were identified, whereas in the undisturbed areas (10 plots) a total of 29 species which belongs to 23 genera and 8 plant families were identified and in the disturbed areas (40 plots) a total of 28 species which belongs to 20 genera and 8 plant families were identified. In the whole forest, for the group of adult trees with Dbh ≥ 4 cm, trees consisted of 67.72%, whereas shrubs consisted of 32.28%. Families Fabaceae (42.51%) were dominant, followed by Combretaceae (29.01%) and Apocynaceae (7.13%). For regenerants (Dbh < 1 cm), trees consisted of 61%, whereas shrubs consisted of 39%. Family Combretaceae (36.93%) was dominant, followed by Fabaceae (34.85%) and Apocynaceae (8.71%). In the disturbed sites (n = 40 plots), trees consisted of 67.92%, whereas shrubs consisted of 32.08%. Family Fabaceae (37.9%) was dominant, followed by Combretaceae (35.19%). From the undisturbed sites (n = 10 plots), trees consisted of 67.21%, whereas shrubs consisted of 32.79%. Family Fabaceae (53.97%) was dominant, followed by Combretaceae 13.65%.

3.3. Species Diversity

In the whole forest (50 plots), the Shannon-wiener diversity index (H') for adults with Dbh ≥ 4 cm and for the saplings with Dbh 1 cm to < 4 cm were 3.72 and 3.01 respectively. In an undisturbed forest area (10 plots), the H' value for adults with Dbh ≥ 4 cm was higher with a value of H'= 3.68 in contrast with disturbed sites (40 plots) which showed lower H'value of 3.02. The results are different when it comes to saplings. The H' value was lower in an undisturbed forest area (H' = 2.82) than in the disturbed forest area (H' = 2.86). With regards to the Importance Value Index (IVI), across the whole forest (50 plots) *Combretum zeyheri* (25.29%) was the most dominant species, followed by *Senegalia mellifera* (23.83%), *Commiphora africana* (23%), and *Julbernardia globiflora* (14.44%) for adults with Dbh ≥ 4 cm. The results are different in the undisturbed area (n = 10 plots) in which *Julbernardia globiflora* (24.42%) was the most dominant species, followed by *Brachystegia boehmii* (20.80%), *Combretum zeyheri* (20.21%), and *Diplorhynchus condylocarpon* (15.82%), and in the disturbed area (n = 40 plots), *Senegalia mellifera* (33%) was the most dominant species, followed by *Commiphora africana* (31.15%), *Combretum zeyheri* (28.61%), *Terminalia sericea* (17.38%), *Pterocarpus angolensis* (17.07%), and *Bauhinia petersiana* (17.02%).

3.4. Forest Stocking and Stem Distribution

3.4.1. Stem Density

The results for the stems density in the undisturbed part was higher (868 ± 588 stem/ha) than in the disturbed part (117 ± 93 stem/ha) for adults with Dbh ≥ 4 cm. The value was also higher than the whole forest average of 267 ± 177 stem/ha. The results were different when it comes to saplings; stems density was higher in the disturbed areas (31,615 ± 16,986 stem/ha) than in the undisturbed areas (6,370 ±5,262 stem/ha) and the whole forest average (26,566 ±14,302 stem/ha). Species contributed the highest in terms of stem density (stems/ha) for adults with Dbh ≥ 4 cm in the undisturbed part were *Diplorhynchus condylocarpon* (96 ±80 stem/ha), *Combretum zeyheri* (84 ±40 stem/ha), and *Julbernardia globiflora* (68 ± 15 stem/ha), whereas in the disturbed part were *Senegalia mellifera* (13 ± 10 stem/ha), *Pterocarpus angolensis* (11 ± 10 stem/ha) and *Combretum molle* (10 ±10 stem/ha). The stem density distribution of standing trees in both disturbed and undisturbed parts followed an inverted J-shape, with the highest density in the 0–10.1 cm Dbh class and progressively lower densities in larger diameter classes (Figure 4).

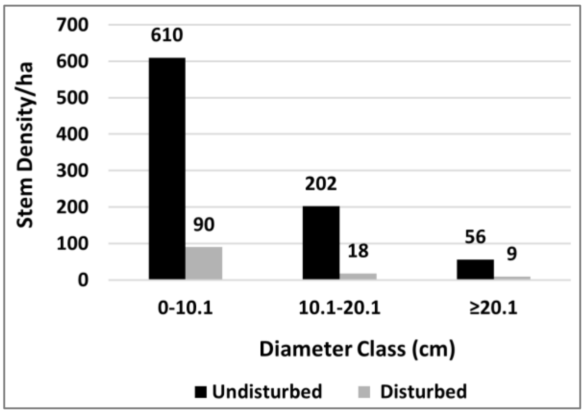


Figure 4. *Stem density distribution of standing trees across Dbh classes in disturbed and undisturbed parts of Mbiwe Forest Reserve in Tanzania.*

For stumps, the disturbed part also showed an inverted J-shaped pattern, while the undisturbed site showed a relatively uniform distribution of individuals across all Dbh classes (Figure 5).

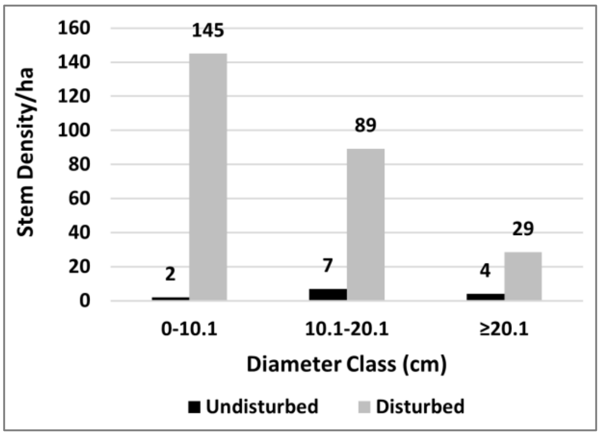


Figure 5. *Stem density distribution of stumps across Dbh classes in disturbed and undisturbed parts of Mbiwe Forest Reserve in Tanzania.*

3.4.2. Basal Area

The same trends of higher values in the undisturbed part were observed in the basal areas eastimes. The results indicate a value of 8.75 ±4.95 m2/ha higher than 1.27 ±0.91 m2/ha observed in the disturbed part for adults with Dbh ≥ 4 cm. The value was also higher than the whole forest average of 2.77 ± 1.65 m2/ha. For the saplings, undisturbed part had basal area of 1.92 ±1.35 m2/ha higher than that of disturbed part of 0.53 ± 0.35 m2/ha and the whole forest average of 0.81 ± 0.49 m2/ha. Species contributed the highest in terms of basal area/ha for adults with Dbh ≥ 4 cm in the undisturbed part were *Julbernardia globiflora* (0.94 ± 0.17 m2/ha), *Brachystegia boehmii* (0.93 ±0.38 m2/ha), and *Sterculia quinqueloba* (0.85 ±0.47 m2/ha), whereas in the disturbed part were

Terminalia sericea (0.27 ±0.14 m2/ha), *Combretum zeyheri* (0.20 ± 0.14 m2/ha), and *Sclerocarya birrea* (0.11 ± 0.09 m2/ha). The basal area distribution of standing trees in both disturbed and undisturbed parts followed a typical J-shaped pattern, with the lowest values in the smallest Dbh class (0–10.1 cm) and progressively increasing basal area in larger diameter classes (Figure 6).

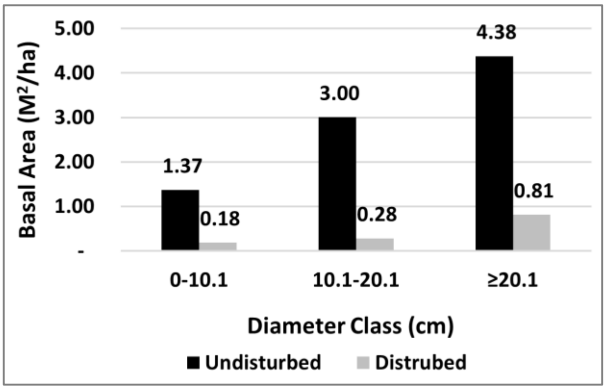


Figure 6. *Distribution of basal area across Dbh classes for standing trees in disturbed and undisturbed parts of Mbiwe forest reserve in Tanzania.*

For stumps, the disturbed part also exhibited a J-shaped distribution, while the undisturbed part showed lower and more evenly distributed basal area across all Dbh classes (Figure 7).

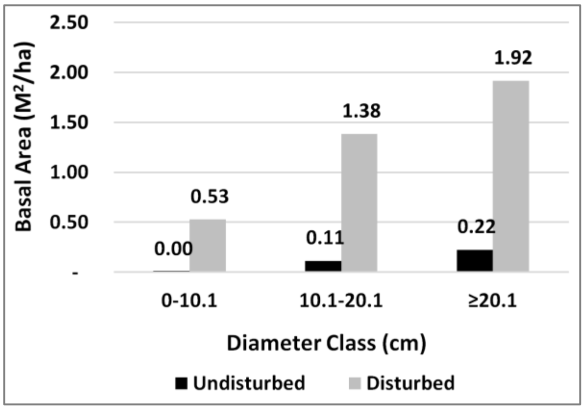


Figure 7. *Distribution of basal area across Dbh classes for stumps in disturbed and undisturbed parts of Mbiwe forest reserve in Tanzania.*

3.4.3. Volume

The results for mean volume of adult tree species (Dbh ≥ 4 cm) in the disturbed part was lower (12.05 ±9.09 m3/ha) than that which was found in the undisturbed part (73.61 ±44.68 m3/ha). Species contributed the highest in terms of volume/ha for adults with Dbh ≥ 4 cm in the disturbed part were *Terminalia sericea* (2.86 ±1.53 m3/ha), *Combretum zeyheri* (2.25 ± 1.71 m3/ha), and *Sclerocarya birrea* (1.66 ± 1.41 m3/ha), whereas in the undisturbed part were *Sterculia quinqueloba* (11.57 ± 6.64 m3/ha), *Brachystegia boehmii* (8.8 ± 4.26 m3/ha), *Julbernardia globiflora* (6.37 ±1.19 m3/ha), and *Brachystegia bussei* (5.25 ±1.87 m3/ha). The volume distribution of standing trees in both disturbed and undisturbed parts showed a typical J-shaped pattern, with the lowest volumes in the 0 –10.1 cm Dbh class and progressively increasing values in larger diameter classes (Figure 8).

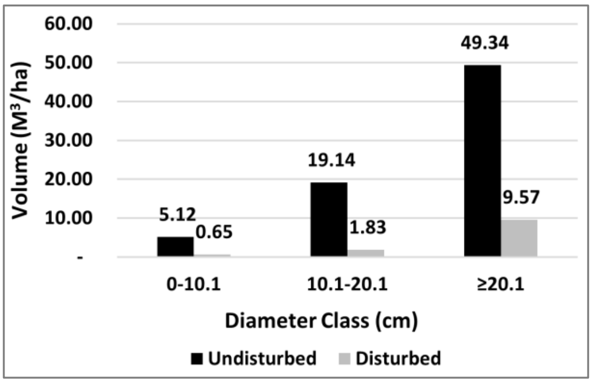


Figure 8. *Distribution of tree volume across Dbh classes for standing trees in disturbed and undisturbed parts of Mbiwe forest reserve in Tanzania.*

For stumps, the disturbed part followed a J-shaped trend, while the undisturbed part exhibited consistently lower and more evenly distributed volumes across all Dbh classes (Figure 9).

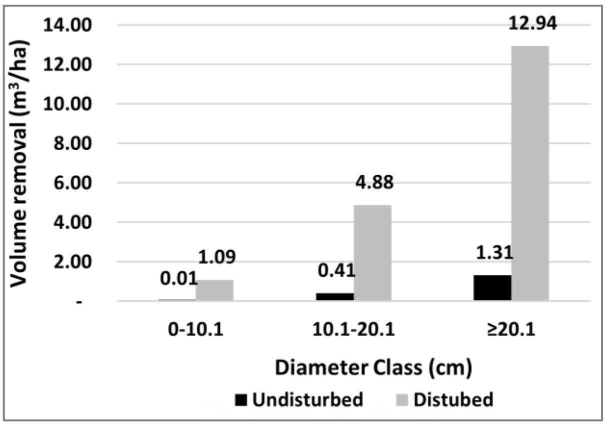


Figure 9. *Distribution of tree volume removal across Dbh classes for stumps in disturbed and undisturbed parts of Mbiwe forest reserve in Tanzania.*

3.5. Stumps

The summary results for parameters assessed for stumps are presented in Table 1. The most harvested species according to

IVI in the whole forest were *Combretum zeyheri* (45.5%), *Terminalia sericea* (28.2%), *Pterocarpus angolensis* (27.5%) and *Julbernardia globiflora* (26.1%), whereas in the disturbed area were *Combretum zeyheri* (49%), *Terminalia sericea* (29.2%), *Pterocarpus angolensis* (25.4%) and *Julbernardia globiflora* (22.5%), and in the undisturbed area were *Brachystegia bussei* (78.5%), *Julbernardia globiflora* (65.8%), *Pterocarpus angolensis* (50.8%) and *Burkea africana* (25.3%). Species that contributed the most to stump volume removal (m^3/ha) in the whole forest were *Pterocarpus angolensis* (3.7 ± 1.3), *Terminalia sericea* (2.22 ± 0.93), *Combretum zeyheri* (1.8 ± 0.45), whereas in the disturbed area were *Pterocarpus angolensis* (4.55 ± 1.6), *Terminalia sericea* (2.77 ± 1.15), and *Combretum zeyheri* (2.24 ± 0.54), and in the undisturbed area were *Burkea africana* (0.59 ± 0.59), *Pericopsis angolensis* (0.37 ± 0.37), *Pterocarpus angolensis* (0.31 ± 0.21), and *Julbernardia globiflora* (0.25 ± 0.18).

Table 1. *Summary statistics of parameters for stumps assessed in Mbiwe Forest Reserve, Tanzania.*

Parameters assessed	**Whole forest (n = 50 plots)**	**Disturbed areas (n = 40 plots)**	**Undisturbed areas (n = 10 plots)**
Diameter range (cm)	2 - 62.5	2 - 62.5	4 - 33.5
Species richness	40	39	8
Genera	8	8	8
Plant families	26	25	3
Shannon-Wiener diversity Index (H’)	2.87	2.87	1.93
Stem density (stems/ha)	213 ± 73	263 ± 88	13 ± 10
Basal area (m^2/ha)	3.13 ± 1.27	3.83 ± 1.54	0.19 ± 0.09
Total volume of stumps removed (m^3/ha)	15.47 ± 7.29	18.9 ± 8.87	1.73 ± 1.53

4. Discussion

4.1. Species Accumulation Curve and Sampling Adequacy

There was an evident difference in the Species Accumulation Curve (SAC) between the disturbed and undisturbed forest stand. The disturbed forest stand had relatively low species richness compared to the undisturbed stand. Sampling efforts for the disturbed stand reached near-asymptote curve at the 20th plot. Conversely, sampling efforts for undisturbed stand were relatively inadequate. More efforts could yield more unique species. The comparison between disturbed and undisturbed sites reveals distinct differences in woody species composition and dominance across adult individuals. Undisturbed sites demonstrated higher species of 71 woody species diversity reflecting relatively stable ecological conditions typical of less impacted Miombo woodlands [25]. In contrast, disturbed areas showed reduced diversity of 35 woody species and a shift in floristic composition. These shifts are often associated with anthropogenic pressures such as wood harvesting, repeated burning, cultivation, and artisanal mining, which selectively remove adult individuals and alter the regenerative capacity of native species as studied by [26] as well [27]. According to [6] human activities significantly affect the diversity and species composition of the disturbed miombo woodlands.

4.2. Woody Species Richness and Composition

The findings of this study demonstrate that the composition of woody vegetation in Mbiwe Forest Reserve (MFR), particularly the dominance of species from the family Fabaceae, corresponds well with earlier classifications of plant communities from dry Miombo woodland [27]. Nonetheless, the leading species based on the Importance Value Index (IVI), especially those from the genera Combretum, Senegalia, and Commiphora, differ from the species composition that is usually considered common for Miombo woodlands. Similar deviations exist as reported by [28] from dry Miombo woodlands of Gangalamtumba Village Land Forest Reserve located in Iringa Region. [28] reported a dominance of Dalbergia, Commiphora, and Combretum deviating from the conventional dominance by Brachystegia and Julbernardia as highlighted in studies by [29] and [30]. Notably, Combretum was also documented in their research areas, though often not as the primary genera. These results support the view that species composition within Miombo woodlands is highly variable, and that across broader spatial scales, diversity is high while the dominance of the characteristic Miombo genera Brachystegia, Julbernardia, and Isoberlinia may not consistently dominant at the local scale.

The species richness of 78 species reported in this study using 50 plots of 0.1 ha of individuals with Dbh ≥ 4 cm is higher than the species richness reported in other dry Miombo woodlands elsewhere. For instance, [31] reported a species richness of 71 species from SUA Kitulanghalo Training Forest using 52 plots of 0.71 ha, [32] reported a richness of 51 species using 40 plots of 0.1 ha from Angola. However, the species richness enumerated in this a study is lower than that reported by [28] who reported a richness of 88 species using 35 plots of 0.071 ha from Gangalamtumba Village Land Forest Reserve (GVLFR), [6] who reported a total of 80 species using 30 plots of 0.071 ha from Kitulanghalo Catchment forest reserve, [27] reported a richness of 95 species using 120 plots of 0.071 ha from dry Miombo woodland of Chenene forest reserve in Tanzania, [29] reported a total of 110 species using 80 plots of 0.071 ha from dry Miombo woodland of Bereku forest reserve in Tanzania. Additionally, the richness value of 78 species found in this woodland was much lower than that reported by [33] who reported a total of 122 species from Kipembawe division, [34] reported a total of 124 species from Mlele Beekeeping Zone and [35] reported much higher richness of 229 species using 133 plots of 0.071 ha from Katavi-Rukwa Ecosystem in Tanzania.

The higher number of the species reported in this study of 78 species align in range of 51-229 species which are commonly found in dry Miombo woodland [32, 35]. The higher number reported in this study might be due to climatic condition, presence of streams that contributes to the growth of many species and low level of disturbance in undisturbed area of the reserve. This underscores the need to strengthen forest conservation initiatives, given the high species abundance observed in the area. Other studies have higher species richness values due to more extensive sampling, covering larger areas, using more sample plots of varying sizes and low level of human disturbance in their study sites compared to this study. For example, the relatively high species richness reported by [35] may be largely influenced by the selective sampling approach they adopted, which targeted a variety of microhabitat types, thereby increasing the likelihood of encountering more woody species. Similarly, the higher species richness observed by [29] was likely due to the presence of riverine forest which offers favorable microclimatic and edaphic conditions that support a wide range of species. In the case of Gangalamtumba Village Land Forest Reserve (GVLFR), the higher number of species richness was due to the regulated harvesting practices, which maintained woody biomass extraction below the annually allowable cut and due to high soil fertility, which promotes species establishment and growth [28].

The comparison between disturbed and undisturbed sites in Mbiwe Forest Reserve reveals distinct differences in woody species composition and dominance across adult individuals. Undisturbed sites demonstrated higher species of 71 woody species diversity reflecting relatively stable ecological conditions typical of less impacted Miombo woodlands [25]. In contrast, disturbed areas showed reduced diversity of 35 woody species and a shift in floristic composition. These shifts are often associated with anthropogenic pressures such as wood harvesting, repeated burning, cultivation, and artisanal mining, which selectively remove adult individuals and alter the regenerative capacity of native species as studied by [26] as well [27]. According to [6] human activities significantly affect how Miombo Woodlands function.

4.3. Species Diversity and Distribution

The Shannon- wiener diversity index of (H’) 3.72 reported in this study is higher than that reported from other dry Miombo woodlands. For instance, [28] reported a H’ value of 3.44 from GVLFR, [32] reported four H’ values with an average of 2.76 from Angola, and [36] reported H’ value of 3.12 from Zimbabwe. However, the H’ Value reported in this study is lower than that reported from other dry Miombo woodlands, for example [29] reported a H’ value of 4.27 from Bereku Forest Reserve, [27] reported a H’ value of 4.17 from Chenene Forest Reserve, Additionally the H’ value of this study (3.72) was relatively lower to that documented by [6] who reported a H value of 3.75 from dry Miombo woodland of KCFR.

Diversity values, represented by the H’ value, typically fall between 1.5 and 4.5 but do not surpass 5 [37]. According to [38] and [28] an ecosystem can be categorized as moderately to highly diverse if its value is at least 2. Consequently, there is still a high species diversity in the ongoing human activities in MFR. This suggests that the MFR's ecosystem is strong and healthy, which is essential for preserving ecological resilience and balance. To maintain this degree of diversity for upcoming generations, conservation initiatives ought to be given top priority. When the data are disaggregated by disturbance level, a clear trend emerges. In an undisturbed forest area, the Shannon-Wiener diversity index was higher with a value of $H' = 3.68$ in contrast with disturbed sites showed lower diversity index of $H' = 3.02$ similarly, the study by [29] as well [27] observed that anthropogenic activities reduce species diversity in Miombo ecosystems. These results reinforce the notion that human disturbances reduce species diversity and regeneration potential, particularly among smaller size classes, which represent future forest structure [39]. The consistently higher values in undisturbed plots underscore the importance of forest protection in conserving woody species diversity in Miombo woodlands.

Based on the Importance Value Index (IVI), *Combretum zeyheri* and *Terminalia sericea* were the most important species among harvested (stumps) in the disturbed areas (Table 1). This result agreed well with the large values of stump in terms of stem density, basal area and volume. Local scouts and few members of the village environmental committee reported that *Combretum zeyheri* and *Terminalia sericea* are frequently used in construction at the mining camps, while *Pterocarpus angolensis* is harvested mostly for timber. Additionally, Brachystegia bussei and *Julbernardia globiflora* are commonly used for charcoal making and for "Matimba" is also mentioned as essential for supporting and maintaining the wall of mining holes to prevent them from collapsing. In contrast, the undisturbed areas were dominated by *Brachystegia bussei* and *Julbernardia globiflora*, with significantly lower volume removal. These species are less frequently harvested, contributing to the stability and natural regeneration in the undisturbed area. The difference in volume removal between the disturbed and undisturbed areas highlights the greater anthropogenic impact in the disturbed sites, influencing species composition and forest structure.

4.4. Forest Stocking and Stem Distribution

4.4.1. Stem Density

The total mean stem density of 267 ± 177 stems/ha for the standing of large individuals (Dbh ≥4 cm) reported in this study is lower than the mean density for standing individuals reported by [31] who reported 995 ± 256 stems/ha from SUA-KCTF, [29] who reported 616 ± 46 stems/ha from dry Miombo woodland of Bereku forest reserve in Tanzania, [28] reported 1521 ± 594 stems/ha from dry Miombo woodland of Gangalamtumba VLFR in Iringa, Tanzania and [6] reported a mean stem density of 2,199 ± 1325 stems/ha from dry Miombo woodland of TFS-Kitulanghalo Catchment Forest Reserve, Morogoro, Tanzania. However, the mean stem density of 267 ±177 stems/ha reported in this study is relatively lower compared to mean stem density reported by [40] who reported a mean stem density of 276 stems/ha from Kilengwe Forest Reserve in Morogoro, Tanzania. The higher stem densities reported in other studies may be attributed to more favorable microclimatic conditions that support increased species growth, low level of disturbance and sampling size to capture large number of stems.

The mean stem density value in this study is outside the range typically found in other dry Miombo woodlands of 276 - 2199 stems/ha [6, 28, 29, 40]. The low stem density value in this study may be due to results of human activities such as agriculture, mining, charcoal production, wildfire and illegal logging. These activities decrease the number of trees/shrubs that could be available for measurement during data collection. This scenario was observed in disturbed and undisturbed areas whereby, in disturbed areas the mean stem density for adult trees was 117 ± 93 stems/ha which is significantly lower than the 868 ± 588 stems/ha found in undisturbed area. This demonstrates how human activities as mentioned above impacted the stem density of MFR similarly, as studied by [27].

Regardless, the ongoing human disturbances in MFR, the mean stem density of 26,566 ± 14,302 stems/ha for regenerants was obtained. This regeneration potential was higher when compared with that reported by [6] who reported 5358 ± 4319 stem/ha from dry Miombo woodland of KCFR, [31] reported 6121 ± 2777 stem/ha from dry Miombo woodland of SUA-KCTF, [29] from Bereku Forest Reserve reported 2,780 ± 20 stem/ha for regenerants. The higher number of regenerants in MFR may indicate a strong capacity for resprouting, a well-known trait of Miombo woody species following disturbances. According to, [41] the promotion of regeneration depends on the degree of protection of the Miombo stands against anthropogenic activities.

The diameter distribution of standing trees and stumps in both disturbed and undisturbed parts of MFR exhibits a clear trend of decreasing stem density with increasing diameter, forming an inverted "J" shape (Figures 4 and 5). This pattern is typical of natural forests with active regeneration and recruitment [28]. In the undisturbed area, a high density of small-diameter standing trees indicates healthy regeneration. In contrast, the disturbed area shows significantly fewer standing trees across all diameter classes, particularly in the large size classes. A notable number of large stumps were recorded in the disturbed parts compared to the undisturbed part, suggesting heavy exploitation through anthropogenic activities such as charcoal production. The removal of mature trees, coupled with frequent fires especially late season fires that kill seedlings limits the progression of young trees into larger diameter classes. Consequently, the scarcity of seed-bearing trees in disturbed areas may impair natural regeneration and pose a threat to the woodland's long-term biodiversity and structural integrity.

4.4.2. Basal Area Dominance and Distribution

The lower basal area in this study may be due to a result of the reduced stem density caused by ongoing human activities such as illegal timber harvesting, charcoal production, and land clearing for cultivation in the reserve that led to reduced number of mature stands that might contribute much on basal area. Other factors, including plot sizes, sampling methods, geographical variations, study area characteristics, and temporal changes, may had influenced the variation in results [28, 40]. Higher basal areas in other studies may be linked to a greater stem density of individuals with higher Dbh classes compared to this woodland. However, the mean basal area in this study is outside the commonly reported range of 7.61–13.55 m^2/ha in dry Miombo woodlands [6, 28, 31]. The aforementioned human activities have a significant impact on the basal area of the woodland as found based on the disturbed levels. The undisturbed site had a basal area of 8.75 ± 4.95 m^2/ha, while the disturbed sites had a basal area of 1.27 ± 0.91 m^2/ha. The difference in basal area between disturbed and undisturbed areas illustrates the influence of human activities on forest ecosystems. The reduction in basal area in disturbed areas demonstrates the need for conservation efforts to maintain the health and biodiversity of woodlands.

4.4.3. Volume

The mean total volume of 24.36 ±15.85 m^3/ha, for trees with Dbh ≥4 cm reported in this study area was lower than mean volume documented in other dry Miombo woodlands. For instance, [28] reported a mean volume of 92.17 ±39.0 m^3/ha, [31] from SUA-KCTF reported a mean volume of 54.73 ±11.3 m^3/ha, [6] reported a mean volume of 56.25 ±35.03 m^3/ha, [42] reported four values of mean volume of 36.85 m^3/ha, 110.56 m^3/ha, 41.42 m^3/ha and 58.63 m^3/ha from different study sites in Iringa, Tanzania. The lower volume estimated in this study can be due to the low number of stem density and high level of human activities which lead to the removal of the trees with the higher Dbh which could contribute much on standing volume in the reserve. The standing volume for the disturbed sites was 12.05 ±9.09 m^3/ha and that of the undisturbed site was 73.61 ±44.68 m^3/ha. The difference in stand volume between disturbed and undisturbed sites reflect the significant impact of the observed human activities on the total stand volume of the MFR as studied by [27] in Chenene Forest Reserve.

Regardless the high diversity of species and low stem density of MFR, study also revealed that there were 40 species of stump with equivalent to Shannon Wiener diversity index of 2.87, Stem density of 213 ±73 stems/ha, Basal area of 3.13 ± 1.27 m^2/ha and Removal volume of 15.47 ±7.29 m^3/ha. The removal volume of 15.47 ±7.29 m^3/ha reported in this study was higher than that reported in other dry Miombo woodlands. For instance, [6] reported a removal volume of 5.94 ±4.47 m^3/ha also [31] reported removal volume of 0.58 m^3/ha. The high removal volume in this study was due to the results of different anthropogenic activities like agriculture, mining, charcoal making and illegal logging of valuable tree species which were recorded during data collection. Other disturbances recorded were grazing, settlements and mining camps. Different studies in Miombo woodlands [6, 27, 29] reported that the mentioned disturbances had the effects on species composition, diversity and forest structure.

5. Conclusion and Recommendations

5.1. Conclusion

This study reveals anthropogenic activities such as illegal logging, mining, and agricultural activities have significantly degraded the woody species composition, diversity, and structure of Mbiwe Forest Reserve. Undisturbed areas exhibited higher species richness, stem density, basal area, and volume, while disturbed sites were dominated by disturbance tolerant species and showed signs of overexploitation. The spatial variability in vegetation structure reflects differing disturbance intensities across the landscape.

5.2. Recommendations

To reverse these effects, we recommend enforcing laws against illegal logging, regulating artisanal and licensed mining activities through strict environmental monitoring, and restoring degraded areas through enrichment planting with native species. Particular attention is needed in heavily affected area near to Infwenkenya Ward, where human settlement and cultivation pressure are greatest. Lawful eviction from encroached areas and reforestation are essential to ensure long-term conservation, promote natural regeneration, and sustain ecosystem services in the reserve.

Abbreviations

DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization of United Nations
H’	Shannon-Wiener Diversity Index
IVI	Importance Value Index
MFR	Mbiwe Forest Reserve
MNRT	Ministry of Natural Resources and Tourism
TFS	Tanzania Forest Services Agency
TAFORI	Tanzania Forest Research Institute
SUA	Sokoine University of Agriculture
URT	United Republic of Tanzania
UTM	Universal Transverse Mercator

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Conflicts of Interest

The authors declare no conflicts of interest.

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