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Structure and Composition of a Selectively Logged Miombo Woodland in Central Mozambique

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Abstract: This study assessed the structure and composition of a Miombo woodland stand subjected to selective logging through a forest inventory, measuring all trees with DBH $\geq$ 10 cm across 34 plots (1 ha each) for diameter, height, stem quality, and health status. The stand had a mean stem density of 255 stems/ha, basal area of 15 m^2/ha, above ground biomass of 110 Mg/ha, and total volume of 145 m^3/ha. The *Fabaceae* family, particularly *Brachystegia spiciformis*, dominated the composition. Diversity indices revealed moderate diversity (Shannon = 2.3, Simpson = 0.8, Pielou = 0.6), with a few dominant species. The diameter distribution followed a reverse J-shaped pattern typical of Miombo woodlands. The study (LevasFlor. (2024). *Plano De Maneio Da LevasFlor, LDA*) highlighted common features of selectively logged woodlands, including a low occurrence of large-diameter individuals from high-value commercial species, prevalence of disturbance-tolerant species, and limited regeneration for some species. These findings underscore the need for management strategies that balance ecological and socio-economic factors, mitigate logging impacts, promote regeneration, and ensure long-term sustainability. Effective policies are crucial for maintaining the ecological integrity and economic value of Miombo woodlands while addressing climate resilience and biodiversity conservation.

Keywords: *selective logging*; woodland structure; species composition

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1. Introduction

Mozambique has four forest types, namely mopane, mecrusse, semi-deciduous, and semi-evergreen forests [1]. Among these, the predominant forest type in the country is the semi-deciduous forest, which includes Miombo woodlands (MW's), that covers two-thirds of the country's forested area [1]. These woodlands provide a wide range of socio-economic benefits, on which communities living in their vicinity are highly dependent [2–4]. Additionally, these woodlands provide ecosystem services including mitigating the effects of climate change [2,5].

The structure and composition of these woodlands are influenced by rainfall gradient [6], species tolerance to shade and fire [7–9], edaphic factors, herbivory, successional stage, as well as past and current land use and management practices [10–12]. The rainfall gradient divides MWs into dry and wet Miombo [6]. According to [7–9], usually, pioneer species are highly intolerant to shade but highly tolerant to fire, while climax species show high shade tolerance and low fire tolerance. Thus, after a disturbance, MWs undergo an ecological succession process, in which pioneer species that are light-demanding and fire-tolerant are gradually replaced by shade-tolerant species that are more susceptible to fire, indicating a dynamic process where each stage facilitates the next [8,9]. However, climax MWs also include species that are tolerant to both shade and fire [7–9]. Within this successional process, the typical and dominant Miombo species are primarily from the genera Brachystegia, Julbernardia, and Isoberlinia [6,13], which are characteristic of intermediate successional stages [7–9]. These species are moderately sensitive to fire and require some degree of shading to establish [7–9]. However, within a single stand, there is a significant overlap in the presence of these species groups [8,14], and as noted by [15], the distinctiveness of this grouping may be debatable.

Additionally, the structure and composition of MWs can be affected and altered by the wood extraction to which they are subjected, mainly through commercial logging, charcoal production, and fuelwood collection [3,16,17]. The following methods support these extractions, namely complete coppice, clear-cutting, coppice with standards, and selective logging [18]. Among these wood exploitation methods, selective logging is the most prominent in Mozambique [19], as well as at global level [20–22]. This predominance of selective logging stems from the belief that this practice promotes the maintenance of woodland structure and canopy cover by minimizing disturbance, and is therefore widely regarded as a good forestry practice for preserving biodiversity and sustainability [20,22].

However, selective logging by targeting a few of the largest trees of high-value commercial timber species [23–25] can change the structure, composition, and value of these woodlands [26–28], unless practiced at very low harvest intensities [21,29,30]. Additionally, this practice has the disadvantage of favoring the regeneration of shade-tolerant species at the expense of light-demanding species, which are generally the most valuable species in Miombo woodlands [24,25]. This is because the canopy gaps caused by the fall of individual trees due to selective logging are not large enough to promote the regeneration and vigorous growth of light-demanding species [5,31,32]. The selective logging also lacks interventions that promote adequate regeneration, growth, or quality of future trees within MWs [2,3]. This factor, combined with the promotion or inhibition of grass growth, due to its influence on the frequency and intensity of fire, can also affect species composition based on the fire tolerance of these species [7,8,32]. Hence, this practice has been shown to alter structure, composition, and commercial value of these woodlands [26–28], especially through reduction of stem density, basal area, total and merchantable wood volume, and stand biomass [21,30], leading to its degradation or even deforestation [29].

Looking at the dynamics of MWs, it is evident that a study promoting an effective description and understanding of the stand's structure and composition is crucial for evaluating the economic, ecological, and climatic value of the stand [33]. This can provide guidance on the availability of resources, as well as the impacts and benefits resulting from different levels and combinations of their exploitation. This information can guide management strategies, optimizing the exploitation, conservation or even the restoration of these woodlands [34–41]. Finally, this description can also work as a baseline study [38].

The parameters of structure and composition are therefore useful tools for the qualitative and quantitative description and monitoring of the resources of a stand [40–42]. Furthermore, characterizing these stands based on the percentage of wood from different categories (e.g., commercial species, commercial species with marketable diameters, high-value species, rare species) can provide valuable insights into the current and future merchantable value of the forest [43–45]. It can also shed light on the potential effects of interventions, such as timber exploitation, on woodland resilience, species reduction, biomass extraction, and consequently on carbon sequestration, storage and removal [43–46]. Thus, this study aimed to describe the structure and composition parameters of a Miombo woodland under selective logging based on the following trees categories: all species combined, each high-value species, the most abundant species in the stand, and the most abundant non-commercial species. The structural description was based on the mean per hectare of stem density, basal area, total volume, stem volume, and above ground biomass, while the composition description included the Shannon index, Simpson index, and Pielou index.

The findings will improve our understanding of the structure, composition, and various values of this woodland, as well as how logging can affect these parameters in this and other woodlands. This knowledge will support adaptive forest management by optimizing harvesting intensities to create suitable gap sizes for seedling establishment and developing fire management strategies to maintain stand integrity.

2. Materials and Methods

2.1. Study Area

The study was conducted in the woodland concession of LevasFlor, Lda, located in Sofala Province, central Mozambique (Figure 1). The region has a tropical savanna climate with an annual rainfall of 1000–1200 mm, primarily occurring between November and March. The mean annual temperature ranges from 24 to 26 °C [47,48]. The terrain is predominantly flat, with elevations between 0 and 200 m.a.s.l. Soils are sandy, well drained, and characterized by low nutrient content and water retention capacity. The vegetation consists mainly of semi-deciduous Miombo woodlands [47,48].

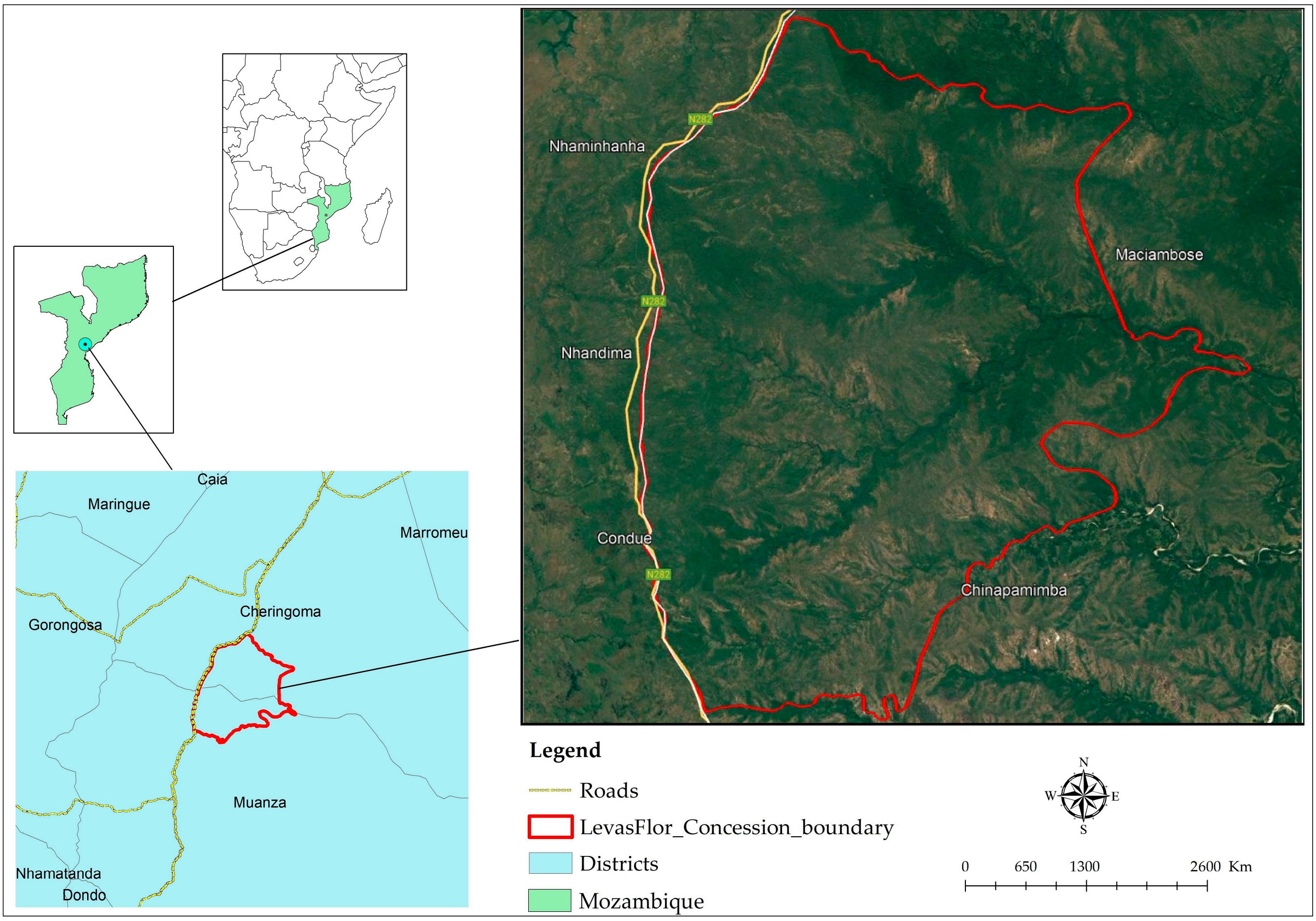

Figure 1. Map of Mozambique and the forestry concession.

Since its establishment in 2005, the LevasFlor woodland concession in Sofala Province has covered 46,239 ha, subdivided into 20 annual cutting blocks. Logging is carried out through selective harvesting, regulated by species-specific minimum cutting diameters and an annual allowable cut (AAC). The AAC is determined based on the individual volume of 80% of the trees with commercial quality for each species, ensuring that 20% of the trees of each exploited species with acceptable commercial quality remain in the stand. The harvesting of 80% of the trees with commercial quality equates to an average of two trees per hectare (LevasFlor, 2024).

The company's primary silvicultural practices in the concession include reforestation, natural regeneration management, and fire protection [47–49]. Regeneration management focuses on species with strong resprouting ability, such as *Pterocarpus angolensis* and *Millettia stuhlmannii* [49]. In areas with high regeneration density, stem density is reduced to approximately 10,000 stems per hectare, maintaining a spacing of 2–2.5 m. Thinning is conducted based on sapling quality and overall health [49]. Advanced regeneration (DBH $\geq$ 10 cm) is selectively removed considering species, form, vigor, ecological significance, rarity, and economic value, while maintaining a minimum spacing of 5 m between retained trees [49].

2.2. Methods

2.2.1. Data Collection

The data for this study were obtained from an inventory conducted in 34 permanent plots established between March and June 2022. Each plot measured 100 $\times$ 100 m and was oriented in a north–south direction. The plots were georeferenced by recording the coordinates of their vertices using a GPS Garmin Etrex 32x (Garmin Ltd., Olathe, KS, USA). During the inventory, all trees, standing snags, lianas, and palms with a DBH $\geq$ 10 cm were identified and tagged. For each marked tree, DBH, total height, and commercial height (measured up to the first major branch or defect affecting timber value) were recorded. The height was measured using a Nikon Hypsometer (Nikon Corporation, Tokyo, Japan). Additionally, growth form (trees, standing snags, lianas, and palms), stem quality, and health status were documented. Species identification, including local and scientific names, was conducted by specialized concession personnel. For species not identifiable in the field, voucher specimens were collected, pressed, and sent to the Herbarium of Eduardo Mondlane University in Maputo for identification. The identification at the herbarium was carried out using taxonomic keys.

During the inventory, trees were categorized into three main groups: (1) living or dead individuals, (2) commercial or non-commercial species, and (3) trees with merchantable or non-merchantable wood. The commercial/non-commercial classification followed the Mozambican law on tree harvesting, which defines species into sub-groups: precious, first-, second-, third-, and fourth-class species. In this study, these groups were reclassified as (i) high-value commercial trees (precious and first-class), (ii) normal commercial trees (second-, third-, and fourth-class species), and (iii) non-commercial trees species. Additionally, trees were classified by stem quality and health status into the following categories: excellent stem, good stem, usable stem, usable stem but a threat, not usable stem, fallen but still alive, and dead. This visual classification was based on parameters such as straightness, tapering, trunk defects (e.g., injuries, diseases, rot), and the number and height of the first branches. An "excellent stem" was straight, with minimal tapering, had no trunk defects, thin branches, and a healthy appearance. A "good stem" was straight, with minor tapering, had no significant trunk defects, moderately thick branches, and a healthy condition. A "usable stem" had at least one characteristic preventing it from being classified as good, but could still be used for timber. The "usable stem but a threat" category included trees with visible pathogens or conditions that posed risks to other trees in the stand. “Not usable stem” trees could not be processed for timber. “Fallen but still alive” included trees that had fallen but remained alive, while “dead trees” were those that had died.

2.2.2. Data Analysis

The data from forest inventories were analyzed on a per-hectare basis. The initial analysis categorized all inventoried trees by their status (alive or dead), health condition, and stem quality. This was the only evaluation conducted for all inventoried trees. Subsequent analyses focused on trees with a minimum DBH of 10 cm and classified as alive. Living trees were further categorized into five groups: all living trees, commercial species, non-commercial species, merchantable trees, and high-value species. For structural characterization, the mean values of structural parameters were calculated, while compositional indices were used for describing species composition. The inclusion of trees with a minimum DBH of 10 cm is based on the assumption that this size class adequately represents the woodland’s floristic composition and physical structure [50]. In cases where the most abundant species in each category significantly influenced the structural parameter under analysis, particularly the diameter distribution, it was excluded and analyzed separately. The stand parameters assessed in this study included *stem density* (number of stems or plants per unit area), frequency (proportion of samples where a species occurs), *volume*, *basal area*, and *biomass* [51]. Total *tree volume* and *stem volume* were calculated using Equation (1) and Equation (2), respectively [52].

$$V_{total} = \frac{\pi * DBH^2}{4} * Ht * 0.65 \quad (1)$$

$$V_{stem} = \frac{\pi * DBH^2}{4} * Hc * 0.80 \quad (2)$$

where

V_{total} is total volume (m^3), V_{stem} is stem volume (m^3), DBH is diameter at breast height (m), Ht is total height (m), Hc is commercial height (m).

The above ground biomass (AGB) of each tree was calculated using Equation (3) [53]

$$AGB = 0.1754 * DBH^{2.3238} \quad (3)$$

The computed stand parameters were then distributed by species across eight DBH classes: $10 \leq$ DBH < 20, $20 \leq$ DBH < 30, $30 \leq$ DBH < 40, $40 \leq$ DBH < 50, $50 \leq$ DBH < 60, $60 \leq$ DBH < 70, $70 \leq$ DBH < 80, and DBH ≥ 80 cm.

The species composition and diversity were determined using the Shannon Diversity Index, Simpson’s Diversity Index, Pielou’s equitability index and Importance value index. The Shannon Diversity Index (H) was calculated using Equations (4) and (5) [54].

$$H = -\sum_{i=1}^{s} *(p_i * ln(p_i)) \ \ldots \quad (4)$$

$$p_i = \frac{n_i}{N} \quad (5)$$

where

n_i is the number of individuals of species i;

N is the total number of individuals of all species.

The *Simpson's Diversity Index (q)* was computed using Equation (6) [55,56].

$$q = \sum_{i=1}^{s} * \left(\frac{n_i - 1}{N - 1}\right)^2 \approx \left(\frac{n_i}{N}\right)^2 \quad (6)$$

where

n_i is the number of individuals in the ith species;

N equals the total number of individuals.

The *Pielou's equitability index* was calculated using Equation (7) [57]

$$E = \frac{H}{lnS} \quad (7)$$

where

E is the *Pielou's* equitability index;

H is *Shannon index;*

S is the *total number of species* in all stands.

The *importance value index* was determined using Equation (8) [58]

$$IVI_i = 100 * \left(\frac{n_i}{N} + \frac{d_i}{D} + \frac{x_i}{X}\right) \quad (8)$$

where

IVI_i is *Importance value index*;

n_i is the number of sampling units where the ith species is present (species frequency);

N is total number of sampling units;

d_i is the number of individuals of the Ith species present in the sample population;

D is total number of individuals in the sample population (D = Σdi);

x_i is the sum of the size parameter (generally *basal area* or volume) for the ith species;

X is the total of the size parameter across all species (X = Σxj).

3. Results

3.1. Stand Structure

3.1.1. Stand Structure by Stem Quality and Health Status

Across all 34 plots, we measured a total of 9300 trees, of which 8635 were live standing, 640 were dead standing, and 25 were still alive but fallen trees. In terms of stem quality and health status, 90% of the inventoried individuals exhibited an excellent commercial stem quality for timber processing, while 1% of the individuals were classified as good (Figure 2). Stem quality unsuitable for processing also constituted approximately 1% of the individuals. In terms of volume, excellent stems accounted for 91%, the good stems formed 1%, the dead and unusable trees accounted for approximately 7% of the total wood volume. On average, we found 19 dead trees per ha, totaling to a wood volume of 9 m^3/ha. Out of a total of 58 species, 42 (74%) had dead individuals while 15 species (26%) did not have any dead individual recorded. *Brachystegia spiciformis* alone accounted for 37% of the dead individuals, followed by *Millettia stuhlmannii* 10% and *Combretum zeyheri* 8%.

Of the total dead trees, approximately 50% occurred at the regeneration level (DBH 10 to 20 cm class) while 74% were within the DBH range of 10 to 30 cm (Figure 3). Only one plot recorded no dead individuals in the 10–20 cm DBH class, while two plots had no dead individuals in the 20–30 cm DBH class. Conversely, dead individuals in the DBH 70–80 cm and >80 cm were found in only one plot each. Additionally, in the 60–70 cm DBH class, dead individuals were recorded in only six plots. These findings highlight the uneven distribution of mortality across diameter classes, suggesting potential size-dependent mortality patterns within the stand.

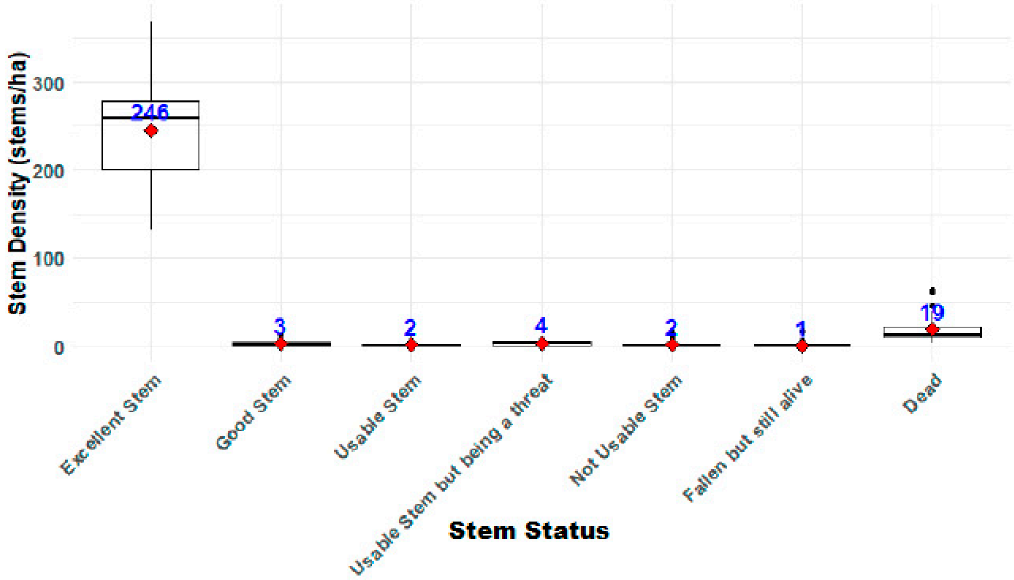

Figure 2. Average of stem density by stem quality and health across 34 plots. Numbers in blue are the averages.

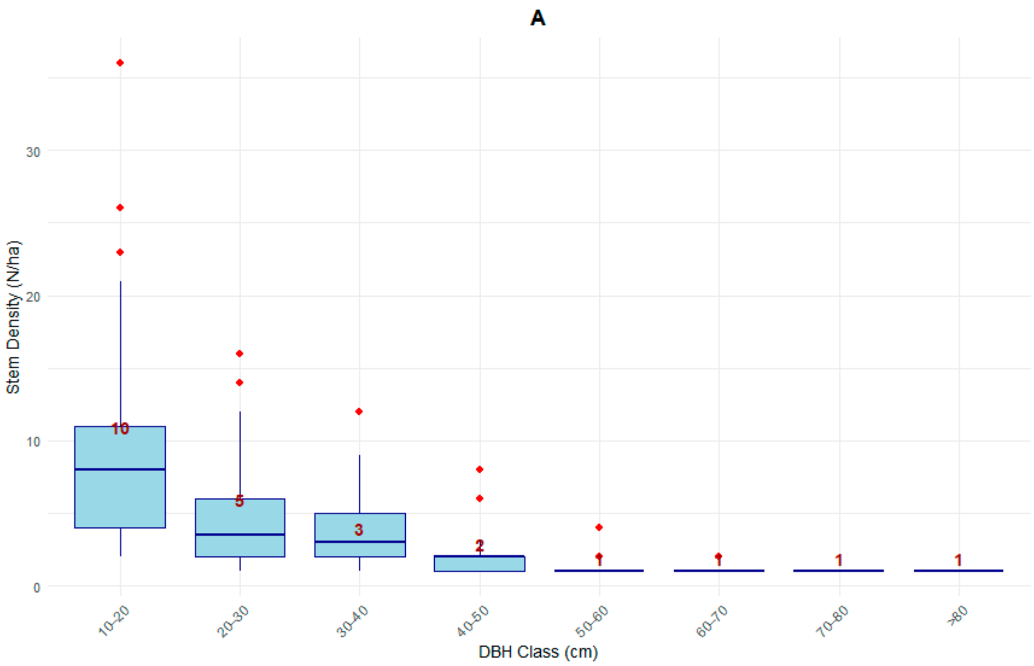

Figure 3. Average of stem density of dead trees for DBH classes across 34 plots. Numbers in red are the averages.

3.1.2. Stand Structure by Stem Density, Basal Area, Above Ground Biomass, Stem and Total Volume for All Trees Within the Stand

We observed a total of 8660 live trees, constituting *stems density* of 255 ± 21 stems/ha, *basal area* of 15.43 ± 0.95 m^2/ha, *AGB* of 109.68 ± 6.83 Mg/ha, and *total volume* of 145 ± 10.11 m^3/ha (Figure 4).

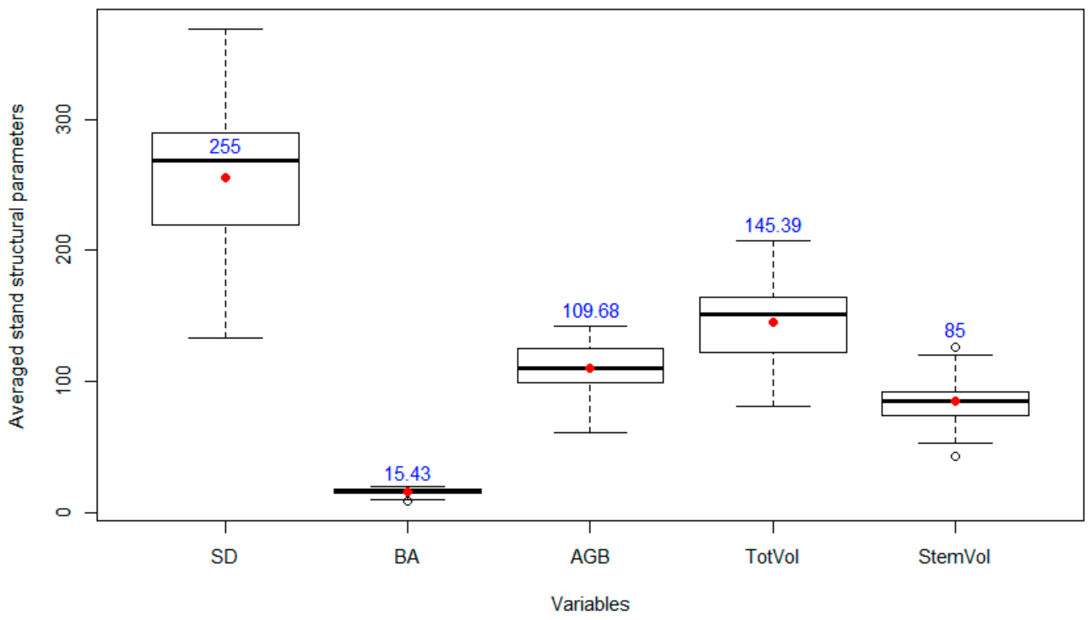

Figure 4. Structural parameters of the 34 plots that make up the stand. Numbers in blue are the averages. SD: stem density (stems/ha), BA: basal Area (m^2/ha), TotVol: total wood volume (m^3/ha), StemVol: volume of wood stem (m^3/ha), AGB: above ground biomass (Mg/ha).

Within the stand, five tree species (*Brachystegia spiciformis*, *Pseudolachnostylis maprouneifolia*, *Millettia stuhlmannii*, *Combretum zeyheri*, and *Cleistanthus holtzii*) contributed highly to the *total volume* as showed in Figure 5. Four species were found in all 34 plots, except for *Combretum zeyheri*, which was present in only 33 plots. These same species had higher contributions for other stand parameters (stems, *basal area* and biomass) as indicated (Appendix A). From the five dominant species, *Brachystegia spiciformis* alone accounted for approximately 58% of the stand volume, followed by *Pseudolachnostylis maprouneifolia* and *Amblygonocarpus andongensis* with each contributing only about 10% of the *Brachystegia spiciformis* volume fraction. A similar scenario applies to the *above ground biomass* (Appendix A).

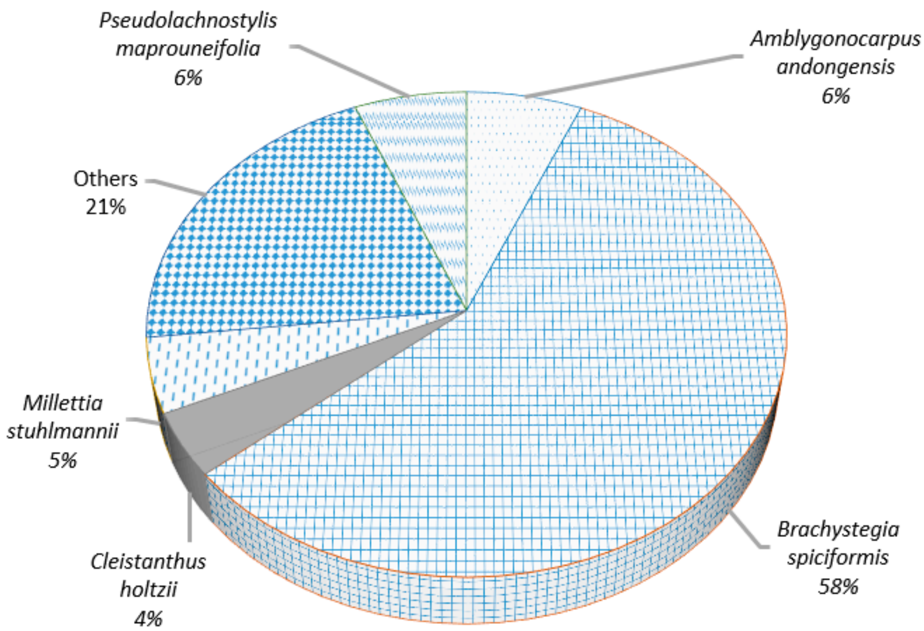

Figure 5. Distribution of total stand volume by species.

3.1.3. Diameter Distribution of Stand Structural Variables, i.e., Stem Density, Basal Area, Above Ground Biomass, Stem and Total Volume

The distribution of the number of stems per hectare by *DBH* classes follows a reverse J-shaped trend with many individual trees in lower *DBH* class and few in the upper *DBH* classes (Figure 6A). Trees from the 10–60 cm DBH classes were recorded across all plots. However, individuals in the 60–70 cm DBH class were absent in five plots, while those in the 70–80 cm class were not recorded in 12 plots. Additionally, individuals with DBH > 80 cm were present only in two plots. These patterns indicate a decreasing occurrence of trees with increasing DBH. We did not include 33 species which had only less than 25 individuals in the analysis.

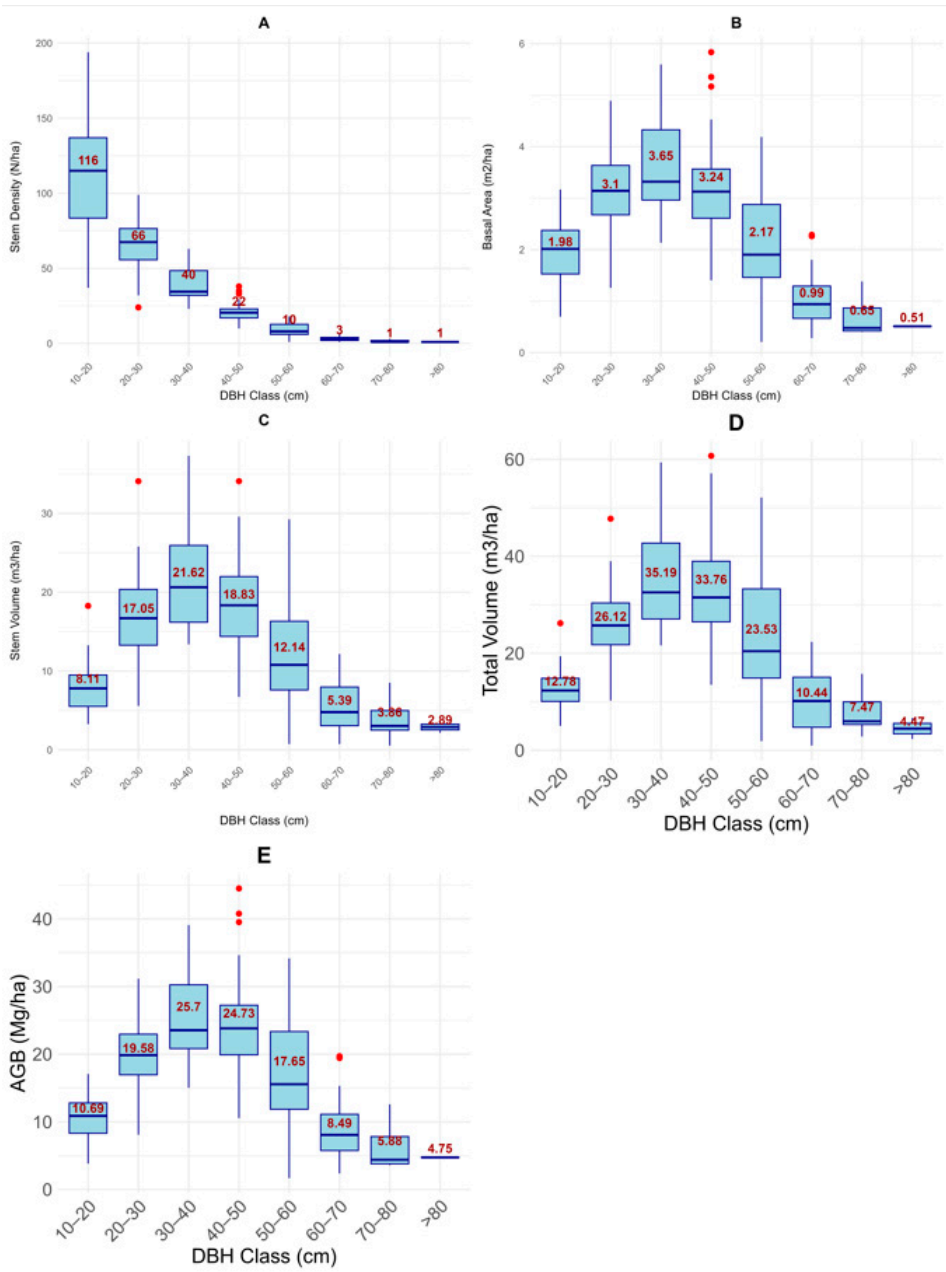

Figure 6. Average of structural parameters for *DBH* classes across 34.1 ha plots: stem density (**A**), basal area (**B**), stem volume (**C**), total volume (**D**), above ground biomass (**E**). Numbers in red are the averages.

The distribution of *basal area, stem volume, total volume and AGB* are shown in Figure 6B–E. The *total volume* was mostly concentrated in middle *DBH classes*. The same pattern was exhibited for *stem volume*, *basal area* and *above ground biomass*. We found 48% of the stand *volume* was within the diameter range of 30 to 50 cm, while less than 10% of the stand *volume* was constituted each by DBH 10 to 20 cm and DBH ≥ 60 cm. Importantly, *B. spiciformis* dominated within all the structural parameters with contribution of 42% for total stem density, 58% total basal area, 65% of the stem *volume*, 64% of the total wood *volume*, and 59% of the *above ground biomass*.

3.2. Tree Species Composition

3.2.1. Species Richness, Importance Value Index, and Family

We found a total of 8660 live trees across 34 plots, consisting of 57 species and 25 families. The first four species with the highest IVI (Table 1) occurred in all 34 plots while the fifth one occurred only in 33 plots. The tree species with the highest IVI was *Brachystegia spiciformis*, followed by *Pseudolachnostylis maprouneifolia*, and least was *Combretum zeyheri*. The five species with the highest IVI are also predominantly light-demanding, according to the literature [7,8,24,27]. Note that the first four are commercial timber species while the fifth is the only non-commercial timber species in this category. Of the total species (57), 33 species (58%) are commercial, of which 25 species (44%) have individuals with diameters exceeding the MCD; nine species (16%) were classified as high-value species, with seven species having trees with *DBH* above MCD.

Table 1. IVI of the first five most abundant species.

IVI Position	Scientific Name	Frequency	Min (trees/ha)	Max (trees/ha)	Mean (trees/ha)	Value of IVI
1	*Brachystegia spiciformis*	34	34	231	108	0.66
2	*Pseudolachnostylis maprouneifolia*	34	5	47	20.5	0.38
3	*Millettia stuhlmannii*	34	10	31	19.5	0.38
4	*Amblygonocarpus andongensis*	34	3	26	11.3	0.37
5	*Combretum zeyheri*	33	0	45	16.5	0.35

IVI Position: position of each species in the ranked IVI.

3.2.2. Composition of Rare Tree Species

The data on rare species included eight singletons, namely; *Dalbergia nitidula*, *Dyospiros mespiliformis*, *Margaritaria discoidea*, *Markhamia obtusifolia*, *Sphaerocoryne gracilis*, *Vangueria infausta*, *Ximenia caffra* and *Ziziphus abyssinica* (14% of species with living individuals) and the following two doubletons (*Albizia adianthifolia* and *Celtis gomphophylla*) (4% of species with living individuals). Of these species, three are classified as commercial: *Dyospiros mespiliformis* (precious class), *Albizia adianthifolia* (second-class), and *Celtis gomphophylla* (third-class). The remaining species are considered non-commercial.

3.2.3. Tree Species Diversity

Tree species diversity was assessed using the Shannon Diversity Index, Simpson's Diversity Index, and Pielou's Equitability Index. The Shannon index was 2.3, Simpson's index was 0.8, Pielou's equitability was 0.6.

3.3. Structural Variables of a Selectively Logged Stand by Tree Categories

3.3.1. Stem Density, Basal Area, Above Ground Biomass, Stem and Total Volume for All Trees Categories

The structural variables (stem density, basal area, AGB, stem volume, and total volume) are categorized by tree type: all trees, commercial trees, non-commercial trees, merchantable trees, high-value species, and merchantable high-value trees (Figure 7). Of the living trees, commercial species comprised 86%, merchantable species 14%, high-value species 11%, and merchantable high-value species 1%. For *basal area*, *biomass*, and *volume*, the proportions shifted: commercial species accounted for 95%, merchantable species 45%, high-value species 6%, and merchantable high-value species 2% (Figure 7).

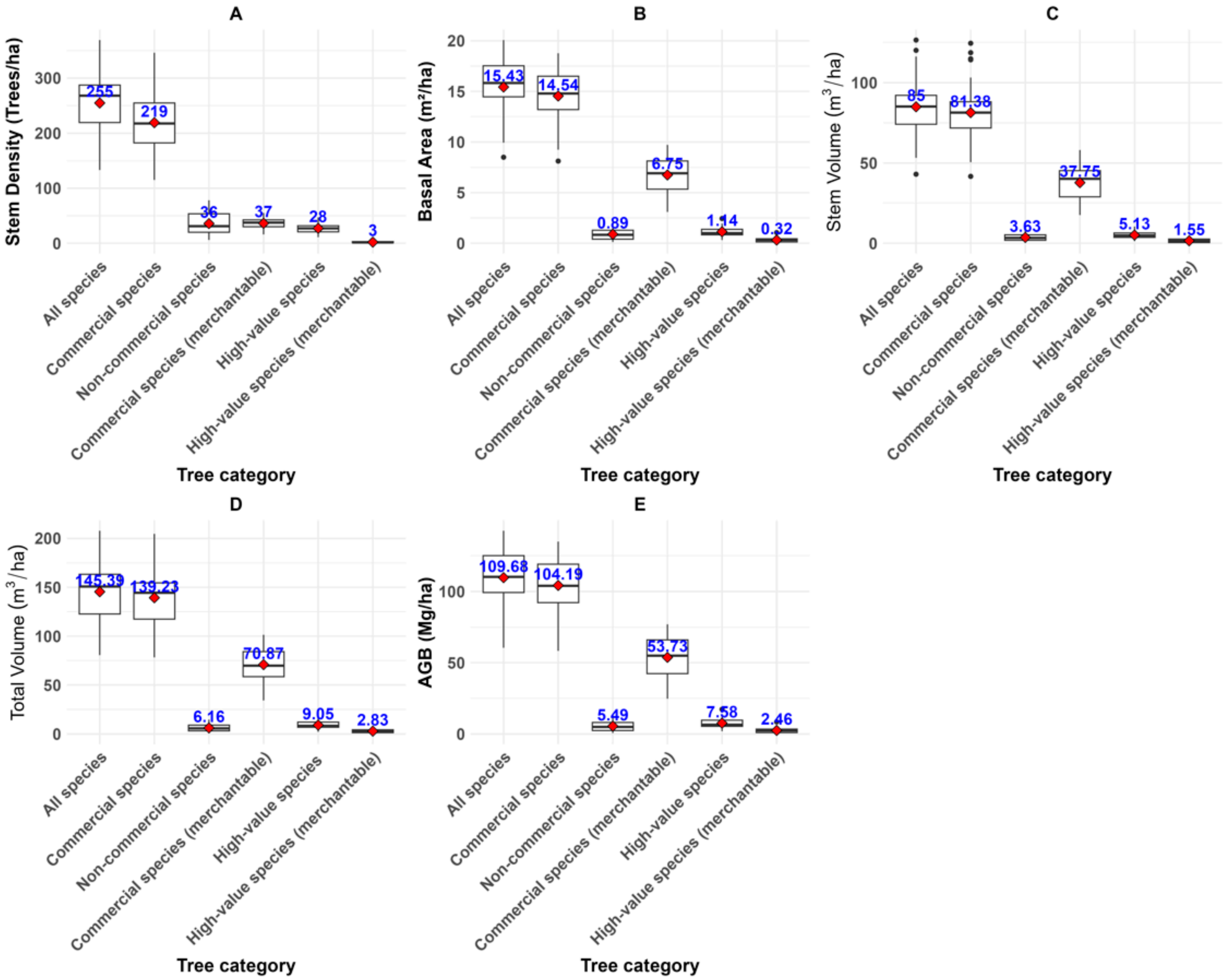

Figure 7. Averages of the structural parameters of the 34 plots that make up the stand by tree categories. Numbers in blue are the averages. Stem density for several tree categories (**A**), basal area for several tree categories (**B**), stem volume for several tree categories (**C**), total volume for several tree categories (**D**), above ground biomass for several tree categories (**E**).

3.3.2. Diameter Distribution by Tree Species Categories

The diameter distribution of stem density exhibited a continuous decreasing trend across all categories: the entire stand, commercial species, high-value species, and non-commercial species (Figure 8). Most trees were concentrated in the smallest diameter class (10–20 cm), with the lowest proportion in *Brachystegia spiciformis* (26%) and the highest in non-commercial species (83%). Other categories had at least 50% of their trees within this class. When combining the first two diameter classes (10–30 cm), *Brachystegia spiciformis* still had the lowest proportion (56%), while non-commercial species remained the highest (95%). Most species have a minimum cutting diameter of 40 cm, and under this threshold, only

10% of trees exceeded this size, except for *Brachystegia spiciformis* (21%) and non-commercial species (2%).

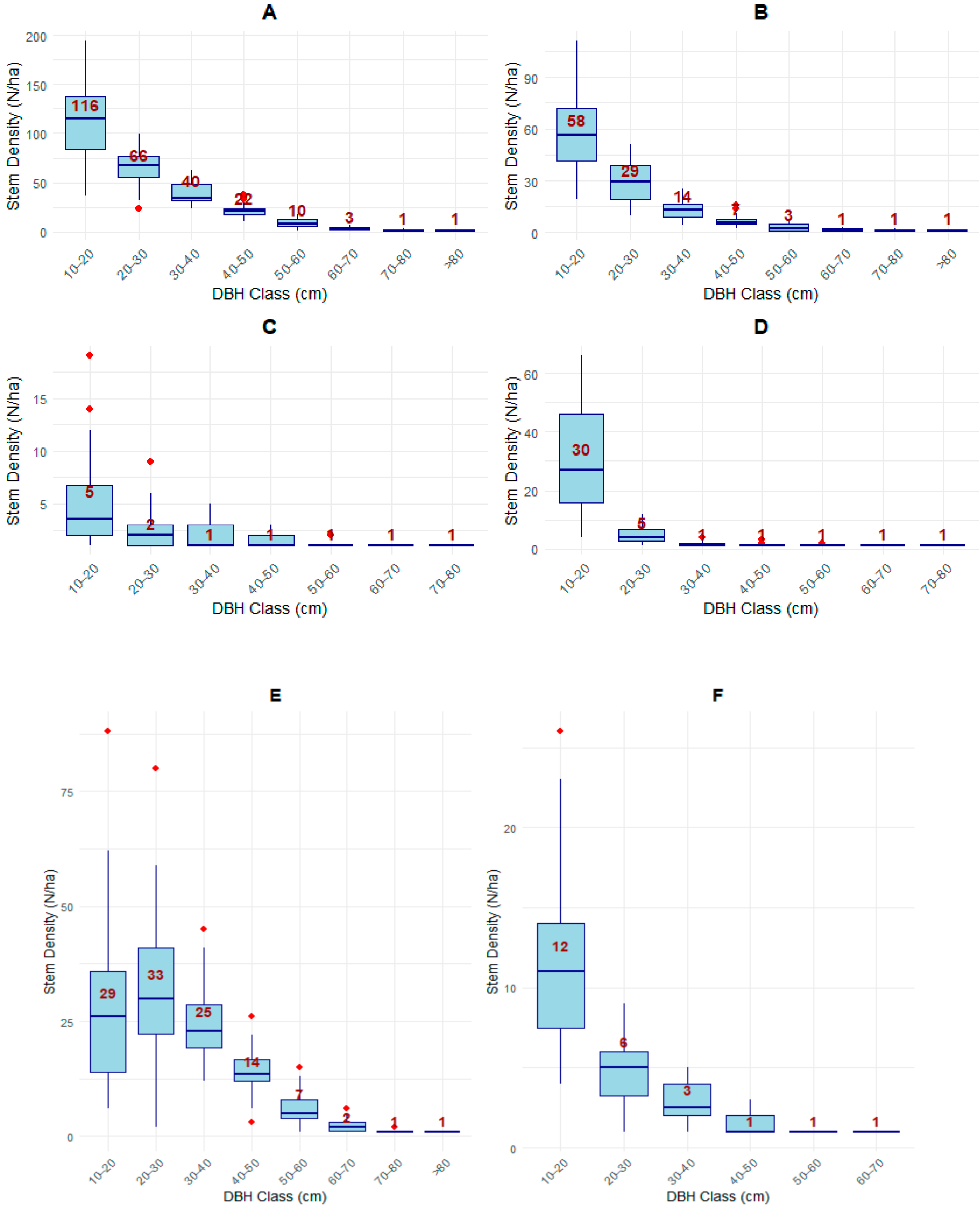

Figure 8. Averages of *DBH distribution* for *stem density* of the 34 plots that make up the stand by trees categories: the entire stand (**A**), commercial species excluding *Brachystegia spiciformis* (**B**), high-value species excluding *Milletia stuhlmannii* (**C**), non-commercial species (**D**), *Brachystegia spiciformis* (**E**), and *Milletia stuhlmannii* (**F**). Numbers in red are the averages.

Twenty-five species had individuals exclusively in the first two diameter classes (DBH < 30 cm). Although there is a trend for species to exhibit individuals solely in the first diameter class, three species (*Xeroderris stuhlmannii, Diospyros mespiliformis, and Markhamia obtusifolia*) did not exhibit individuals in the first diameter class (Appendix A). Only seven species (*Brachystegia spiciformis, Burkea africana, Erythophloeum suaveolens, Scolopia stolzii, Xeroderris stuhlmannii, Diospyros mespiliformis, and Markhamia obtusifolia*) showed a lower number of individuals in the first diameter class. However, out of the seven species, five species (Erythophloeum suaveolens, Scolopia stolzii, Xeroderris stuhlmannii, Diospyros mespiliformis, and Markhamia obtusifolia) had a stand density of less than 5 stems/ha. Among the remaining two species, Brachystegia spiciformis exhibited a higher number of individuals in the second class, whereas Burkea africana showed higher number of individuals in the third DBH class. The species *Brachystegia spiciformis* and *Amblygonocarpus andongensis* which belong to the five most abundant species did not exhibit a reverse J-shaped trend (Appendix A). The commercial species *Burkea africana, Mimusops obtusifolia* also did not exhibit a reverse J-shaped trend.

The DBH distribution of high-value species, including *Millettia stuhlmannii, Pterocarpus angolensis, Balanites maughamii*, and *Albizia versicolor*, followed a decreasing trend, resulting in a reverse J-shape (Appendix A). However, for *Pterocarpus angolensis, Balanites maughamii*, and *Albizia versicolor*, this pattern occurred within a low number of individuals (*Balanites maughamii*: 15, *Albizia versicolor*: 3) or was restricted to only the first two size classes (*Pterocarpus angolensis and Albizia versicolor*) (Appendix A). Consequently, *Pterocarpus angolensis, Albizia versicolor*, and *Diospyros mespiliformis* showed a complete absence of individuals with a DBH above the minimum cutting diameter (MCD). This pattern was less clear *for Spirostachys africana and Afzelia quanzensis* that, however, contained the same number of individuals within at least two consecutive diameter classes. Notably, all high-value species, except *Millettia stuhlmannii*, exhibited a density of less than one individual per hectare across most diameter classes. *Combretum zeyheri* lacked merchantable individuals as it was not considered a commercial species. Additionally, *Xeroderris stuhlmannii* (commercial), *Diospyros mespiliformis* (high-value species), and *Markhamia obtusifolia* (non-commercial) had no trees within the 10–20 cm DBH class.

For total volume and other variables, commercial species and *Brachystegia spiciformis* showed a peak in intermediate diameter classes, followed by a sharp decline from the 40–50 cm class onward (Figure 9). In contrast, high-value species (excluding Millettia stuhlmannii) exhibited a steadily increasing trend, with *Millettia stuhlmannii* itself showing the same pattern, while non-commercial species followed a parabolic pattern.

Of the 57 species, 33 (58%) are commercial and 24 (42%) are non-commercial. The commercial species account for 7445 trees (86% of the total), while the non-commercial species make up 1215 trees (14% of the total). Among the commercial species, eight (*Albizia adianthifolia, Celtis gomphophylla, Tamarindus indica, Parinari curatellifolia, Piliostigma thoningii, Antidesma venosum, Albizia versicolor*, and *Pterocarpus angolensis*) lacked individuals with a DBH equal to or greater than their respective MCD. The stand contained 1231 merchantable trees (14%) and 7429 non-merchantable trees.

The high-value species exhibited low abundance and frequency, comprising nine species (16%). Sixteen plots (47%) showed the simultaneous occurrence of both precious and first-class species, while nine plots (26%) contained merchantable individuals from these classes. Six plots (18%) recorded the simultaneous absence of exploitable individuals from both the first and second classes.

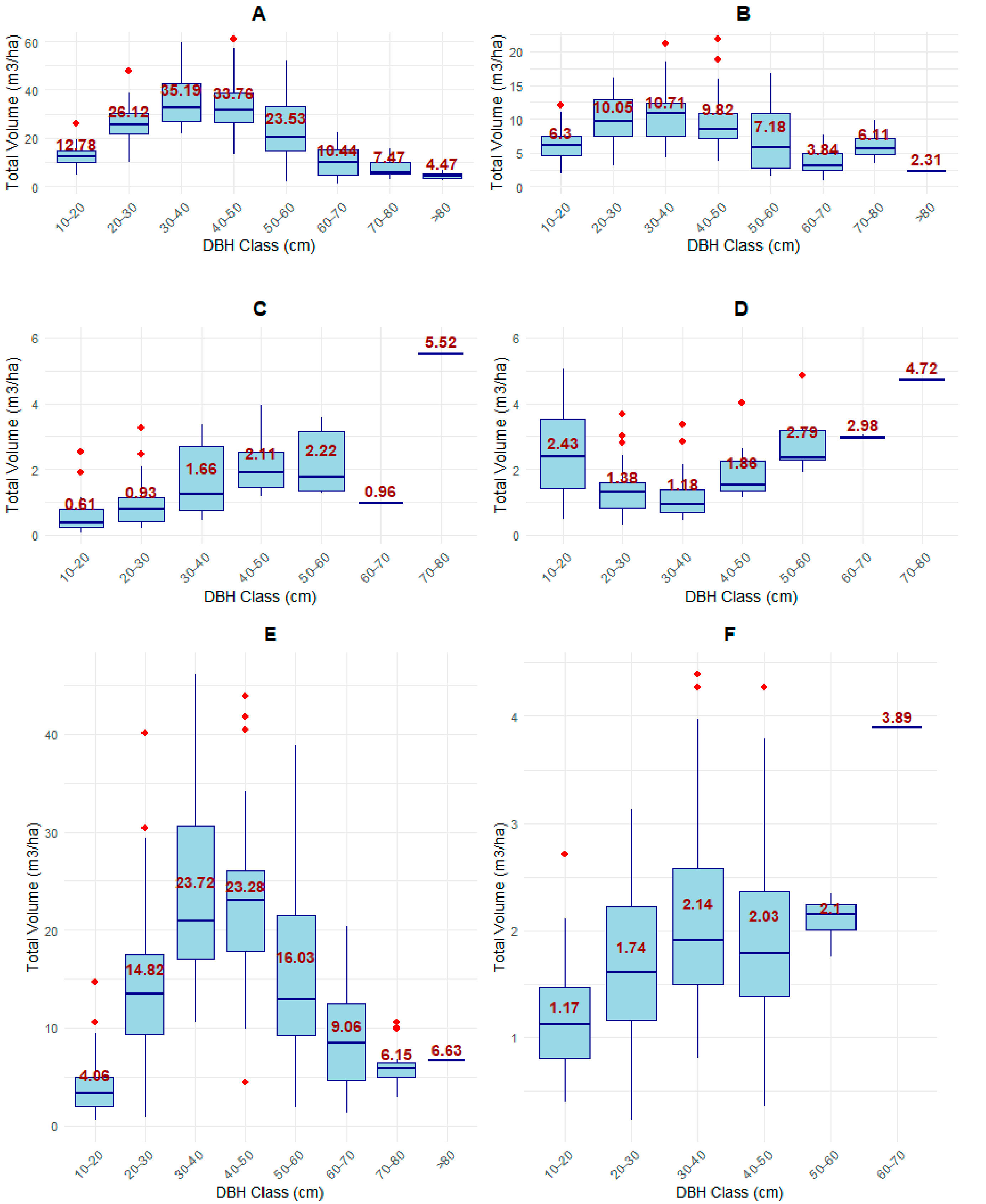

Figure 9. Averages of *DBH distribution* for total volume of the 34 plots that make up the stand by trees categories: the entire stand (**A**), commercial species excluding *Brachystegia spiciformis* (**B**), high-value species excluding *Millettia stuhlmannii* (**C**), non-commercial species (**D**), *Brachystegia spiciformis* (**E**), and *Millettia stuhlmannii* (**F**). Numbers in red are the averages.

The *Brachystegia spiciformis* was the most abundant commercial species, occurring in all plots and exhibiting the highest structural parameters, including among merchantable trees (Appendix A). *Millettia stuhlmannii* was the most abundant high-value species, present in all plots, although its merchantable individuals were found in only 20 plots. The merchantable wood of *Millettia stuhlmannii* represented less than 5% of the merchantable wood of *Brachystegia spiciformis*. Erythophloeum suaveolens was the only high-value species in which merchantable individuals occurred in more plots than non-merchantable ones. Among the high-value species, Diospyros mespiliformis had no individuals with a DBH smaller than its MCD (regeneration). The highest density of merchantable individuals within high-value species was recorded for Spirostachys africana (6 trees/ha), followed by *Millettia stuhlmannii* and *Balanites maughamii* (3 trees/ha). All other high-value species had a density of no more than 1 tree/ha in any plot.

4. Discussion

4.1. Structural Dynamics and Mortality Patterns

In the Miombo eco-region, the number of dead trees is mostly examined in the context of firewood harvesting [59], although some scholars recognize its value in the context of the carbon sink [60]. Tree mortality in Miombo is more frequent in suppressed trees [61]. Our study found a tree mortality of 7% which is comparable to the value of 5.9% found in Miombo [62]. Surprisingly, our value was nearly twice the average value of 3.1% found for tree mortality in a Miombo experiment [63]. However, in areas of late burning and thinning, tree mortality was higher at average of 5.1% [63], suggesting the possibility of our higher observed mortality to be related to the past fire occurrence. Again, most of the tree mortalities in our study were observed in the smaller diameter classes, and are consistent with the findings for MW [61]. We obtained a volume of 9 m^3/ha for dead trees in our study, which is lower than the value of 20 m^3/ha recommended for effective management of woodlands [64]. The low volume observed in our study may be attributed to the fact that, during silvicultural interventions, the removal of dead, diseased, and low-vigor trees is implemented, which could contribute to the reduction in mortality recorded within the stand. In MWs, most of the tree mortalities are related to fire disturbances [7–9], implying that the high deaths of trees in the smaller diameter classes (Figure 3) could be linked to past fire incidences.

We observed an average *stem density* of 255 stems*ha^{-1} (Figure 4), which is intermediate of the values observed in MWs, i.e., 183 stems*ha^{-1} [65], and 3616 stems*ha^{-1} [66]. Our stem density observed is related to the minimum DBH 10 cm included in our study compared to the higher value of stem density observed with the inclusion of DBH 1.5 cm in MW [66]. Again, we obtained a total *basal area* of 15.43 m^2*ha while other studies reported basal areas of 9.65 to 18.50 m^2*ha [67], 7.78 to 9.13 m^2*ha [68], 18.97 m^2*ha [28], and 14.34 m^2*ha in MWs [69].

The wood *volume* values obtained in the present study (Figure 4) are slightly higher than those reported by [67], (65.99 m^3 ha^{-1}, with a range of 54.49 to 104.47 m^3 ha^{-1}), [68], (43.9 to 76.03 m^3 ha^{-1}) and [66] 78.57 m^3/ha, close to the value found by [60], (142.36 $\pm$ 52.17 m^3 ha^{-1}). The biomass values obtained in the present study (Figure 4) are higher than those reported by [68], (29.31 to 43.56 Mg·ha^{-1}), and fall within the ranges defined by [70] for all Miombo categories, being also close to the value reported by [60] of 95.86 $\pm$ 35.16 Mg ha^{-1}, and were lower than the values found by Miapia et al., (2021) [66]. Specifically, old-growth Miombo biomass ranged from 22.57 to 228.19 Mg·ha^{-1}, with an average of 114.5 Mg·ha^{-1}; disturbed Miombo varied from 3.15 to 160.47 Mg·ha^{-1}, with an average of 56.81 Mg·ha^{-1}; and regrowth Miombo ranged from 0.19 to 163.98 Mg·ha^{-1}, with an average of 40 Mg·ha^{-1} [71]. This overlap between the classes of different categories, combined with the large variation in values within each category, suggests that other factors, such as rainfall, species composition, and variable growth conditions also influence biomass values across these woodlands [71,72]. Thus, the management strategies, and silvicultural interventions, appear to be maintaining a moderate level of disturbance, which results in intermediate values within this range.

In general, the structural values obtained in our study are consistent with other values and patterns reported in logged Miombo woodlands. The high variability of these parameters across the region can be attributed to the interplay of multiple factors, forest management practices, silvicultural interventions, land-use history [5,73,74], gap sizes [75] and environmental factors [10,76,77]. Additionally, the predominance of typical Miombo species can be attributed to their adaptation to the varying degrees of disturbance commonly present in these woodlands [7–9]. Thus, although the values observed align with the broad regional range, the specific structural patterns in the stand analyzed may be primarily driven by local climatic conditions, management strategies, and silvicultural interventions. These factors appear to be maintaining a moderate level of disturbance while simultaneously promoting regeneration, which results in intermediate values within this range.

4.2. Distribution of Parameters by DBH Classes

Our stem diameter distribution for most species and tree categories observed in the stand conformed to a reverse-J distribution, which is typical of natural forests and is a common phenomenon in Miombo woodlands [11,78,79]. The reverse J-shaped curve of forest structure in a stand is an indicator of the occurrence of shade-tolerant species and population stability [51,80], which is the case of Miombo woodlands, indicating a continuous recruitment in a sustainable system [65,80]. However, the presence of this pattern at the stand level does not necessarily imply sustainability at the species level within the population [30], as our study noted that same tree species such as *Brachystegia spiciformis*, *Burkea africana, Erythophloeum suaveolens, Scolopia stolzii, Xeroderris stuhlmannii, Diospyros mespiliformis, Markhamia obtusifolia, Pterocarpus angolensis, Albizia versicolor*, among others, had distorted J-shaped patterns. This pattern indicates that several species in this stand are disturbed, resulting in a potential lack of species population sustainability [81]. A study also revealed that even dominant tree species such as *Millettia stuhlmannii* did not have a stable population [82], suggesting that many factors could be affecting population stability and sustainability of many species including the dominant species within both a stand and landscape in the MWs.

The distribution of *total volume* (Spiecker's volume distribution) in our study (Figure 6B) did not conform to the expected J-shaped structure for a natural forest [67], but a similar pattern was observed in MWs in Tanzania [60]. Overextraction of large diameter trees tends to reduce the volume, which is expected to be higher in larger stems compared to medium stems, resulting in more volume being concentrated within the medium DBH category than larger DBH categories. However, this pattern is similar to that obtained by [83] when modelling a teak plantation in Nigeria as well as the one found by [60] for a Miombo woodland in Tanzania.

4.3. Species Composition, Dominance Patterns, and Ecological Implications of Disturbance in Managed Miombo Woodlands

The most abundant family and species in our study was the *Fabaceae* and *Brachystegia spiciformis*, respectively, following the common pattern in disturbed Miombo [84]. The Fabaceae and *Combretaceae* families, as well as the species *B. spiciformis* and *Millettia stuhlmannii*, are typically dominant in many parts of disturbed MWs [85–87]. While the genera such as *Pterocarpus, Pseudolachnostylis, Terminalia and Burkea* are fire tolerant and generally dominate early stages of regrowth [7,88], these facts indicate historical disturbances and other management practices are creating favorable conditions for the occurrence of these families and species that are usually more pronounced in disturbed MWs [84,85,89]. Additionally, these results highlight the structural importance of *B. spiciformis* within the stand (Figure 5, Table 1), as well as its predominance in MWs [18,51]. These data indicate that the *Fabaceae* and *Combretaceae* family and the species *B. spiciformis* and *Millettia stuhlmannii* are well adapted to the ecological conditions of the MW eco-region. This dominance of these families and species is related to their adaptation to varying levels of disturbance, climate, management practices, and soil nutrients [65,90]. These families and species equally contribute a greater percentage to carbon sequestration in MWs [91] as a result of their better performance in gaps rather than under the canopy, suggesting that the practice of selective logging has a high potential to affect the long-term performance of these species, as it does not allow for the creation of gaps with the minimum dimensions required by them [5,24,25]. We did not find *Julbernardia globiflora* among the species with the highest IVIs in our study, suggesting our area is more disturbed as the species is more predominant in intact Miombo woodlands. This is in line with a study in a MW which observed reduction/decline in the stem density of Julbernardia *globiflora* with an increase in degradation [89]. The *Julbernardia globiflora* has been shown to regenerate well under moderate shade compared to overly dense canopy [7,14]. These patterns reinforce the idea that selective logging can contribute to significant ecological changes that potentially lead to a reduction in biodiversity or at least a change in species composition.

Our findings on rare species, including singletons (14.04%) and doubletons (3.51%), suggest a relatively low occurrence of some species and our values are lower than those reported, i.e., 39.3% and 11.3% [92], 34.2% and 17.9% [93]. This pattern of singletons and doubletons relates to species ecological behaviors but also can be influenced by management interventions such as selective logging, natural thinning, and fire disturbance; thus, putting them at risk of local extinction.

4.4. Impact of Management on Species Diversity in Miombo Woodlands

The diversity index values observed in the present study (*Shannon* = 2.3, *Simpson index* = 0.8) are slightly lower than the *Shannon index* range (2.54 and 3.04) reported in MWs [65]. However, our value is within the 2.66 and 1.78 reported for communal and protected areas, respectively [77], close to the *Shannon index* value of 2.27 also reported in MWs [60]. The fact that the value falls between the values of communitarian and protected woodland suggests that the woodland, due to the selective logging, suffered moderate impacts on species diversity. In communal areas, where resource extraction is more intensive, the lower diversity index value (1.78) likely reflects a greater disturbance. On the other hand, the higher value (2.66) found in protected areas suggests that, without logging pressures, species diversity is better preserved. Importantly, the high value of the *Simpson index* shows that this woodland exhibits dominance of certain species [60].

4.5. Relationship Between Structural Variables and Tree Categories

We found a higher number of commercial species (33 species) in our study compared to only seven commercial species reported in MWs [65]. The deviation could be attributed to the difference in the site conditions and sampling size since the seven species were only for an area of 4 ha compared to our 34 ha inventoried. This applies equally to the proportions of *merchantable stem density* and *merchantable volume* (45%) in our study, which is considerably higher than the total *merchantable volume* of 25% reported by [65]. Our higher value of merchantable volume could also be a result of better silvicultural management within the logging concessions that promote good growth of commercial species, but it could also be due to the fact that the harvestings were conducted under strict regulations that do not cause overexploitation.

The diametric distribution of structural parameters (*basal area*, *volume*, and *biomass*) generally exhibited a sharp decline in the merchantable diameter classes. This pattern is also observed in the diameter distribution of *stem density* across all high-value species (with the exception of *Millettia stuhlmannii*), resulting in some species (e.g., *Pterocarpus angolensis*, *Albizia versicolor*, and *Diospyros mespiliformis*) lacking individuals in these diameter ranges, which is in line with the findings reported by [80]. Thus, the *volume* distribution profile in the present study differs from that obtained by [65], which showed an increasing trend for commercial species. The lower values for structural parameters in the merchantable diameter classes can be explained by the concentration of logging activities in these diameter classes [94]. The distribution found in this study has the drawback of logging targets, the largest trees with potentially better quality timber and lower growth potential, implying less future carbon sequestration potential. They may have detrimental consequences for the reproduction, regeneration and future quality and value of the stand, as the values indicate a low number of large individuals which are the responsible for reproduction [73,95]. Conclusively, we recommend that species which are allowed to be harvested at minimum stem diameters that fall within the middle *DBH classes* could also be removed to allow other commercial species to continue to accumulate more merchantable volume and biomass, in order to optimize long-term financial returns and carbon sequestration from logging [96–98].

Our study found only one high-value species, *Millettia stuhlmannii*, within the top fifteen species with the highest IVI (Table 1), indicating a relatively low contribution of commercially valuable species to structural parameters. Furthermore, the fact that only 18 of the 33 commercial species and only seven out of nine high-value species possess merchantable individuals, suggests that selective logging by targeting the most robust and larger-sized trees within high-value species, potentially caused this imbalance [23,25,65]. Other studies also reported disproportionately low values for merchantable volumes from high-value species [23,25]. Such imbalances could compromise the long-term sustainability of these species by reducing the presence of reproductively mature individuals, thereby affecting natural regeneration processes and the overall structural stability of the stand [23,25]. Also, the *stem density* of high-value species such as *Milicia excelsa*, *Pterocarpus angolensis and* Afzelia *quanzensis* were lower in this study (Figure 7) compared to the values reported in MWs [44,99–101], implying that overexploitation could be leading to the regeneration failure of these species. The biomass of high-value species such as *Pterocarpus angolensis and Afzelia quanzensis* in this study were 0.56 Mg*ha^{-1} and 0.46 Mg*ha^{-1}, respectively, which were lower compared to the values reported for the same species, *Pterocarpus angolensis* (4.1 Mg*ha^{-1}) and *Afzelia quanzensis* (9.9 Mg*ha^{-1}) [101]. This low biomass for these species may result from the species being commercially highly sought after in the country as reported in other studies [27,102,103]. However, in commercial species with high light requirements, this occurrence is typically more frequent and severe due to selective logging not creating enough gap sizes required for their establishment [104]. Conversely, in this study, *Millettia stuhlmannii*, which is one of the most valuable species, showed higher structural parameters especially in merchantable volume (6.1 m^3*ha^{-1}), due to its tendency of being gregarious and locally dominant in the Miombo habitats, to the extent of even forming pure stands [24,27].

5. Conclusions

This study analyzed the structure and composition of a Miombo woodland stand subjected to selective logging. The results show that the stand exhibits high stem density in the smallest diameter class, with basal area, volume, and biomass concentrated in the middle diameter classes, typical of Miombo woodlands. The Fabaceae family and Brachystegia spiciformis dominate the stand. The study confirms moderate species diversity, with certain species exhibiting dominance. It also highlights the impact of selective logging, particularly the reduced occurrence of large-diameter individuals in high-value commercial species. These findings emphasize the need for socio-ecological considerations in management practices to promote a sustainable balance between economic and ecological sustainability in logged MWs.

Future research should prioritize experiments that reflect common forms of Miombo woodland exploitation, monitoring their effects over time. The focus should be on regeneration, species succession, forest value variation, and biomass restoration. Comparative studies between logged and untouched Miombo woodlands, enhanced by remote sensing technologies, would provide valuable insights. From a policy perspective, these findings highlight the need for legislation that incorporates differentiated interventions based on the ecological needs of each species. Such interventions should respect species-specific characteristics while promoting silvicultural practices that balance socio-economic, environmental, and ecological factors.

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Abbreviations

The following abbreviations are used in this manuscript:

MW Miombo woodlands

Appendix A

Table A1. Average by Plot of Structural Parameters by Species.

Scientific Name	10–20				20–30				30–40				40–50			
	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB
Brachystegia spiciformis	28	0.53	4.06	2.93	32	1.57	14.82	9.99	25	2.32	23.72	16.34	14	2.12	23.28	16.17
Amblygonocarpus andongensis	5	0.08	0.5	0.44	2	0.09	0.66	0.58	1	0.13	1.09	0.91	2	0.24	2.15	1.8
Pseudolachnostylis maprouneifolia	11	0.19	1.13	1.02	5	0.26	1.83	1.61	3	0.25	1.94	1.76	1	0.15	1.19	1.18

Table A1. *Cont.*

Scientific Name	10–20				20–30				30–40				40–50			
	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB
Millettia stuhlmannii	11	0.19	1.17	1	5	0.24	1.74	1.48	2	0.2	1.76	1.41	1	0.11	1.01	0.82
Cleistanthus holtzii	7	0.12	0.84	0.67	4	0.19	1.52	1.18	2	0.14	1.27	1	1	0.09	0.89	0.66
Burkea africana	1	0.02	0.12	0.1	2	0.08	0.56	0.48	2	0.15	1.51	1.08	1	0.15	1.62	1.14
Julbernardia globiflora	2	0.03	0.17	0.13	2	0.08	0.6	0.48	1	0.12	1	0.87	1	0.12	1.03	0.88
Combretum zeyheri	14	0.21	1.18	1.14	2	0.1	0.62	0.6	0	0.01	0.05	0.05	0		0.03	0.03
Pteleopsis myrtifolia	5	0.08	0.59	0.45	2	0.1	0.8	0.62	1	0.05	0.47	0.35	0	0.03	0.29	0.2
Lannea antiscorbutica	5	0.09	0.55	0.49	2	0.11	0.82	0.67	1	0.05	0.44	0.38	0	0.01	0.12	0.1
Mimusops obtusifolia	1	0.02	0.1	0.08	0	0.02	0.15	0.12	0	0.02	0.16	0.14	0	0.05	0.38	0.36
Mundulea sericea	1	0.01	0.05	0.05	0	0.01	0.08	0.06	0	0.01	0.12	0.1	0	0.03	0.33	0.24
Spirostachys africana	1	0.01	0.1	0.08	0	0.02	0.17	0.14	0	0.04	0.37	0.31	0	0.04	0.3	0.3
Acacia gerrardii	1	0.01	0.07	0.06	0	0.02	0.14	0.12	1	0.05	0.45	0.33	0	0.02	0.22	0.17
Combretum molle	5	0.07	0.38	0.36	0	0.02	0.13	0.13	0	0.01	0.06	0.06	0		0.04	0.03
Kigelia africana	1	0.01	0.07	0.06	1	0.03	0.22	0.17	0	0.02	0.18	0.13	0	0.02	0.2	0.15
Pterocarpus angolensis	3	0.05	0.34	0.28	1	0.04	0.36	0.27								
Terminalia sericea	2	0.03	0.18	0.18	1	0.04	0.28	0.28	0	0.01	0.07	0.07				
Turraea nilotica	6	0.09	0.41	0.45	0	0.01	0.04	0.06								
Afzelia quanzensis	0	0.01	0.04	0.03	0	0.01	0.07	0.05	0	0.02	0.19	0.14	0	0.01	0.09	0.06
Sclerocarya birrea	0		0.01	0.01	0		0.02	0.02	0	0.02	0.16	0.12	0	0.02	0.17	0.13
Strychnos madagascariensis	2	0.02	0.12	0.13	0	0.02	0.14	0.13	0	0.01	0.05	0.04	0		0.03	0.03
Uapaca nitida	1	0.02	0.12	0.1	0	0.01	0.09	0.07	0		0.02	0.02				
Balanites maughamii	0		0.03	0.02	0		0.04	0.03	0		0.01	0.01				
Erythophloeum suaveolens	0				0		0.02	0.01					0	0.02	0.19	0.14
Hirtella zanguebarica	1	0.01	0.06	0.07	0	0.01	0.04	0.04	0		0.02	0.03				
Vitex payos	0		0.01	0.01												
Milicia excelsa	0		0.02	0.02	0		0.02	0.02	0		0.01	0.01	0		0.04	0.03
Maytenus guyansis	1	0.01	0.06	0.05	0		0.03	0.03								
Acacia nigrescensis	0		0.02	0.01	0		0.03	0.02					0		0.04	0.04
Parinari curatellifolia	1	0.01	0.08	0.07												
Erythophleum africanum	0								0		0.03	0.02	0	0.01	0.06	0.04
Dyospiros mespiliformis																
Combretum hereroense	0	0.01	0.03	0.03	0		0.01	0.02								
Xeroderris stuhlmannii					0		0.02	0.02					0		0.04	0.03
Scolopia stolzii	0		0.01	0.01	0		0.02	0.02	0		0.02	0.02				
Euclea natalensis	0		0.02	0.02	0		0.01	0.01								
Grewia transzambesica	0		0.02	0.02												
Diplorhynchus condylocarpon	0		0.02	0.02												
Tabernaemontana elegans	0		0.01	0.02	0			0.01								
Antidesma venosum	0		0.01	0.01	0		0.01	0.01								
Albizia versicolor	0		0.01	0.01	0		0.01	0.01								
Tamarindus indica	0		0.02	0.01												
Hugonia busseana	0		0.01	0.01												
Piliostigma thoningii	0		0.01	0.01	0		0.01	0.01								
Casearia gladiiformis	0		0.01	0.01												
Garcinia livingstonei	0		0.01	0.01												
Strichnos spinosa	0				0		0.01	0.01								
Markhamia obtusifolia					0		0.01	0.01								
Albizia adianthifolia	0		0.01													
Celtis gomphophylla	0															
Dalbergia nitidula	0															
Margaritaria discoidea	0															
Sphaerocoryne gracilis	0															

Table A1. *Cont.*

Scientific Name	10–20				20–30				30–40				40–50			
	N	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**
Vangueria infausta	0															
Ximenia caffra	0															
Ziziphus abyssinica	0															
Total	116	1.98	12.78	10.69	65	3.1	26.12	19.58	39	3.65	35.19	25.7	21	3.24	33.76	24.73
Scientific Name	**50–60**				**60–70**				**70–80**				**>80**			
	N	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**
Brachystegia spiciformis	6	1.42	16.03	11.55	2	0.62	6.93	5.29	1	0.29	3.44	2.57	0	0.01	0.2	0.14
Amblygonocarpus andongensis	1	0.29	3.02	2.39	0	0.09	0.74	0.78	0	0.05	0.52	0.48	0	0.01	0.07	0.14
Pseudolachnostylis maprouneifolia	0	0.1	0.88	0.78	0	0.02	0.14	0.15								
Millettia stuhlmannii	0	0.03	0.31	0.24	0	0.01	0.11	0.09								
Cleistanthus holtzii	0	0.08	0.78	0.64	0	0.03	0.31	0.24	0	0.01	0.18	0.12				
Burkea africana	0	0.04	0.5	0.36												
Julbernardia globiflora	0	0.06	0.51	0.45	0	0.02	0.12	0.14								
Combretum zeyheri																
Pteleopsis myrtifolia	0	0.01	0.12	0.11	0	0.01	0.06	0.07								
Lannea antiscorbutica																
Mimusops obtusifolia	0	0.01	0.1	0.1	0	0.02	0.18	0.17	0	0.03	0.28	0.26				
Mundulea sericea	0	0.06	0.65	0.48	0	0.02	0.18	0.15	0	0.01	0.14	0.13				
Spirostachys africana	0	0.01	0.08	0.1												
Acacia gerrardii	0	0.01	0.09	0.06												
Combretum molle																
Kigelia africana					0	0.01	0.1	0.07								
Pterocarpus angolensis																
Terminalia sericea																
Turraea nilotica																
Afzelia quanzensis	0	0.01	0.05	0.05					0	0.01	0.16	0.13				
Sclerocarya birrea	0	0.01	0.11	0.1												
Strychnos madagascariensis																
Uapaca nitida	0	0.01	0.09	0.06												
Balanites maughamii	0	0.01	0.09	0.12	0	0.01	0.03	0.07								
Erythophloeum suaveolens																
Hirtella zanguebarica																
Vitex payos									0	0.01	0.12	0.11				
Milicia excelsa																
Maytenus guyansis																
Acacia nigrescensis																
Parinari curatellifolia																
Erythophleum africanum																
Dyospiros mespiliformis	0	0.01	0.1	0.06												
Combretum hereroense																
Xeroderris stuhlmannii																
Scolopia stolzii																
Euclea natalensis																
Grewia transzambesica																
Diplorhynchus condylocarpon																
Tabernaemontana elegans																
Antidesma venosum																
Albizia versicolor																
Tamarindus indica																
Hugonia busseana																
Piliostigma thoningii																

Table A1. *Cont.*

Scientific Name	50–60				60–70				70–80				>80			
	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB	N	BA	Vol	AGB
Casearia gladiiformis																
Garcinia livingstonei																
Strichnos spinosa																
Markhamia obtusifolia																
Albizia adianthifolia																
Celtis gomphophylla																
Dalbergia nitidula																
Margaritaria discoidea																
Sphaerocoryne gracilis																
Vangueria infausta																
Ximenia caffra																
Ziziphus abyssinica																
Total	9	2.17	23.52	17.65	3	0.84	8.91	7.24	1	0.42	4.83	3.81	0	0.03	0.26	0.28

ScientificName	Merchantable				Total			
	N	BA	Vol	AGB	N	BA	Vol	AGB
Brachystegia spiciformis	23	4.46	49.87	35.72	108	8.88	92.47	64.98
Pseudolachnostylis maprouneifolia	4	0.52	4.16	3.88	21	0.96	7.12	6.51
Millettia stuhlmannii	1	0.15	1.44	1.15	20	0.77	6.1	5.05
Combretum zeyheri					16	0.32	1.88	1.82
Cleistanthus holtzii	1	0.12	1.28	1.01	13	0.66	5.79	4.51
Amblygonocarpus andongensis	3	0.69	6.5	5.59	11	0.99	8.74	7.52
Lannea antiscorbutica	0	0.01	0.12	0.1	8	0.27	1.93	1.65
Pteleopsis myrtifolia	0	0.05	0.47	0.38	8	0.28	2.32	1.8
Turraea nilotica					6	0.1	0.46	0.51
Julbernardia globiflora	1	0.19	1.66	1.47	6	0.41	3.42	2.95
Burkea africana	1	0.19	2.13	1.5	5	0.44	4.31	3.16
Combretum molle					5	0.1	0.62	0.58
Pterocarpus angolensis					4	0.1	0.7	0.56
Terminalia sericea	0	0.01	0.07	0.07	3	0.09	0.54	0.52
Strychnos madagascariensis					2	0.05	0.34	0.33
Mimusops obtusifolia	1	0.11	0.96	0.91	2	0.16	1.34	1.23
Spirostachys africana	1	0.1	0.75	0.72	2	0.13	1.01	0.94
Acacia gerrardii					2	0.11	0.98	0.73
Kigelia africana	0	0.03	0.3	0.22	2	0.08	0.76	0.57
Mundulea sericea					2	0.16	1.55	1.21
Uapaca nitida	0	0.01	0.11	0.08	1	0.04	0.31	0.26
Parinari curatellifolia					1	0.01	0.08	0.07
Hirtella zanguebarica	0		0.02	0.03	1	0.02	0.12	0.14
Afzelia quanzensis	0	0.02	0.21	0.18	1	0.06	0.6	0.47
Maytenus guyansis					1	0.01	0.09	0.08
Sclerocarya birrea	0	0.01	0.11	0.1	1	0.05	0.48	0.38
Balanites maughamii	0	0.03	0.13	0.21	0	0.03	0.2	0.26
Combretum hereroense					0	0.01	0.04	0.05
Euclea natalensis					0		0.03	0.03
Milicia excelsa	0		0.01		0	0.01	0.09	0.09
Grewia transzambesica					0		0.02	0.02
Acacia nigrescensis	0	0.01	0.04	0.04	0	0.01	0.09	0.08
Diplorhynchus condylocarpon					0		0.02	0.02
Erythophloeum suaveolens	0	0.02	0.19	0.14	0	0.02	0.21	0.15
Tabernaemontana elegans					0		0.02	0.02
Tamarindus indica					0		0.02	0.01

Table A1. *Cont.*

ScientificName	Merchantable				Total			
	N	**BA**	**Vol**	**AGB**	**N**	**BA**	**Vol**	**AGB**
Vitex payos	0	0.01	0.12	0.11	0	0.01	0.13	0.11
Antidesma venosum					0		0.02	0.02
Hugonia busseana					0		0.01	0.01
Piliostigma thoningii					0		0.01	0.01
Scolopia stolzii					0	0.01	0.05	0.04
Albizia versicolor					0		0.02	0.02
Casearia gladiiformis					0		0.01	0.01
Erythophleum africanum	0	0.01	0.06	0.04	0	0.01	0.1	0.06
Garcinia livingstonei					0		0.01	0.01
Strichnos spinosa					0		0.01	0.01
Xeroderris stuhlmannii	0		0.04	0.03	0	0.01	0.06	0.05
Albizia adianthifolia					0		0.01	
Celtis gomphophylla					0			
Dalbergia nitidula					0			
Dyospiros mespiliformis	0	0.01	0.1	0.06	0	0.01	0.1	0.06
Margaritaria discoidea					0			
Markhamia obtusifolia					0		0.01	0.01
Sphaerocoryne gracilis					0			
Vangueria infausta					0			
Ximenia caffra					0			
Ziziphus abyssinica					0			
Total	36	7	71	54	255	15.43	145.38	109.68

N: number of stems (stems/ha), BA: basal area (m^2/ha), Vol: total wood volume (m^3/ha), AGB: above ground biomass (Mg/ha). N value of zero indicates an average of less than 0.5 individuals per plot, Empty cells (without numbers) indicate the absence of a tree.

Appendix B

Table A2. Family, Scientific Name, Shade and Fire Tolerance, Economic Value and Conservation Status for the 57 Tree Species Registered in Sample Plots.

	Specie	Family	Shade Tolerance/ Intolerance	Fire Resistance	Commercial Value	Conservation Value
1	*Brachystegia spiciformis*	*Fabaceae*	LD	FS	SC	LC
2	*P. maprouneifolia*	*Euphorbiaceae*	LD	FT	TC	NIL
3	*Millettia stuhlmannii*	*Fabaceae*	ST	FT	FiC	NIL
4	*A. andongensis*	*Fabaceae*	LD	FT	SC	NIL
5	*Combretum zeyheri*	*Combretaceae*	LD	FT	NC	LC
6	*Lannea antiscorbutica*	*Anacardiaceae*	Ubiquitous	FT	FoC	NIL
7	*Pteleopsis myrtifolia*	*Combretaceae*	LD	FT	SC	NIL
8	*Turraea nilotica*	*Meliaceae*	LD		NC	LC
9	*Burkea africana*	*Fabaceae*	LD	FT	SC	LC
10	*Cleistanthus holtzii*	*Phyllanthaceae*			TC	NIL
11	*Combretum molle*	*Combretaceae*	LD	FT	NC	LC
12	*S. madagascariensis*	*Loganiaceae*	LD		NC	NIL
13	*Acacia gerrardii*	*Fabaceae*	LD		NC	NIL
14	*Kigelia africana*	*Bignoniaceae*	LD		TC	LC

Table A2. *Cont.*

	Specie	Family	Shade Tolerance/ Intolerance	Fire Resistance	Commercial Value	Conservation Value
15	*Julbernardia globiflora*	*Fabaceae*	LD	FS	SC	NIL
16	*Pterocarpus angolensis*	*Fabaceae*	LD	FT	FiC	LC
17	*Mundulea sericea*	*Fabaceae*	LD		NC	LC
18	*Mimusops obtusifolia*	*sapotaceae*	ST		FoC	NIL
19	*Terminalia sericea*	*Combretaceae*	LD	FT	TC	LC
20	*Afzelia quanzensis*	*Fabaceae*			FiC	LC
21	*Parinari curatellifolia*	*Chrysobalanaceae*	LD	FT	SC	LC
22	*Spirostachys africana*	*Euphorbiaceae*	LD		P	LC
23	*Sclerocarya birrea*	*Anacardiaceae*	LD		SC	LC
24	*Uapaca nitida*	*Euphorbiaceae*	LD		TC	LC
25	*Hirtella zanguebarica*	*Chrysobalanaceae*			FoC	NIL
26	*Maytenus guyansis*	*Celastraceae*	ST		NC	LC
27	*Balanites maughamii*	*Zygophyllaceae*	LD		FiC	LC
28	*Combretum hereroense*	*Combretaceae*		FT	NC	LC
29	*Milicia excelsa*	*Moraceae*	LD		P	NT
30	*Erythophloeum suaveolens*	*Fabaceae*			FiC	NIL
31	*Grewia transzambesica*	*Malvaceae*	LD		NC	LC
32	*Acacia nigrescensis*	*Fabaceae*	LD		TC	NIL
33	*Vitex payos*	*Lamiaceae*	LD		TC	LC
34	*Euclea natalensis*	*Ebenaceae*	ST		NC	LC
35	*Scolopia stolzii*	*Salicaceae*	ST		NC	NIL
36	*Piliostigma thoningii*	*Fabaceae*	LD		TC	LC
37	*D. condylocarpon*	*Meliaceae*	LD	FT	NC	NIL
38	*Erythophleum africanum*	*Fabaceae*			TC	NIL
39	*Tabernaemontana elegans*	*Apocynaceae*	LD		NC	LC
40	*Tamarindus indica*	*Fabaceae*	LD		FoC	LC
41	*Hugonia busseana*	*Linaceae*	ST		NC	
42	*Albizia versicolor*	*Fabaceae*	Ubiquitous	FT	FiC	LC
43	*Casearia gladiiformis*	*Salicaceae*			NC	LC
44	*Strichnos spinosa*	*Loganiaceae*	LD		NC	
45	*Antidesma venosum*	*Phyllanthaceae*	LD		FoC	LC
46	*Garcinia livingstonei*	*Clusiaceae*			NC	LC
47	*Celtis gomphophylla*	*Cannabaceae*	LD		TC	LC
48	*Xeroderris stuhlmannii*	*Fabaceae*			TC	
49	*Dyospiros mespiliformis*	*Ebenaceae*	LD		P	
50	*Albizia adianthifolia*	*Fabaceae*	Ubiquitous	FT	SC	LC
51	*Markhamia obtusifolia*	*Bignoniaceae*	ST		NC	LC
52	*Sphaerocoryne gracilis*	*Annonaceae*			NC	LC
53	*Dalbergia nitidula*	*Fabaceae*	LD		NC	LC
54	*Margaritaria discoidea*	*Phyllanthaceae*			NC	LC
55	*Ximenia caffra*	*Olacaceae*	LD		NC	LC

Table A2. *Cont.*

	Specie	Family	Shade Tolerance/ Intolerance	Fire Resistance	Commercial Value	Conservation Value
56	*Ziziphus abyssinica*	*Rhamnaceae*	LD		NC	LC
57	*Vangueria infausta*	*Rubiaceae*	ST		NC	LC
58	*Rourea orientales*	*Cannabaceae*			NC	LC

Light demanding (LD), shade tolerant (ST), fire sensitive—needs fire protection (FS), fire resistant (FR), precious (P), first-class (FiC), second-class (SC), third-class (TC), fourth-Class (FoC), non-commercial (NC), least concern (LC), near threatened (NT), not in the IUCN red List (NIL), empty cells indicate no consistent information found.

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