Hindawi
International Journal of Forestry Research
Volume 2021, Article ID 5534930, 22 pages
https://doi.org/10.1155/2021/5534930

Research Article

Woody Species Composition, Vegetation Structure, and Regeneration Status of Majang Forest Biosphere Reserves in Southwestern Ethiopia

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Received 20 February 2021; Accepted 19 May 2021; Published 7 June 2021

Academic Editor: Ahmad A. Omar

The aim of this study was to analyse the species composition, structures, and regeneration of woody plant species and the impacts of site factors on the natural regeneration of tree species in four study sites of MFBR. The vegetation data were collected systematically in 140 plots with the size of 400 m^2 for trees; 25 m^2 for seedlings, saplings, shrubs, and lianas; and 1 m^2 for herbs. Individual tree and shrub DBH $\geq$ 5 cm were measured and counted. The diameter at breast height (DBH), frequency, basal area, importance value index (IVI), and density were used for vegetation structure description and regeneration. A total of 158 plant species belonging to 115 genera, 56 families, and 80 species (51%) trees, 26 (16%) shrubs, 19 (12%) herbs, and 33 (21%) lianas were identified and recorded. The most dominant families were *Euphorbiaceae, Rubiaceae,* and *Moraceae*, each represented by 13 species (7.4%), 12 species (6.8%), and 10 species (5.7%), respectively. The tree densities varied from 1232 to 1478 stem ha^{-1}, sapling density 176.8 to 708.7 stem ha^{-1}, and seedling density 534.7 to 1657.5 stem ha^{-1}, with an average basal area of 63.6 m^2 in the study sites. *Dracaena afromontana* was the most frequent woody species in the MFBR occurring in 90% followed by *Celtis zenkeri* (65%) and *Pouteria altissima* (62.5%). The regeneration status of all the woody plant species was categorised as "not regenerate" (9.6%), "poor" (30.7%), "fair" (59.5%), and "good" (10.8%) in all sites. The correlation result between natural regeneration and site factors revealed both positive and negative relationships. However, the main threat to the biosphere reserve is illegal logging for different purposes. Therefore, awareness creation on sustainable forest management, utilisation, conservation of priority species, and livelihood diversification to the local community and encouraging community and private woodlot plantation in the transitional zone of biosphere reserves are recommended.

1. Introduction

Ethiopia is the centre of biological diversity because of its wide range of geographical scale [1, 2]. The various topographic factors with diverse climatic factors have created diversified vegetation types in the country. These make Ethiopia have above 6000 higher plant species, of which about 10% are endemic [3]. The vegetation type at Majang forest biosphere reserves is part of the moist evergreen Afromontane forest and is found in the southwestern parts of Ethiopia. Most of these moist evergreen Afromontane forests are very crucial for the conservation of fauna and flora as well as water sources for the low land area [4, 5]. However, moist evergreen Afromontane forest resources are being dwindled at an alarming rate because of anthropogenic disturbance [6, 7].

Hence, studying plant population structure and regeneration status is significant to understanding the dynamics of vegetation and their disturbance factors [8]. Stand structure is displaying the distribution of an individual in each species and provides the general regeneration profile of the forest [9, 10]. Population structure can show whether or not a continuous regeneration and stable population take place. Inspection of species population structure patterns could provide vital information about the recruitment status and the sustainability of population management. It is evidence for further planning and conservation strategies and helps recognise forest ecosystems and biodiversity [11].

Regeneration is a vital part of any forest ecosystem dynamics, as well as it regulates the existence of species and restoration of forest land degradation [12], and it could be playing a great role in planning, forest conservation, and sustainable management [13]. Sustainable forest management and utilisation could be possible if there is sufficient evidence available on the regeneration dynamics and factors influencing important canopy tree species [8]. The regeneration status of sample species can be accessed based on total seedling and sapling density dynamics in a given plant community [9, 14]. As a result, the assessment of population structure and regeneration status is necessary to establish the effective conservation and management of forest resources base [15].

Population dynamics of seedlings, saplings, and tree plant species can demonstrate the regeneration profile of a given species. A population with a sufficient number of seedlings and saplings depicts satisfactory regeneration [16], but a scarce number of seedlings and saplings of the species show a poor regeneration state [17]. Furthermore, the regeneration status of a species is poor if the number of seedlings and saplings is much less than mature individuals [18]. The major causes for the destruction of natural forests are agricultural expansion and overexploitation for various purposes such as fuel wood, charcoal, construction material, and timber [19], which are responsible for the high degradation of regeneration status and population structure of the species in Majang forest biosphere reserves [20].

A biosphere reserve is an area established to conserve the biological and cultural diversity of a region while promoting sustainable economic and social development [21]. The requirements of biosphere reserves should, explicitly, fulfil three basic functions: conservation function, development function, and logistics function [22]. Nowadays, there are 699 biosphere reserves in 120 countries of the world. Out of the total biosphere reserves, 79 are found in 29 African countries, of which Ethiopia has five biosphere reserves such as Kafa besides Yayo, Sheka, Lake Tana, and Majang nominated in 2010, 2012, 2015, and 2017, respectively [23].

The Majang biosphere reserve is located in the Majang zone of the Gambella Peoples National Regional State. The Majang biosphere reserve is a newly established forest biosphere reserve; however, there is no first-hand information on vegetation ecology. For effective management and conservation of the biosphere reserves, detailed baseline information on species composition, population structure, and regeneration status is needed, which are crucial for the conservation and sustainable management of biosphere reserve tree species. The population structure of a tree species is indicative of its past distraction and environment. Moreover, it can be used to forecast its future status of Majang forest biosphere reserves [24]. Therefore, the objectives of this study are (1) to assess species composition, structures, and regeneration of woody plant species and (2) to analyse the impacts of site factors on the natural regeneration of tree species of Majang forest biosphere reserves.

2. Materials and Methods

2.1. Description of Study Area. This study was conducted in the Majang Forest Biosphere Reserve (MFBR), which is found in the Majang Zone, Gambella Peoples National Regional State of Ethiopia. It has unique biogeography and shares a border with the Illubabor zone of the Oromia regional state and Sheka and Bench-Maji zones of the Southern Nations, Nationalities, and Peoples (SNNP). It covers a total area of 233,254 ha of forest, woodland, agricultural and rural settlement, and towns (Figure 1). The MFBR is located between 07°08′00″–07°50′00″ latitude and 34°50′00″–35°25′00″ longitude, and the area has an altitude of 562 m to 2444 m [1].

The climate of the zone is generally characterised by a hot and humid type, which is marked on most rainfall maps of Ethiopia as being the wettest part of the country. The annual average rainfall is 1774 mm, and means annual minimum and maximum monthly temperature ranges between 13.9 and 31.8°C in the Tinishu Meti metrological station. The annual average rainfall is 2053 mm, and means annual minimum and maximum monthly temperature ranges between 11.8 and 29.7°C in the Ermichi metrological station. The maximum average monthly temperature is in February (29.8°C and 31.8°C), while the minimum is in January (11.9°C and 13.9°C) in Ermichi and Tinishu Meti, respectively. The maximum rainfall is between April and October and low rainfall from November to March (NMSA, 2019) (Figure 2).

The pattern of land use is changing from time to time depending on cultural background and socioeconomic change. There is a changing trend in the major land use/land cover types in Majang forest biosphere reserves [19] (Table 1).

According to the vegetation classification of Ethiopia [25], the major vegetation types of the Majang biosphere are Montana evergreen forest, low-land semievergreen forest, and riparian vegetations [26]. Besides, the vegetation of this area has different categories in terms of life forms such as high natural forest, woodlands, bushlands, and grasslands. The dominant families were *Euphorbiaceae, Asteraceae, Moraceae, Fabaceae, Poaceae, Solanaceae, Rubiaceae*, and *Sapotaceae*.

2.2. Sampling Design. A reconnaissance survey was conducted from 15 February up to 10 May 2020 in Majang biosphere reserves to inspect a local area. The forest cover and vegetation pattern related to topography and other apparent environmental conditions were recognised. Local variation of forest cover and management measures was assessed. Some geographical location of each forest was recorded to delineate the area. Then, the measurement of forest cover (ha) was determined using Google Earth map and ground survey GPS coordinates (Figure 1).

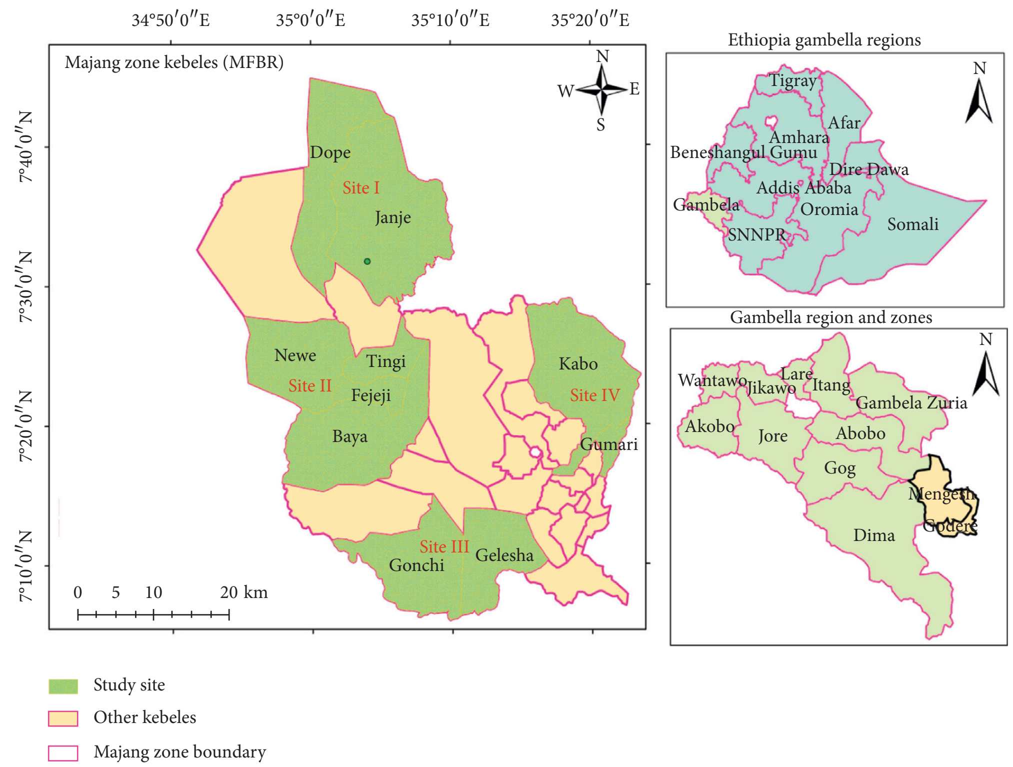
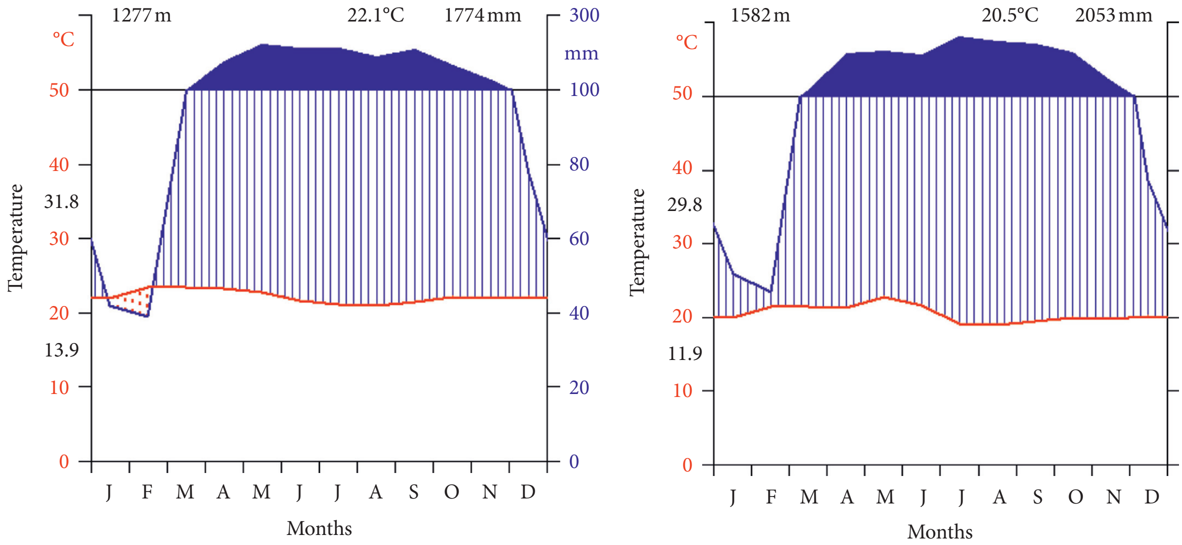


Figure 1: Location of the study area (Site I–IV).



(a)

(b)

Figure 2: Mean annual temperature and rainfall recorded: (a) Tinishu Meti (1987–2017) and (b) Ermichi (1987–2017) metrological stations. Source: NMA (2020) for climatic data.

Table 1: Area of land use/land change in MFBR.

Study period	Land use classes (ha)					
	Forestland	Farmland	Grassland	Settlement	Water body	Total
1987	196,761.6	30,791.8	3,509.2	2,050.4	141.0	**233,254**
2002	188,403.7	36,902.4	3,072.6	4,734.3	141.0	**233,254**
2017	181,504.9	40,554.8	3,192.2	7,861.1	141.0	**233,254**
Mean	188890.1	36083	3258	4881.9	141.0	**233,254**

Source: [19].

The systematic sampling design was adapted from [27] to collect vegetation. The studies were arranged in four sites considering altitudinal deference to represent Majang forest biosphere reserves: site I (Janje–Dope with an altitude of <1200 m.a.s.l.), site II (Newi–Kumi with an altitude between 1200 and 1500 m.a.s.l.), site III (Gelesha–Gubeti with an altitude between 1500 and 1800 m.a.s.l.), and site IV (Gumare–Kabo with an altitude of >1800 m.a.s.l.) (Table 2).

There are a total of 7–9 parallel transect lines, 2000 m (2 km) apart from each other. The sizes of quadrates were determined based on the growth forms of plants [27], i.e., 400 m^2 for trees; 25 m^2 for seedlings and saplings, shrubs, and lianas; and 1 m^2 for herbs in a nested plot design. A total of 140 large quadrats were laid down, i.e., site I, 1–45 in "Janje–Dope"; site II, 46–85 in "Newi–Baya"; site III, 86–115 in "Gelesha-Gonchi"; and site IV, 116–140 in "Gumare–Kabo" of Majang forest biosphere reserves (Figure 3).

2.3. Data Collection. In this study, the shrub is defined as a woody plant that is multistemmed at the base of the plant, whereas a liana is any long-stemmed, woody vine that uses trees or other means for vertical support. Seedlings are defined as woody plants with a height less than 1.30 m and diameter of <2.5 cm; saplings as woody plants with a height of >1.30 m and diameter at breast height (DBH) of 2.5–5 cm; and adult trees as plants with a DBH of ≥5 cm [28].

All tree species with diameters (DBH) of ≥5 cm were counted and recorded. The DBH, height, and crown cover of individuals of the species were measured using a diameter tape, clinometers, and meter tape, respectively. When the branching of multistemmed individuals occurred below the DBH, the DBH of each stem was measured separately and a common diameter of all stems by summing uptake average diameter was developed. To determine the diversity and estimate the abundance of shrubs and lianas, subplots (area = 25 m^2 each) were established. Similarly, the identity of species and abundance of seedlings and saplings were counted and recorded in 25 m^2 area. The cover-abundance of herbaceous was estimated in five subplots (1 m^2) visually within the main plot in 400 m^2. And then, cover-abundance of herbaceous from each plot was converted into 9 cover-abundance scale classes: 1 = (<0.%), 2 = (0.5–1.5%), 3 = (1.5–3%), 4 = (3–5%), 5 = (5–12.5%), 6 = (12.5–25%), 7 = (25–50%), 8 = 50–75%, and 9 = >75% cover [29].

The site factors such as elevation (m) and slope (%), harvesting index, and canopy openness were measured and documented. Elevation and slope were measured using the GPS and clinometer, respectively. Canopy openness was measured using the densitometer located at the centre of each plot, while harvesting index was measured by means counting the stumps individual which was an illegally logged tree inside the plot [30]. Stumps are a small part of a stem that remains after harvesting of trees reaching a minimum diameter of ≥5 cm.

Plants were identified in the field, and for those difficult to identify in the field, specimens were collected, pressed, and identified in the National Herbarium (ETH) of Ethiopia. The nomenclature of plants in this study follows those published in the Flora of Ethiopia as well as the Flora of Ethiopia and Eritrea [31, 32].

2.4. Data Analysis. The field data were compiled and arranged in an excel sheet, and the data such as stem density, relative density, frequency, relative frequency, dominance, relative dominance, important value index, and Jaccard's similarity coefficient (JSC) were analysed using the equations provided in Table 3.

For the sake of setting priority for conservation, all woody species encountered in the forest were grouped into five IVI classes based on their total IVI values according to the criteria developed by the Institute of Biodiversity Conservation and Research (IBCR). Species that receive lower IVI values need high conservation priority, while species that receive high IVI values need monitoring and management (Table 4) [38].

The regeneration pattern of woody species was assessed by employing a total count of seedlings (woody species of height ≤ 1.3 cm and DBH ≤ 2.5 cm) and saplings (woody species of height > 1.30 and DBH ≥ 2.5 cm) within the main quadrates [39]. *Pattern 1* = If the regeneration results of woody species show seedlings > sapling > adults, "*good regeneration*". *Pattern 2* = if seedlings > or ≤ saplings ≤ adults, "*fair regeneration*", and *Pattern 3* = if the woody species survive only in the sapling stages, "*poor regeneration*". *Pattern 4* = If a woody species is present only in the adult stage, it is considered as not regenerating ("*not regenerated*") [40].

Harvesting index was measured by means counting the stumps individual which was an illegally logged tree inside the plot and computed from the relative density of individual tree stump [30]. The stump relative density was computed as the sum of stump density divided by the total density (the sum of the logged stump and live individual tree).

The variation of basal area and density of seedlings, saplings, and mature trees of all woody species in response to altitude along with study sites and sampling plots were computed using ANOVA (R statistical package). A correlation analysis was performed using the R statistical package to analyse the status of natural regeneration in response to site factors (elevation, slope, canopy openness, harvesting index, and herbaceous cover). Descriptive statistics such as tables and graphs were performed using the Microsoft Office Excel 2007 software.

3. Results

3.1. Species Composition. A total of 158 plant species (Appendix 1) belonging to 115 genera and 56 families were recorded and identified in the sample plots in the MFBR (Table 5). Of these, 80 species (51%) were trees, 26 species (16%) were shrubs, 19 species (12%) were herbs, and 33 species (21%) were lianas (Figure 4). Moreover, the number of families and species were 43 (77), 45 (78), 44 (82), and 34 (84) in study sites I, II, III, and IV, respectively (Table 5).

The most dominant families recorded in the MFBR were *Euphorbiaceae*, *Rubiaceae*, and *Moraceae*; each represented

Table 2: Locations and topographic characteristics of studied forests.

Study site	Area (ha)	Elevation (m)	Aspects	Latitude	Longitude	MAR (mm)	Tmax (°C)	Tmin (°C)	Sample plots
Site I	22,826.1	1042 ± 42.5	NE, NW, SE, W, E, SW	7°40′00″–7°30′00″	35°0′00″–35°10′00″	1774	31.8	14.8	40
Site II	25,220.5	1365 ± 24.6	S, E, NE, SE	7°15′00″–7°26′00″	34°30′00″–35°10′00″	1774	31.8	14.8	45
Site III	14,053	1635.8 ± 24.6	NW, S, NE, N, SE	7°05′00″–7°12′00″	35°0′00″–35°15′00″	1774	31.8	14.8	30
Site IV	11,783.5	2011.4 ± 42.5	S, N, NE, NW	7°18′00″–7°28′00″	35°15′00″–35°25′00″	2053	29.8	12.8	25

MAR = mean annual rainfall, Tmin = minimum temperature, Tmax = maximum temperature. Sites I, II, and III are found in the Tinishu Meti metrological station, while site IV is found in the Ermichi metrological station. Source: NMA (2020) for climatic data.

(a) (b) (c) (d)

Figure 3: (Photo 1) Feature of the study sites. Source: Semegnew T (2020). (a) Site I (Janje–Dope). (b) Site II (Newi–Baya). (c) Site III (Gonchi–Gelesha). (d) Site IV (Gumare–Kabo).

Table 3: List of equations used for the calculation of vegetation parameters.

Vegetation parameters	Equation	Equation no.	Reference
Density	$D = n/N$	1	[33]
Relative density	$RD = (n/N)^{*}100$	2	[34, 35]
Frequency	$F = (x/y)^{*}100$	3	[33]
Relative frequency	$RF = (Fi/\sum_{i=1}^{s}(Fi))^{*}100$	4	[34, 35]
Basal area	$BA = (\pi Db H^2/4)$	5	[36]
Relative basal area	$BA = Bi/\sum_{i=1}^{s} Bi$	6	[36]
Dominance	$Do = \sum_{i=1}^{s} Bi/Bi$	7	[36]
Relative dominance	$Do = Di/\sum_{i=1}^{s} Di$	8	[36]
Important value index (IVI)	$IVI = RD + RF + RD$	9	[33, 35, 36]
Jaccard's similarity coefficient (JSC)	$Sj = a/(a + b + c)$	10	[37]

a = number of tree species common to sites A and B; b = number of tree species recorded only site A; c = number of tree species recorded only in site B; n: total number of individuals of the species; N: total number of individuals of all the species; x: total number of quadrats in which the species occurs; y: total number of quadrats studied; Fi: frequency of one species; Bi: basal area of one species; Di: dominance of one species.

Table 4: Criteria for setting IVI classes and conservation priority based on IVI values.

IVI values %	IVI class	Priority class	Required intervention
>30	1	5	Monitoring and management
20.1–30	2	4	Monitoring and management
10.1–20	3	3	Conservation/restoration
1–10	4	2	Conservation/restoration
<1	5	1	Conservation/restoration

Source: Institution of Biological Conservation Research [38].

Table 5: Stand characteristics of woody species and analysis of variance in four study sites.

Forest characteristics	Site I	Site II	Site III	Site IV
No. of plots (n)	45	40	30	25
No. of families	43	45	44	34
No. of species	77	78	82	84
No of genera	68	72	74	60
D (stem ha^{-1})	1232^{*a}	1318^{*b}	1478^{*c}	1309^{*d}
BA (m^2 ha^{-1})	54.8^{*a}	56.8^{*b}	67.1^{*c}	76.3^{*d}
Harvesting index (mean ± standard error %)	134 ± 4.2	158 ± 4.9	164 ± 6.1	176 ± 6.5
Herbaceous cover (mean ± standard error %)	165 ± 5.2	182 ± 5.4	182 ± 6.7	147 ± 5.4

*Significant at $P < 0.05$; different letters indicate significant differences between sites. Site I = Janje–Dope, Site II = Newi–Baya, Site III = Gonchi–Gelesha, and Site IV = Gumare–Kabo.

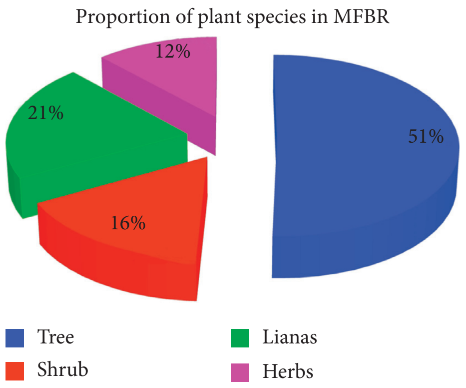


Figure 4: Proportion of plant species of MFBR in different habitats.

by 13 species (7.4%) and 9 genera (7.8%), 12 species (6.8%) and 8 genera (7%), and 10 species (5.7%) and 4 genera (3.5%), respectively, of total floristic composition. The genus *Ficus, Asplenium, Dracaena, Vernonia,* and *Albizia* were represented by seven, six, six, five, and four species, respectively, whereas *Justicia, Pseuderanthemum, Alangium, Polyscias, Schefflera, Tacazzea, Combretum, Macaranga, Millettia, Olea, Pittosporum, Leptaspis, Rothmannia, Psychotria, Fagaropsis, Vepris,* and *Allophylus* were represented by 2 species each, and the rest genera contained a single species each (Appendix 1).

3.2. Similarity in Species Composition. The similarities in species composition were ranged from 2% to 71% between study sites in Majang forest biosphere reserves. There is dissimilarity in tree species composition between sites I and IV (2%), sites II and IV (4%), and sites III and IV (2%). The highest similarity species composition of the tree was 71% between sites I and II, whereas the lowest similarity was 2% between sites I and IV as well as between sites III and IV. Similarly, species composition similarity between site I and site III as well as between site II and site III was 61% and 63%, respectively (Table 6).

3.3. Vegetation Structure

3.3.1. Density of Woody Species. Woody species densities in Majang forest biosphere reserves were analysed, and the result was described as a number of stems per hectare. The overall density of woody species in the study area was 1350 individuals (DBH > 5 m) per hectare. There were a total of 80 woody species in all density classes. The species were classified into 6 density classes, A–F, as follows: A ≤ 1; B = 1.01–10; C = 10.1–20; D = 20.1–35; E = 35.01–50; and F = >50. Based on density classes, 21 (B), 32 (C), 14 (D), 7 (E), and 6 (F) species exist in each density class respectively, while no species exist in density class A (Figure 5). The highest tree density was in site III (1478 stems ha^{-1}) (Table 5

Table 6: Species composition similarity among study sites.

Study sites	Jaccard's similarity coefficient (SJ)			
	Site I	Site II	Site III	Site IV
Site I				
Site II	0.71			
Site III	0.61	0.63		
Site IV	0.02	0.04	0.02	

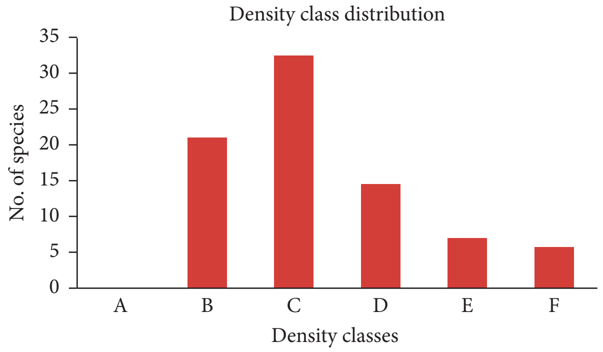


Figure 5: Density class distribution of woody species in MFBR.

and Appendix 5), while the lowest tree density ha^{-1} was in site I ($1232\,\text{ha}^{-1}$) (Table 5 and Appendix 3). There was a significant difference in density ha^{-1} between study sites ($F = 156.5$, $df = 56.23$, $P = 0.000003$). Likewise, the tree densities were significantly different between site I and site II ($F = 101.1$, $P = 0.0007$), site II and site III ($F = 26.16$ $P = 0.0087$), and site III and site IV ($F = 176.4$, $P = 0.0012$). The species that showed the highest density were *Celtis zenkeri* ($141\,\text{ha}^{-1}$), *Pouteria altissima* ($102\,\text{ha}^{-1}$), *Blighia unijugata* ($115\,\text{ha}^{-1}$), and *Cyathea manniana* ($96.25\,\text{ha}^{-1}$) in sites I, II, III, and IV, respectively (Table 7). The species that showed the least density were *Albizia grandibracteata* ($5\,\text{ha}^{-1}$), *Teclea nobilis* ($2\,\text{ha}^{-1}$), *Castanea sativa* ($3.75\,\text{ha}^{-1}$), and *Bersama abyssinica* ($10\,\text{ha}^{-1}$) in sites I, II, III, and IV, respectively (Appendixes 13–16).

Furthermore, the density of trees species with DBHs 5–10 cm, 10.1–20 cm, and >20 were 282.2 (20.9%), 617.50 (20.9%), and 450.3 (33.4%) individuals per hectare, respectively. Accordingly, the ratio of individuals between DBH classes 10.1–20 cm (a) to DBH > 20 cm (b) was 1.4 in the study area (Table 8).

3.3.2. Frequency of Woody Species.

Based on their total frequency percentage, the species were grouped in the following five frequency classes: A = 0–20%; B = 21–40%; C = 41–60%; D = 61–80; and E = 81–100%. In this study, 24, 16, 10, 5, and 2 species were recorded in frequency classes A, B, C, D, and E, respectively (Figure 6). *Dracaena afromontana* was the most frequent woody species in the MFBR occurring in 90% of the sample plots followed by *Celtis zenkeri* (65%), *Pouteria altissima* (62.5%), *Triumfetta tomentosa* (45%), *Polyscias fulva* (45%), *Schefflera abyssinica* (45%), and *Pouteria adolfi-friederici* (45%) (Table 7, Appendixes 2–6). The least frequent woody species in the MFBR occurring below 5% of the sampled plots were *Rothmannia urcelliformis*, *Bersama abyssinica*, *Ficus thonningii*, *Ficus exasperata*, *Psychotria orophila*, *Vernonia hochstetteri*, and *Celtis toka* (Appendixes 2–6). The frequency distribution of woody species in the MFBR shows that the number of tree species found in the first frequency classes is higher and gradually decreases towards higher frequency classes (Figure 6). The frequency values of the woody species ranged from 0.1% to 99% in the MFBR.

In the site I, the frequency ranges from 4% to 88%, and the most frequent woody species were *Celtis zenkeri* (88%), *Pouteria altissima* (76%), *Diospyros abyssinica* (72%), and *Antiaris toxicaria* (72%); and the least frequent woody species were *Mimusops lanceolata* (13%), *Combretum molle* (10%), and *Albizia grandibracteata* (5%) (Table 7, Appendix 3).

In site II, the frequency ranges from 4% to 100%, and the most frequent woody species are *Pouteria altissima* (100%), *Celtis zenkeri* (84%), *Lannea welwitschii* (68%), and *Lecaniodiscus fraxinifolius* (64%), while the least frequent woody species were *Tapura guianensis* (8%), *Teclea nobilis* (8%), *Buddleja polystachya* (4%), and *Dombeya torrida* (4%) (Table 7, Appendix 4). *Celtis zenkeri* (95%), *Blighia unijugata* (90%, *Pouteria alnifolia* (75), and *Pouteria altissima* (70%) were the most frequent woody species, while *Apodytes dimidiata* (5%), *Deinbollia kilimandschrica* (5%), and *Plumbago auriculata* (0.1%) were rarely occurred species in study site III (Table 7, Appendix 5). In site IV, *Dracaena afromontana* (100%), *Cyathea manniana* (100%), and *Vernonia auriculifera* (85%) were the highest frequency value, while *Phoenix reclinata* (25%), *Coffea arabica* (20%), and *Psychotria orophila* (15%) exhibited the lowest frequency value.

3.3.3. Basal Area.

The basal area value ranges from 54.8 to $76.3\,\text{m}^2\cdot\text{ha}^{-1}$ from the study site I–IV, respectively. The lowest and highest basal area values were in the study sites I and IV, respectively (Table 5 and Appendixes 9–12). The mean basal area of the four study sites was $63.6 \pm 5.4\,\text{m}^2\cdot\text{ha}^{-1}$. The ANOVA result indicated that there was a significant difference in the basal area ($P < 0.05$) between study sites ($F = 37.5$, $df = 53.44$, $P = 0.000003$). Similarly, the basal area was significantly different ($P < 0.05$) between site I and site II ($F = 6.123$, $P = 0.01912$), site II and site III ($F = 106.4$, $P = 0.0000081$), and site III and site IV ($F = 107.7$, $P = 0.0000075$) (Table 5).

The total dominance was $54.5\,\text{m}^2\cdot\text{ha}^{-1}$ in site I, the highest $4.25\,\text{m}^2\cdot\text{ha}^{-1}$ (7.79%) and the lowest basal area $0.05\,\text{m}^2\cdot\text{ha}^{-1}$ (0.09%) were contributed by *Celtis zenkeri* and *Teclea nobilis*, respectively (Appendix 9). About $28.92\,\text{m}^2\cdot\text{ha}^{-1}$ (53.2%) of the total basal area was covered by ten large-sized tree species in study site I (Table 9). *Cordia africana* exhibited low density and high basal area due to its maximum average DBH value. A total of $25.62\,\text{m}^2\cdot\text{h}^{-1}$ (46.98%) was contributed by 27 species in study site I (Appendix 9).

In study site II, the total basal area was $56.8\,\text{m}^2\cdot\text{ha}^{-1}$ with the highest $4.03\,\text{m}^2\cdot\text{ha}^{-1}$ (7.09%) and the lowest basal area $0.04\,\text{m}^2\cdot\text{ha}^{-1}$ (0.07%) were contributed by *P. altissima* and *P. fulva*, respectively (Table 9 and Appendix 9). About

Table 7: The top ten species with the highest IVI value in all the sites of MFBR.

Species scientific name	D	DO	Fr	RD	RDO	RFr	IVI	CPC
All sites								
Celtis zenkeri (A.Rich) Wedd	81.3	34.9	65.0	6.1	0.3	3.37	9.8	2
Pouteria altissima (A.Chev.) Baehni	64.1	38.2	62.5	4.8	0.3	3.24	8.4	2
Blighia unijugata Bak.	45.6	44.7	40.0	0.2	7.8	0.19	8.2	2
Lecaniodiscus fraxinifolius Bak.	59.4	55.0	38.8	4.4	0.5	2.01	6.9	2
Dracaena afromontana Mildbr.	22.5	46.9	90.0	1.7	0.4	4.67	6.8	2
Antiaris toxicaria Resch	48.4	55.0	41.3	3.6	0.5	2.14	6.2	2
Baphia abyssinica Brummit	48.8	55.0	33.8	3.6	0.5	1.75	5.9	2
Celtis toka (Forssk.) Hepper & Wood	32.5	879.3	3.8	3.4	0.4	2.08	5.9	2
Schefflera abyssinica (Hochst. ex A. Rich.	11.3	239.1	45.0	0.8	2.1	2.33	5.3	2
Pouteria adolfi-friederici (Engl.) Baehni	11.3	68.7	41.3	2.4	0.6	2.14	5.2	2
Site I								
Celtis zenkeri (A.Rich) Wedd	141	14.1	88	10.7	0.74	6.9	18.3	3
Diospyros abyssinica (Hiern) F.White	86	24.6	72	6.5	1.29	5.6	13.4	3
Antiaris toxicaria Resch	88	16.9	72	6.7	0.89	5.6	13.2	3
Pouteria altissima (A.Chev.) Baehni	81	14.9	76	6.1	0.78	5.9	12.8	3
Morus mesozygia Stapf.	53	53.7	68	4.0	2.81	5.3	12.1	3
Teclea nobilis Del.	18	157.6	32	1.4	8.26	2.5	12.1	3
Lecaniodiscus fraxinifolius Bak.	81	20.2	60	6.1	1.06	4.7	11.9	3
Celtis toka (Forssk.) Hepper & Wood	60	24.7	68	4.6	1.29	5.3	11.1	3
Blighia unijugata Bak.	57	21.2	56	4.3	1.11	4.4	9.8	2
Lannea welwitschii (Hiern) Engl.	33	59.8	44	2.5	3.14	3.4	9.0	2
Site II								
Pouteria altissima (A.Chev.) Baehni	102	14.0	100	8.3	3.07	7.3	18.6	3
Celtis zenkeri (A.Rich) Wedd	87	18.1	84	7.1	3.14	6.1	16.3	3
Lecaniodiscus fraxinifolius Bak.	100	20.8	64	8.1	3.52	4.7	16.3	3
Baphia abyssinica Brummit	69	18.2	48	5.6	2.90	3.5	12.0	3
Cordia africana Lam.	59	14.6	60	4.8	2.61	4.4	11.8	3
Antiaris toxicaria Resch	61	25.3	56	5.0	2.59	4.1	11.6	3
Ficus exasperata Vahl	37	42.1	44	3.0	5.28	3.2	11.5	3
Celtis toka (Forssk.) Hepper & Wood	29	42.8	48	2.4	5.14	3.5	11.0	3
Ritchiea albersii Gilg	42	55.9	56	3.4	3.43	4.1	10.9	3
Lannea welwitschii (Hiern) Engl.	43	20.0	68	3.5	1.05	4.9	9.5	2
Site III								
Blighia unijugata Bak.	115	32.6	90	7.8	1.02	5.3	14.10	3
Celtis zenkeri (A.Rich) Wedd	93.7	18.9	95	6.3	0.59	5.6	12.53	3
Pouteria alnifolia (Bak.) Roberty	71.2	97.7	75	4.8	3.06	4.4	12.30	3
Pouteria altissima (A.Chev.) Baehni	77.5	25.0	70	5.2	0.78	4.1	10.15	3
Baphia abyssinica Brummit	80	21.2	60	5.4	0.66	3.5	9.61	2
Margaritaria discoidea (Baill.) Webster	48.7	41.3	65	3.3	1.29	3.8	8.42	2
Antiaris toxicaria Resch	57.5	34.1	45	3.9	1.07	2.6	7.61	2
Trichilia prieuriana A.Juss	53.7	41.3	45	3.6	1.29	2.6	7.58	2
Combretum molle R.Br. ex G.Don	53.7	29.7	50	3.6	0.93	2.9	7.51	2
Lannea welwitschii (Hiern) Engl.	47.5	47.9	45	3.2	1.50	2.6	7.36	2
Site IV								
Cyathea manniana Hook	96.3	27.2	100	11.2	1.1	4.0	16.3	3
Dracaena afromontana Mildbr.	90.0	19.2	100	10.5	0.8	4.0	15.3	3
Trilepisium madagascariense DC	71.3	23.4	65	6.8	1.0	2.6	10.4	3
Allophylus abyssinicus (Hochst.) Radlk.	45.0	24.8	80	5.5	1.0	3.2	9.7	2
Pouteria adolfi-friederici (Engl.) Baehni	45.0	97.2	80	2.2	4.1	3.2	9.5	2
Vernonia auriculifera Hiern	43.8	61.2	85	2.7	2.6	3.4	8.7	2
Schefflera abyssinica (Hochst. ex A.Rich.)	67.5	59.3	40	4.4	2.5	1.6	8.5	2
Schefflera myriantha (Bak.) Drake	45.0	77.5	60	2.7	3.3	2.4	8.4	2
Ilex mitis (L.) Radlk.	40.0	46.9	80	2.6	2.0	3.2	7.8	2
Galiniera saxifraga (Hochst.) Bridson	35.0	53.3	75	2.5	2.2	3.0	7.8	2

D = density, DO = dominance, Fr = frequency, RD = relative density, RDO = relative dominance, RFr = relative frequency, IVI = importance value index, and CPC = conservation priority class.

Table 8: Density of tree species by DBH classes in MFBR.

DBH (cm)	No. of individuals (ha^{-1})	Percentage (%)	Ratio a to b
5–10	282.19	20.9	1.4
10.1–20 (a)	617.50	45.7	
>20 (b)	450.3	33.4	
	1350	**100.0**	

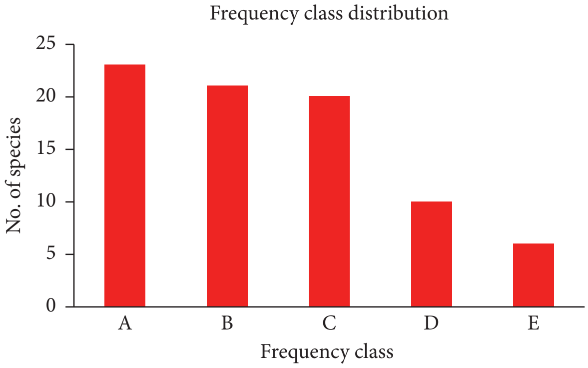


Figure 6: Frequency class distribution of woody species.

Table 9: Dominant trees with their BA and percentage in all the sites of MFBR.

Scientific name	TD	Average DBH	BA (m^2/ha)	% BA
Site I				
Celtis zenkeri (A.Rich.) Wedd	141	20.5	4.25	7.79
Pouteria altissima (A.Chev.) Baehni	81	27	3.87	7.09
Cordia africana Lam.	57	44.5	3.21	5.88
Antiaris toxicaria Resch	88	16.6	3.01	5.52
Blighia unijugata Bak.	57	19	2.69	4.93
Lecaniodiscus fraxinifolius Bak.	81	15	2.61	4.78
Baphia abyssinica Brummit	46	20.5	2.57	4.71
Celtis toka (Forssk.) Hepper & Wood	60	15.5	2.32	4.25
Diospyros abyssinica (Hiern) F.White	86	16.7	2.23	4.09
Mimusops lanceolata A.DC	13	23.2	2.16	3.96
Total	**710**	**218.5**	**28.92**	**53.0**
Site II				
Pouteria altissima (A.Chev.) Baehni	102	27	4.03	7.09
Cordia africana Lam.	59	44.5	3.87	6.81
Celtis zenkeri (A.Rich.) Wedd	87	20.5	3.12	5.49
Baphia abyssinica Brummit	69	20.5	3.10	5.46
Lannea welwitschii (Hiern) Engl.	43	28	2.82	4.96
Lecaniodiscus fraxinifolius Bak.	100	15	2.71	4.77
Blighia unijugata Bak.	31	19	2.69	4.73
Trichilia prieuriana A.Juss.	28	20	2.51	4.42
Grewia mollis A.Juss.	32	25.8	2.35	4.14
Antiaris toxicaria Resch	61	16.6	2.23	3.92
Total	**612**	**236.9**	**29.43**	**51.79**
Site III				
Celtis zenkeri (A.Rich) Wedd	93.75	20.5	3.76	5.61
Pouteria altissima (A.Chev.) Baehni	77.5	27	3.44	5.14
Celtis toka (Forssk.) Hepper & Wood	42.5	15.5	3.38	5.04
Baphia abyssinica Brummit	80	20.5	3.30	4.92
Blighia unijugata Bak.	115	19	2.95	4.40
Cordia africana Lam.	22.5	44.5	2.80	4.18
Lecaniodiscus fraxinifolius Bak.	58.75	15	2.74	4.09
Ficus mucuso (Ficatho)	31.25	27.5	2.70	4.03
Diospyros abyssinica (Hiern) F.White	42.5	16.7	2.66	3.96

Table 9: Continued.

Scientific name	TD	Average DBH	BA (m^2/ha)	% BA
Combretum molle R.Br. ex G.Don	53.75	31	2.34	3.49
Total	**617.5**	**237.2**	**30.07**	**44.86**
Site IV				
Dracaena afromontana Mildbr.	72	25	3.97	5.21
Cordia africana Lam.	16	14	3.46	4.54
Galiniera saxifraga (Hochst.) Bridson	52	18	3.36	4.41
Ficus sur Forssk.	19	17	3.27	4.28
Trilepisium madagascariense DC	57	17	3.27	4.28
Allophylus abyssinicus (Hochst.) Radlk	36	18	3.08	4.04
Cyathea manniana Hook	77	21	2.80	3.68
Schefflera abyssinica (Hochst. ex A.Rich.) Harms	54	18	2.06	2.70
Albizia gummifera (J.F.Gmel.) C.A.Sm.	29	16	2.01	2.64
Dracaena afromontana Mildbr.	35	16	2.01	2.64
Total	**447**	**180**	**29.29**	**38.42**

BA = basal area, MFBR = Majang Forest Biosphere Reserve, and TD = tree density.

$29.43\,m^2\cdot ha^{-1}$ (51.8%) of the total basal area was covered by ten large-sized tree species in study site II. *C. africana* exhibited low density and high basal area due to its maximum average DBH value (Table 9). A total of $27.39\,m^2\cdot h^{-1}$ (48.2%) was contributed by 31 species in study site I (Appendix 10).

In study site III, the total basal area was $67.1\,m^2\cdot ha^{-1}$, the highest $3.76\,m^2\cdot ha^{-1}$ (7.09%) and the lowest basal area $0.07\,m^2\cdot ha^{-1}$ (0.11%) were exhibited by *C. zenkeri* and *Castanea sativa*, respectively (Table 9 and Appendix 11). About $30.07\,m^2\cdot ha^{-1}$ (44.9%) of the total basal area was covered by ten large-sized tree species in study site III. *C. africana* exhibited low density and high basal area due to its maximum average DBH value (Table 9). A total of $36.96\,m^2\cdot h^{-1}$ (55.14%) was contributed by 36 species in study site I (Appendix 11).

Similarly, in study site IV, the total basal area was $76.3\,m^2\cdot ha^{-1}$, the highest $3.97\,m^2\cdot ha^{-1}$ (5.21%) and the lowest basal area $0.64\,m^2\cdot ha^{-1}$ (0.83%) were contributed by *D. afromontana* and *B. abyssinica*, respectively (Table 9 and Appendix 12). About $29.29\,m^2\cdot ha^{-1}$ (38.42%) of the total basal area was covered by ten large-sized tree species in study site III. *C. africana* exhibited low density and high basal area due to its maximum average DBH value (Table 9). A total of $46.96\,m^2\cdot h^{-1}$ (61.58%) basal area was contributed by 36 species in study site I (Appendix 12).

3.3.4. Importance Value Index. The importance value index (IVI) of tree species showed a great variation, ranging from 1.1% to 9.8% in the overall study site (Appendix 2). The first top ten leading and ecologically most important tree species in the MFBR were *C. zenkeri, P. altissima, B. unijugata, L. fraxinifolius, D. afromontana, A. toxicaria, B. abyssinica, C. toka, S. myriantha*, and *P. adolfi-friederici* and contributed 68.5% of the IVI (Table 7). About 231.5% of the IVI was contributed by the remaining 75 species (Appendix 2).

More in detail, the results of IVI in the four study sites showed different values. The IVI value ranges from 3.6% to 18.3%, and the highest IVI values exhibited tree species were *C. zenkeri* (18.3%), *D. abyssinica* (13.4%), *A. toxicaria* (13.2%), and *P. altissima* (12.8%), whereas the lowest tree species were *M. butugi* (4.3%), *A. grandibracteata* (4.3%), and *M. lanceolata* (3.6%). About 123.5% of IVI values was contributed by the top ten tree species, whereas 176.5% was contributed by the remaining 27 tree species from the total of 300 IVI values in study site I (Table 7, Appendix 3).

In study site II, the IVI values of tree species range from 1.4 to 18.6%; and about 129.4% of IVI was contributed by the top ten tree species, whereas 31 tree species contributed the remaining 170.5% IVI value. The highest IVI values exhibited tree species were *P. altissima* (18.6%), *C. zenkeri* (16.3%), *L. fraxinifolius* (16.3%), and *B. abyssinica* (12%), whereas the lowest values exhibited tree species were *P. fulva* (2.3%), *T. nobilis* (1.8%), and *B. polystachya* (1.4%) (Table 7, Appendix 4).

The IVI value ranges from 1.29% to 14.1%, and the highest IVI values exhibited tree species were *B. unijugata* (14.1%), *C. zenkeri* (12.5%), *P. alnifolia* (13.2%), and *P. altissima* (10.2%), whereas the lowest values exhibited tree species were *M. butugi* (4.3%), *A. grandibracteata* (4.3%), and *M. lanceolata* (3.6%). From the total tree species, about 97.2% of IVI values was contributed by top ten tree species and 202.8% IVI was contributed by 37 species in study site III (Table 7, Appendix 5). In study site IV, the IVI values of tree species range from 3.5 to 16.3%, and about 102.5% of IVI was contributed by the top ten tree species, whereas 35 tree species contributed the remaining 197.5% of IVI values.

3.4. Population Structure Woody Species. Tree species of the study area were divided into seven height and DBH classes. The overall height and DBH class distribution of all individuals of different sizes showed more or less an inverted J-shape distribution in the MFBR (Figures 7(a) and 7(b)). Similarly, the distribution of individuals in different height and DBH classes was showed more or less an inverted J-shape distribution in each study site (Figures 8(a) and 8(b)).

In this study, six representative patterns of population distribution based on DBH were revealed for tree species (Figures 9(a)–9(f)), which are mentioned as follows:

(1) Inverted J-shape, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes; e.g., *Celtis zenkeri* and *Lecaniodiscus fraxinifolius* in study site II; *Blighia unijugata* and *Antiaris toxicaria* in study site III; and *Schefflera myriantha* in study site IV.

(2) An increase from DBH class I to DBH class II and followed by a gradual decrease towards the higher DBH classes; e.g., *Celtis zenkeri*, *Diospyros abyssinica*, *Antiaris toxicaria*, *Pouteria altissima*, *Lecaniodiscus fraxinifolius*, and *Celtis toka* in study site I; *Baphia abyssinica* in study sites II and III; and *Cyathea manniana*, *Dracaena afromontana*, and *Vernonia auriculifera* in study site IV. This pattern represents more or less a normal population structure.

(3) U-shape, which shows a type of frequency distribution in which there is a high number of lowest and highest diameter classes but a very low number of intermediate classes; e.g., *Pouteria altissima* in study site II, and *Ilex mitis* and *Schefflera abyssinica* in study site IV.

(4) Irregular shape, which shows a pattern where the frequency is high at lower DBH classes but becomes irregular towards higher classes. The species that show such pattern are *Pouteria altissima*, *Vernonia auriculifera,* and *Morus mesozygia* in study site I; *Antiaris toxicaria* n study site II; and *Pouteria alnifolia*, *Pouteria altissima*, and *Trichilia prieuriana* in study site III.

(5) Bell-shaped is a type of frequency distribution in which several individuals in the middle diameter classes are high and lower in lower and higher diameter classes; e.g., *Cordia Baphia abyssinica* in site I; *Cordia africana* and *Ficus exasperate* in study site II; and *Trilepisium madagascariense* in study site IV.

(6) J-shaped; e.g., *Allophylus abyssinicus* in study site IV. This pattern represents abnormal population dynamics and shows poor reproduction and hampered regeneration since either most trees are not producing seeds due to age or there are losses due to predators after reproduction.

3.5. Regeneration Status of Woody Species. The total density of seedlings, saplings, and trees was 3461 ha^{-1}, 1203 ha^{-1}, and 1350 ha^{-1}, respectively. Out of 80 trees species of DBH >5 cm, 7 tree species were not represented by seedlings and 11 tree species were not represented by saplings. Twelve tree species contributed 73.6% and 34.7% of the total seedling and sapling count, respectively (Table 10). They are *D. abyssinica, A. toxicaria, P. altissima, B. unijugata, C. zenkeri, C. sylvaticus, L. fraxinifolius, B. abyssinica, G. mollis, P. alnifolia, D. afromontana,* and *G. saxifraga* (Appendix 7).

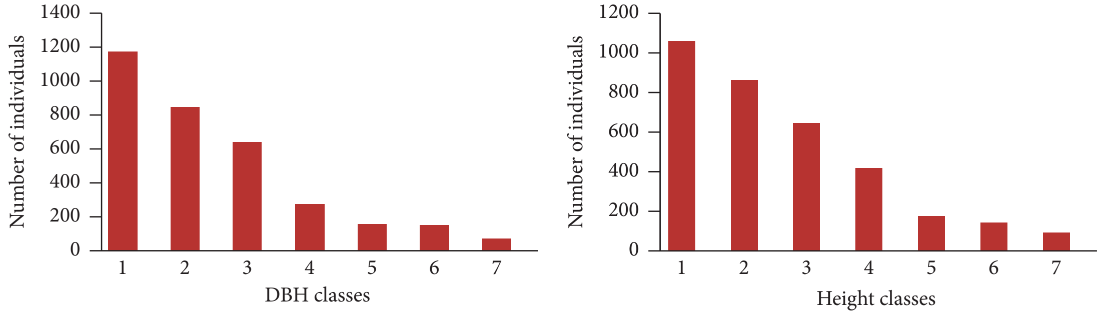
Regeneration status was represented by the following four distribution patterns (Figure 10):

> Pattern (1): this pattern was exhibited by *C. sativa, L. fraxinifolius, B. abyssinica, A. toxicaria, C. manniana, D. afromontana,* and *G. saxifrage* (Figure 10(a), Tables 11–14)
>
> Pattern (2): this pattern was exhibited by *C. zenkeri, L. fraxinifolius, P. altissima, A. toxicaria, D. abyssinica, C. toka, B. unijugata, M. mesozygia, P. alnifolia, G. mollis, L. welwitschii, F. sur Forssk, B. abyssinica, M. oppositifolius, S. abyssinica T. tomentosa, S. myriantha, P. adolfi-friederici,* and *A. abyssinicus* (Figure 10(b) and 10(c), Tables 11–14)
>
> Pattern (3): this pattern was exhibited by *F. mucuso, A. dimidiata, F. sur Forssk, G. buchananii, M. ferruginea, E. fischeri, F. exasperate, C. africana, L. senegalensis, A. grandibracteata, D. torrida, S. myriantha, C. oligocarpum,* and *E. ampliphylla* (Figure 10(d), Appendixes 9–12)
>
> Pattern (4): this pattern was exhibited by *R. albersii, F. angolensis, C. africana*, and *A. chinense* (Figure 10(e), Tables 11–14)

In addition, the regeneration status of the top ten species in each study site is indicated in Tables 11–14. The regeneration status of all the woody plant species was categorised as "not regenerate" (9.6%), "poor" (30.7%), "fair" (59.5%), and "good" (10.8%) in all sites.

In study site I, the total density of the top ten species of trees, saplings, and seedlings were 313.5 ± 3.8, 176.8 ± 3.5, and 534.7 ± 12.1, respectively (Table 11, Appendix 8). Consequently, the regeneration status of saplings and seedlings showed the regeneration categories "not regenerate" (11.1%), "poor" (17.1%), "fair" (65.7%), and "good" (2.9%) in study site I (Figure 11). The densities of tree, sapling, and seedling were 339 ± 3.1, 225.6 ± 7.5, and 646.7 ± 15.7, respectively (Table 12, Appendix 9), and the regeneration status showed different categories including "not regenerate" (7.1%), "poor" (30.2%), "fair" (51.2%), and "good" (9.3%) in the study site II (Figure 11).

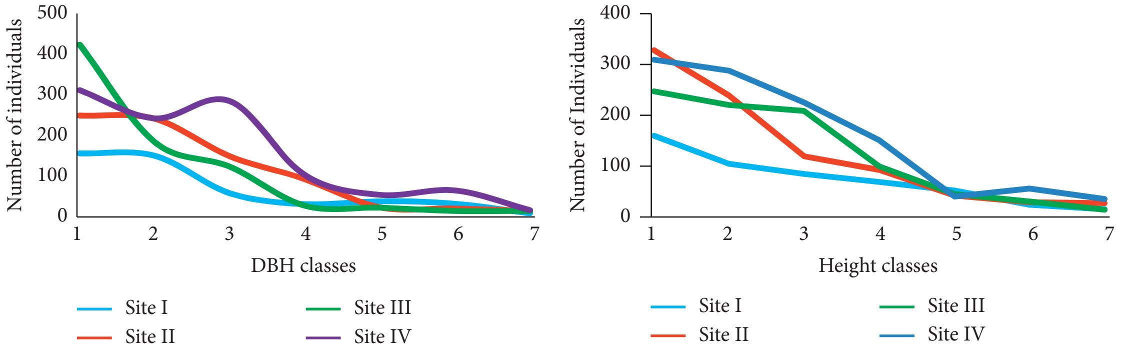
Similarly, in study site III, the densities of trees, saplings, and seedlings were 270.1 ± 3.1, 320.9 ± 7.5, and 978 ± 15.7, respectively (Table 13, Appendix 10), and regeneration status was categorised as "not regenerate" (15.9%), "poor" (13.6%), "fair" (59.1%), and "good" (9.1%), (Figure 11). The densities of trees, saplings, and seedlings were 615 ± 3.1, 708.7 ± 7.5, and 1657.5 ± 15.7, respectively (Table 14, Appendix 11), and showed different regeneration statuses



(a)

(b)

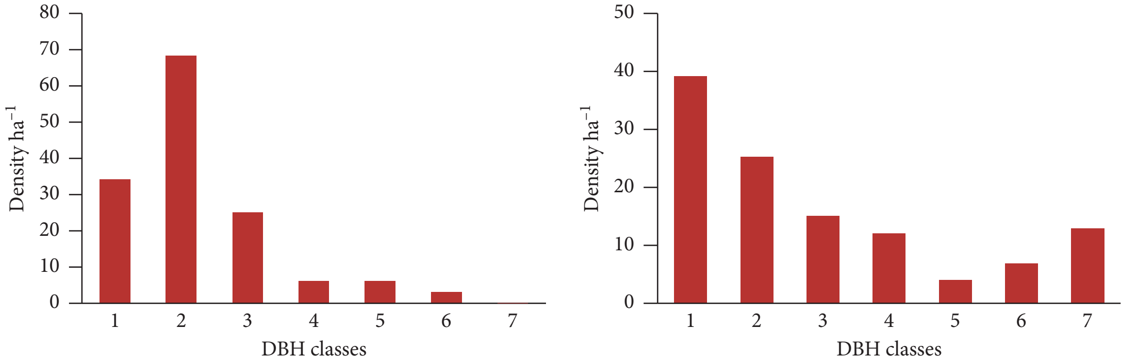
Figure 7: DBH and height class distribution of all individuals. (a) DBH classes: 1 = 5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–30 cm; 4 = >30.01–40 cm; 5 = 40.01–50 cm; 6 = 50.01–80 cm; 7= > 80 cm. (b) Height classes: 1 = 2–5 m; 2 = 5.01–10 m; 3 = 10.01–15 m; 4 = 15.01–20 m; 5 = 20.01–25 m; 6 = 25.01–30 m; 7= > 30 m.



(a)

(b)

Figure 8: DBH and height class distribution of all individuals. (a) DBH classes: 1 = 5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–30 cm; 4 = >30.0140 cm; 5 = 40.01–50 cm; 6 = 50.01–80 cm; 7 = >80 cm. (b) Height classes: 1 = 2–5 m; 2 = 5.01–10 m; 3 = 10.01–15 m; 4 = 15.01–20 m; 5 = 20.01–25 m; 6 = 25.01–30 m; 7 = >30 m.



(a)

(b)

Figure 9: Continued.

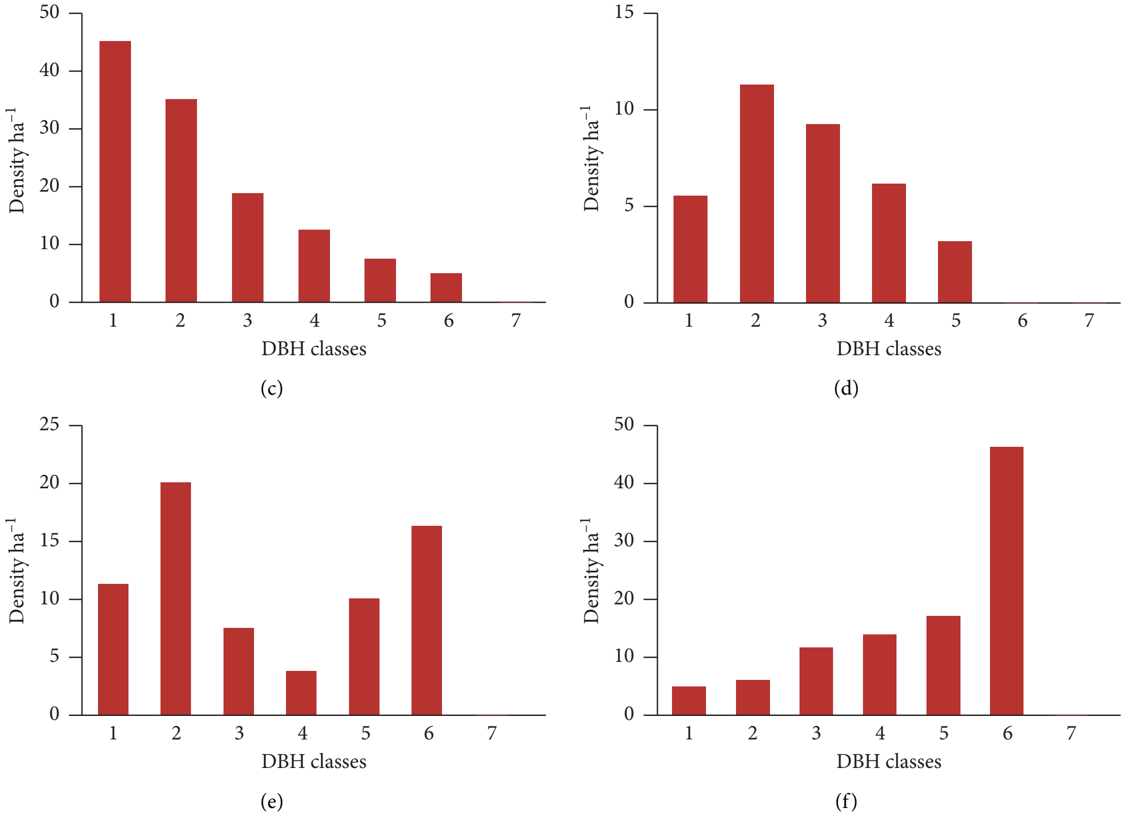


Figure 9: Pattern of frequency distribution of selected tree species over DBH classes (1 = 5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–30 cm; 4 = >30.01–40 cm; 5 = 40.01–50 cm; 6 = 50.01–80 cm; 7 = >80 cm) in all sites. (a) *C. zenkeri* in site I. (b) *P. altissima* in site II. (c) *B. unijugata* in site III. (d) *B. abyssinica* in site I. (e) *V. auriculifera* in site I. (f) *A. abyssinicus* in site IV.

Table 10: List of top 12 species regeneration status in all sites.

Species local name	SP	%	SD	%
Diospyros abyssinica (Hiern) F.White	43.8	3.6	606.6	17.5
Antiaris toxicaria Resch	32.8	2.7	438.1	12.7
Pouteria altissima (A.Chev.) Baehni	28.1	2.3	273.1	7.9
Blighia unijugata Bak.	28.4	2.4	220.0	6.4
Celtis zenkeri A.Rich) Wedd	31.3	2.6	189.7	5.5
Croton sylvaticus Krauss	74.7	6.2	184.1	5.3
Lecaniodiscus fraxinifolius Bak.	55.6	4.6	168.4	4.9
Baphia abyssinica Brummit	50.9	4.2	149.1	4.3
Grewia mollis A.Juss.	9.1	0.8	100.9	2.9
Pouteria alnifolia (Bak.) Roberty	8.1	0.7	90.9	2.6
Dracaena afromontana Mildbr.	32.8	2.7	79.7	2.3
Galiniera saxifraga (Hochst.) Bridson	22.5	1.9	45.3	1.3
Total	**418.125**	**34.7**	**2545.938**	**73.6**

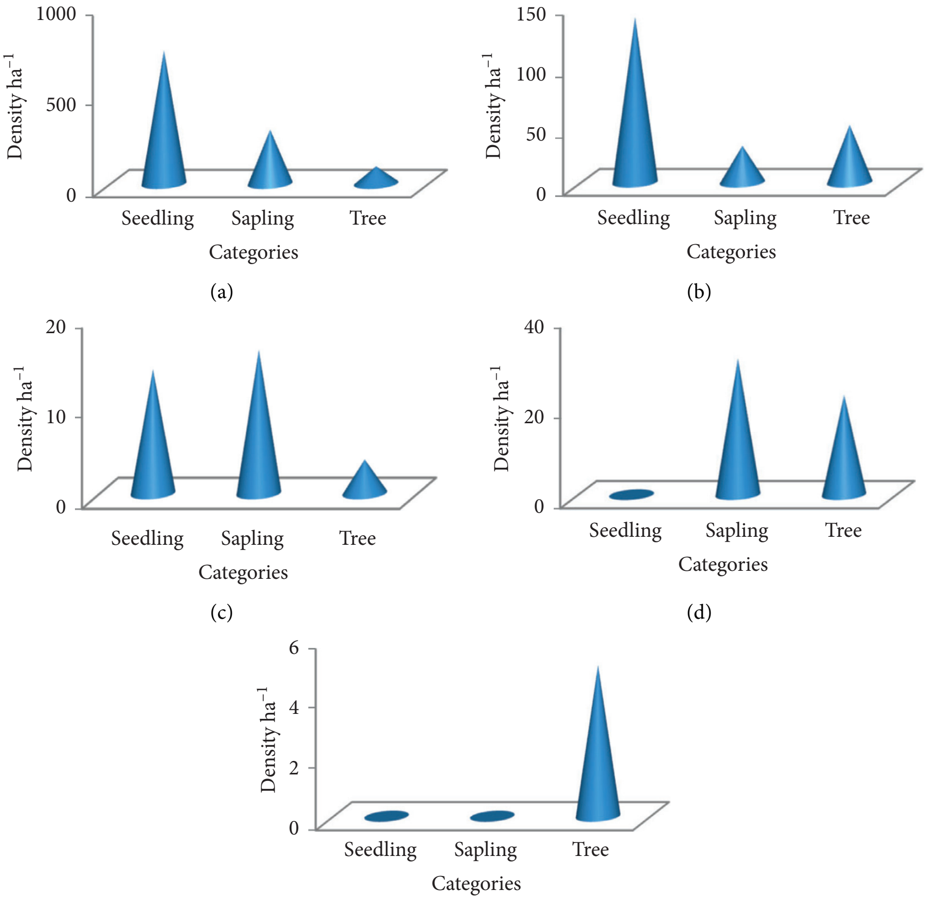
SP = sapling density; SD = seedling density.

including "not regenerate" (4.4%), "poor" (11.1%), "fair" (62.2%), and "good" (22.2%) in study site IV, (Figure 11).

3.6. Site Factors versus Regeneration Status. In the present analysis, site factors were computed and compared with the density of trees, saplings, and seedlings using Pearson correlation (r). The correlation result between natural regeneration of trees, saplings, and seedlings and site factors revealed both positive and negative relationships (Table 15). Canopy openness and harvesting index showed a negative relationship with seedling, sapling, and tree density. The Pearson correlation coefficient between canopy openness with seedling, sapling, and tree density were negative ($r = -0.02$, $P = 0.09$; $r = -0.26$, $P = 0.08$; and $r = -0.13$, $P = 0.0004$, respectively). Similarly, the harvesting index

Table 11: Regeneration status of top ten species in site I (Janje–Dope).

Species name	Family name	TD	SP	SD	RS
Celtis zenkeri A.Rich) Wedd	*Urticaceae*	59.2	36.7	58.3	F
Lecaniodiscus fraxinifolius Bak.	*Sapindaceae*	39.6	27.9	56.7	F
Pouteria altissima (A.Chev.) Baehni	*Sapotaceae*	39.2	25.0	69.6	F
Antiaris toxicaria Resch	*Moraceae*	32.9	13.8	87.1	F
Diospyros abyssinica (Hiern) F.White	*Ebenaceae*	28.8	24.6	68.8	F
Celtis toka (Forssk.) Hepper & Wood	*Ulmaceae*	26.3	7.9	22.1	F
Blighia unijugata Bak.	*Sapindaceae*	23.8	10.4	129.2	F
Fagaropsis angolensis (Engl.) Dale	*Rutaceae*	22.9	0.0	0.0	NR
Morus mesozygia Stapf.	*Moraceae*	20.4	9.2	19.6	F
Vernonia amygdalina Del.	*Asteraceae*	20.4	21.3	23.3	G
Mean ± std. error		**313.5 ± 3.8**	**177 ± 3.5**	**534.7 ± 12**	



(a) (b) (c) (d) (e)

Figure 10: (a-e). Seedlings, saplings, and tree/shrub distribution of selected species occurring in each site of MFBR. (a) *Cyathea manniana.* (b) *Pouteria altissima.* (c) *Vernonia hochstetteri.* (d) *Ficus mucuso.* (e) *Alangium chinense.*

Table 12: Regeneration status of top ten species in site II (Newi–Baya).

Species name	Family name	TD	SP	SD	RS
Pouteria altissima (A.Chev.) Baehni	*Sapotaceae*	47.9	30.4	137.9	F
Celtis zenkeri A.Rich) Wedd	*Urticaceae*	45.8	28.8	76.7	F
Lecaniodiscus fraxinifolius Bak.	*Sapindaceae*	45.0	66.7	123.3	G
Antiaris toxicaria Resch	*Moraceae*	37.9	21.3	110.0	F
Baphia abyssinica Brummit	*Fabaceae*	37.5	58.8	94.6	G
Pouteria alnifolia (Bak.) Roberty	*Sapotaceae*	27.1	4.6	27.9	F
Grewia mollis A.Juss.	*Tiliaceae*	26.3	4.6	38.3	F

Table 12: Continued.

Species name	Family name	TD	SP	SD	RS
Lannea welwitschii (Hiern) Engl.	*Anacardiaceae*	24.6	5.8	16.3	F
Ritchiea albersii Gilg	*Capparidaceae*	23.5	0.0	0.0	NR
Ficus sur Forssk	*Moraceae*	23.4	4.6	21.7	F
Mean ± std. error		**339 ± 3.1**	**225.6 ± 7.5**	**646.7 ± 15.7**	

Table 13: Regeneration status of top ten species in site III (Gonchi–Gelesha).

Species name	Family name	TD	SP	SD	RS
Blighia unijugata Bak.	*Sapindaceae*	41.3	25.8	150.4	F
Celtis zenkeri (A.Rich) Wedd	*Urticaceae*	40.4	10.8	117.9	F
Pouteria altissima (A.Chev.) Baehni	*Sapotaceae*	33.8	7.1	156.7	F
Baphia abyssinica Brummit	*Fabaceae*	27.1	9.2	57.1	F
Antiaris toxicaria Resch	*Moraceae*	22.9	22.5	387.1	G
Pouteria alnifolia (Bak.) Roberty	*Sapotaceae*	22.1	8.8	99.6	F
Ficus ovate Vahl	*Moraceae*	21.3	2.5	6.3	F
Alangium chinense (Lour.) Harms	*Alangiaceae*	20.8	0.0	0.0	NR
Mallotus oppositifolius (Geisel) Mull	*Euphorbiaceae*	20.4	234.2	3.3	F
Cordia africana Lam.	*Boraginaceae*	20.0	0.0	0.0	NR
Mean ± std. error		**270 ± 2.6**	**321 ± 22.6**	**978 ± 37.7**	

Table 14: Regeneration status of top ten species in site IV (Kabo–Gumare).

Species name	Family name	TD	SP	SD	RS
Cyathea manniana Hook	*Cyatheaceae*	96	298.75	736.25	G
Dracaena afromontana Mildbr.	*Dracaenaceae*	90	131.25	318.75	G
Trilepisium madagascariense DC	*Moraceae*	71	60	165	F
Schefflera abyssinica (Hochst. ex A.Rich.) Harms	*Araliaceae*	68	15	7.5	F
Galiniera saxifraga (Hochst.) Bridson	*Rubiaceae*	65	90	181.25	G
Triumfetta tomentosa Boj.	*Tiliaceae*	45	41.25	82.5	F
Schefflera myriantha (Bak.) Drake	*Araliaceae*	45	0	32.5	F
Pouteria adolfi-friederici (Engl.) Baehni	*Sapotaceae*	45	45	38.75	F
Allophylus abyssinicus (Hochst.) Radlk.	*Sapindaceae*	45	10	60	F
Macaranga capensis (Baill.) Sim	*Euphorbiaceae*	45	17.5	35	F
Mean ± std. error		**615 ± 6**	**708 ± 28**	**1657 ± 70**	

Note. TD = tree density, SP = sapling density, SD = seedling density, RS = regeneration status.

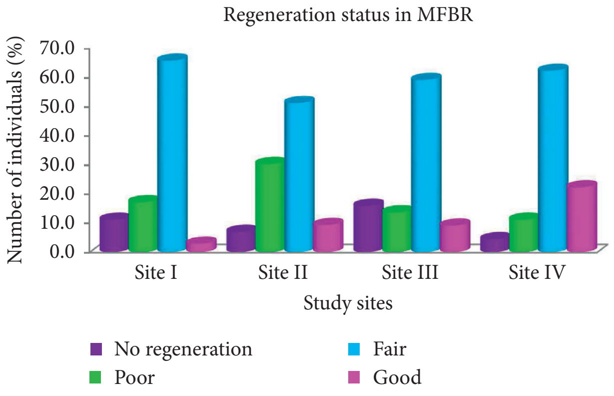


Figure 11: Regeneration status of woody species in MFBR.

showed a negative relationship with seedling, sapling, and tree density ($r = -0.03$, $Pp = 0.09$; $r = -0.29$, $P = 0.1$; and $r = -0.03$, $P = 0.000016$, respectively).

Elevation showed a significant positive relationship with sapling and tree density ($r = 0.28$, $P = 0.000001$, and $r = 0.44$, $P = 0.000001$, respectively), whereas tree density showed a significant negative relationship ($r = -0.02$, $P = 0.000001$). Slope also showed a positive relationship with seedling ($r = 0.03$, $P = 0.07$) and sapling ($r = 0.12$, $P = 0.09$) density, whereas tree density showed a negative relationship ($r = -0.03$, $P = 0.94$). In addition, canopy openness and harvesting index ($r = -0.12$, $P = 0.07$, and $r = -0.06$, $P = 0.09$, respectively) showed a negative relationships with herbaceous cover. The abundance of the herbaceous cover showed a negative relationship ($r = -0.03$, $P = 0.172$) with the density of seedlings (Table 15).

4. Discussion

4.1. Species Composition. The number of species composition in Majang forest biosphere reserves (56 families, 115 genera, and 158 plant species) is higher than other forest sites including Agama forest (35 families, 65 genera, and 72 plant species) [41], Maji forest (55 families, 115 genera, and 146 plant species) [42], Wurg forest (40 families, 64 genera, and 76 plant species) [43], and Oda forest (32 families, 54 genera, and 62 plant species) [44] but lower than Gerba-

Table 15: Pearson correlation matrix in the density of seedlings, saplings, and tree stems ha^{-1}.

Variables	SD	SP	TD	HaCa	CaOp	Hi	Slp	Elv
SD								
SP	−0.11							
TD	−0.09*	0.26*						
HaCa	−0.03	0.12	0.08*					
CaOp	−0.02	−0.26	−0.13*	−0.12				
Hi	−0.03	−0.29	−0.03*	−0.06	0.11			
Slp	0.03	0.12	0.03*	−0.01	−0.13	−0.18		
Elv	−0.02*	0.28*	0.44*	0.05*	0.15*	0.05*	0.12*	

*Significant at $P < 0.05$, SD = seedling density, SD = sapling density, TD = tree density, HaCa = herbaceous cover, CaOp = canopy openness, Hi = harvesting index, Slp = slope, and Elv = elevation.

Dima forest (69 families, 145 genera, and 180 plant species) [45], Yayu forest (72 family, 163 genera, and 217 plant species) [4], and Bonga forest (92 families, 207 genera, and 285 plant species) [42]. The variation of plant species over different habitats of the forest could be attributed to a number of environmental factors, which impose impacts in both temporal and spatial scales [46]. Thus, environmental heterogeneity, regeneration capacity, moderate disturbance, and competition might shape and determine species richness of the forest. Moreover, from the identified woody species, Majang forest biosphere reserves sheltered relatively few numbers of endemic plant species to Ethiopia [47], i.e., *Bothriocline schimperi*, *Clematis longicauda*, and *Vepris dainellii*.

4.2. Vegetation Structure

4.2.1. Density of Woody Species. The stem densities varied with species composition, diameter size classes, and the degree of disturbance. Specifically, the stem densities of tree species with DBH > 5 cm in four study sites ranged from 1232 to 1478 stems ha^{-1} (Table 5) are lower than those reported from Wurg forest (1745 ha^{-1}) [43], Masha forest (1681 ha^{-1}) [48], and Gelesha forest (1659 ha^{-1}) [49] in southwestern moist Afromontane forest and higher than a moist tropical forest (843 stems ha^{-1}) [50]. On the other hand, the density mentioned in this study is more or less comparable with that of Agama forest (1446 ha^{-1}) [41]. The variation of tree densities of MFBR study sites may be due to variations in elevation, aspect, species composition, age, structure [51], and disturbance levels [52].

The ratio of tree/shrub density (10 cm < DBH <20 cm and >20 cm) was taken as a measure of the class size distribution [56]. Accordingly, the value of the tree/shrub density ratio was 1.4 in Majang forest biosphere reserves, which is more or less comparable with Gelesha [53] and Gurafreda [58]. This similarity may be due to connection with geographical location, climatic condition, and altitude factors. On the other hand, the ratio a/b at MFBR was lower than that at Wurg, Agama, Jima, Menna Angetu, Belete, Masha, Masha Anderacha, and Komto; it indicates that all studies have higher proportions of small-sized individuals than the MFBR. This difference may be due to in the stage of secondary succession of the forests (Table 16).

Table 16: Comparisons of tree densities with DBH 10–20 cm (a) and DBH > 20 cm (b) of MFBR with eleven other moist Afromontane forests in southwestern Ethiopia.

Name of forests	Density ha^{-1}				Ratio	Source
	(a)	%	(b)	%	a/b	
Wurg	516	76.3	160.5	23.7	2.3	[43]
Agama	556.3	66.4	280.9	33.6	2.0	[41]
Gelesha	215	56.9	163	43.1	1.3	[49]
Gelesha	315.4	56.3	244.6	43.7	1.3	[53]
Belete	305.1	67.2	149	32.8	2.0	[54]
Masha	633	68.9	286	31.1	2.2	[48]
Komto	330	60.6	215	39.4	1.5	[55]
Menna Angetu	292	67.7	139	32.3	2.1	[56]
Harenna	335	64.5	184	35.5	1.8	[57]
Guraferda	633	55.9	499	44.1	1.3	[58]
Masha Anderacha	387.7	70.7	160.5	29.3	2.4	[59]
Majang	617.5	57.8	450.3	42.2	1.4	**Present study**

4.2.2. Frequency of Woody Species. Frequency indicates the homogeneity or heterogeneity of a given stand [27, 60], an occurrence of a species in a given area which indicates how species are distributed [27, 61]. In all study sites of MFBR, the frequency value of woody species ranges from 0.1% to 99%. The highest frequency was shown by *Celtis zenkeri* (88%) in study site I, *Pouteria altissima* (100%) in study site II, *Celtis zenkeri* (95%) in study site III, and *Dracaena afromontana* and *Cyathea manniana* (100%) in study site IV (Table 7). These may be due to a wide range of seed dispersal mechanisms like wind, livestock, wild animals, and birds.

High values in lower frequency classes and low values in higher frequency classes indicate a high degree of floristic heterogeneity [62]. The frequency distribution of woody species in the MFBR shows that the number of tree species found in the first frequency classes is higher (A and B) and gradually decreases towards higher frequency classes (D and E), which is similar to that mentioned by Dibaba et al. [41] in Agama forest, Girma and Melese [43] in Wurg forest, Edae and Soromessa [49] in Gelesha forest in southwestern moist Afromontane, and Dibaba et al. [63] in dry Afromontane forest. In contrast, Mekonen et al. [64] found that the number of tree species found in the first frequency classes is lower (A and B) and gradually increases towards higher frequency classes (D and E) in Woynwuha natural forest in northwestern Ethiopia. Such variation may be due to uniform species composition or homogeneity in the area.

4.2.3. Basal Area. A species with a greater basal area could be considered the most important species in a given study forest [65]. Basal area per hectare used as an indicator of degradation level or status of standing stock. If the basal area is very small, we can conclude that the forest is degrading. The total basal area of all woody species in the MFBR was about 139.8 m^2 with DBH > 5 cm, which is greater than that of Wurg, Belete, Gelesha, Bibita, and Agama in moist

Afromontane forests, southwestern Ethiopia, and Dodola, Wof-Washa, Manna Angetu, and Yemrehane Kirstos in dry Afromontane forests while lower than that of Wof-Washa in dry Afromontane forest and Masha Anderacha in moist Afromontane, southwestern Ethiopia, which is adjacent to the current study (Table 17).

There was a significant difference between the MFBR study sites in terms of basal area. The total basal area ranges (56.8 to 76.3 $\mathrm{m}^2\,\mathrm{ha}^{-1}$) in the four study sites (I–IV) (Table 5) are greater than the range of basal area (17 to 40 $\mathrm{m}^2\,\mathrm{ha}^{-1}$) reported in dry forests of the world [70]. The increments in the basal area from sites I–IV may be due to more number of individuals in higher diameter size classes with increments in elevation and minimal incidences of disturbance within the study site.

The highest basal area of individual tree species in the study site was contributed by *C. zenkeri* in the study sites I and III, *P. altissima* in study site II, and *D. afromontana* in site IV, whereas the highest density was exhibited by *D. abyssinica* in study site I, *L. fraxinifolius* in study site II, *B. unijugata* in study site III, and *C. manniana* in site IV. This shows that the species with the highest basal area do not necessarily have the greater density and vice versa, which is also true, indicating a size difference between species [65].

4.2.4. Importance Value Index. The importance value index is used for comparison of ecological key species [62] and ranking species for management and conservation priority. In this respect, the IVI of woody species of the MFBR was calculated from relative density, relative dominance, and relative frequency [71]. The species with larger IVI need monitoring and management, whereas the species with smaller importance value index need high conservation effort [62]. In this study, the maximum IVI was contributed by *C. zenkeri* (9.8) and the lowest was by *F. thonningii* in the MFBR or overall study area (1.1). The most ecologically significant tree species in the MFBR were *C. zenkeri*, *P. altissima*, *B. unijugata*, *L. fraxinifolius*, *D. afromontana*, *A. toxicaria*, *B. abyssinica*, *C. toka*, *S. myriantha*, and *P. adolfi-friederici* and could influence the overall forest structure (Table 7 and Appendix 2).

More in detail, the highest IVI value was exhibited by *C. zenkeri* in study site I, *P. altissima* in study site II, *B. unijugata* in study site III, and *C. manniana* study site IV, whereas the least IVI value was exhibited by *M. lanceolata* in study site I, *B. polystachya* in study site II, *L. zeylanica* in study site III, and *F. sur* in study site IV (Table 7, Appendixes 3–6). According to the criteria set by the Institute of Biodiversity Conservation and Research [38], the total values of IVI in each species in all study sites were under conservation/restoration priority classes 1–3 (priority class 1 = <1, priority class 2 = 1–10, and priority classes 3 = 10.1–20). Therefore, the woody species those showed the lower IVI may indicate threatened species and need immediate conservation measure.

4.2.5. Population Structure of Woody Species. Population structure refers to the spreading of individual species in random diameter-height size classes to provide the overall regeneration profile of woody and shrub species [72, 73]. The structural patterns of the population could be understood as an indication of variation in population dynamics that may occur because of natural characters or due to humans and livestock interventions [74, 75]. In this study, the population patterns of height and DBH class distribution of all individuals in different sizes showed more or less an inverted J-shape distribution in the total results of MFBR (Figures 7(a) and 7(b)). This means species frequency distribution had the highest frequency in the lower diameter and height classes and a gradual decrease towards the higher classes. The possible reason for the decreasing higher diameter class may be due to illegal logging of middle and high diameter class trees for various purposes by local people such as for fencing, farm implementing, house construction, and fuel wood. Similarly, the distribution of individuals in different height and DBH classes' dominant species showed more or less an inverted J-shape distribution in each study site (Figures 8(a) and 8(b)). An inverted J-shape population pattern is a normal plant population structure and shows the occurrence of species in a healthier condition. This is similar to other findings that reported moist Afromontane forest in southwestern parts of Ethiopia [41, 43, 48, 53–55, 57, 58, 69, 76] and dry Afromontane forest [66–68]. However, the overall population pattern does not indicate the trends of population dynamics and recruitment processes of individual species [20, 63]. Specifically, six representative patterns of population distribution were exhibited in the MFBR, which is similar to other findings in Ethiopia [20, 43, 57, 77, 78]. Hence, generally assessing the population structure is important to provide a preliminary indication about the regeneration status of woody plants and shrubs in a studied forest [78, 79].

Table 17: Comparison basal area per hectare of Majang biosphere reserves natural forest with other ten moist Afromontane forests in Ethiopia.

Name of forests	Basal area ($\mathrm{m}^2\,\mathrm{ha}^{-1}$)	Sources
Wof-Washa	153.26	[66]
Masha	142.61	[48]
Majang	**139.8**	**Present study**
Dodola	129	[67]
Wurg	126.5	[43]
Belete	103.5	[54]
Gelesha	98.87	[53]
Menna Angetu	94.2	[56]
Agama	80.8	[41]
Yemrehane Kirstos	72	[68]
Bibita	69.9	[69]

4.2.6. Regeneration Status of Woody Species. The status of forest regeneration depends on the composition, distribution, and density of seedlings, saplings, and adult trees in the forest [12]. The recruitment or regeneration condition of woody species is one of the main factors that are valuable to evaluate forest conservation status [80]. The population structure, characterised by the presence of a sufficient population of seedlings, saplings, and adults, indicates the successful regeneration of forest species [81]. In this study, the regeneration status of saplings and seedlings showed four regeneration patterns (no regeneration, poor, fair, and good). The "poor" and "no regeneration" patterns were exhibited by 28.1%, 44.3%, 29.2%, and 15.5% of the woody plants in study sites I, II, III, and IV, respectively, of MFBR. Thus, the variation of hamper regeneration among study sites may be due to the presence of anthropogenic factors and environmental factors [12, 82]. This result is more or less similar to that reported in Berbere forest (32.26%) [83], Wof-Washa (48%) [84], Central Highland (20.9%) [85], and Wurg forests (14%) [43]. The lower seedling count in the MFBR showed limited regeneration potential that could be due to unlimited vegetation exploitation by the local community. However, there are some germination of seeds due to few remaining mother trees; most of these seedlings vanished before reaching sapling and mature stages for various reasons including grazers, browsers pressure, and illegal exploitation [86].

The "poor" and "no regeneration" of the woody species in the study sites of MFBR generally falls below half percent. These conditions might have occurred through the existence of disturbances such as overgrazing [9, 66, 87–89], fuel wood collection, agricultural expansion, settlement, and poor biotic potential of tree species that affects the fruit setting and germination of seeds [20, 90, 91]. Poor regeneration is an indication of poor reproduction and hampered regeneration, which is due to old age individuals and loss of seeds by predators after reproduction or successful conversion of seedling to sapling stage [92]. Moreover, individuals in young stages of any species are more vulnerable to any kind of environmental stress and anthropogenic disturbance [93]. Therefore, the absence of seedlings and saplings of woody species designates the immediate requirement of a forest management plan to improve forest regeneration [20, 94].

4.3. Site Factors versus Regeneration Status. In this study area, the correlation result between natural regeneration of trees, saplings, and seedlings and site factors revealed both positive and negative relationships (Table 15). The correlation analysis of elevation indicated a negative relationship with seedling and a positive relationship with sapling densities. The negative relationship of elevation with seedling density may be due to human disturbance coupled with population density increment when elevation increased, which is similar to the findings of other tropical forests [95]. The slope also showed a positive relationship with seedling and sapling densities. This may be due to difficulty to reach an area of human disturbance with increasing of the slope (Table 15).

Harvesting index and canopy openness showed a negative relationship with seedling, sapling, and tree densities, which ultimately affects the regeneration status of the species. For instance, illegal logging of tree species leads to a reduction in the mother tree or seed sources, and it facilitates the growth of understory, shrubs, and composition of species in the area. This also enforces abiotic stress like evapotranspiration and loss of soil moisture that retard regeneration [88]. It was also reported that the canopy openness of forests affects the species composition, richness, and regeneration of tree species [96]. However, different studies reported that most species had increased regeneration with increased canopy openness [97, 98]. This might be due to the species characteristics of shade-tolerant and intolerant species that exhibit variations of regeneration with the degree of canopy openness.

Numerous structural characteristics influence the regeneration of species, especially the stem density of trees and abundance of herbaceous cover. The density of trees had a negative relationship with that of seedlings; this may be due to high competition with trees and herbaceous cover, causing the survival of seedlings. This result coincides with previous results in tropical forests [99]. In other studies, however, positive correlations were found between densities of trees and herbaceous cover and seedling density [100]. The interactions between seedlings and herbaceous cover result in forest dynamics because dense herbaceous cover decreases light availability near the forest floor and results in the decline of seedling regeneration [101]. The seedlings density was reduced in response to high herbaceous cover, indicating competitive effects for space and resources between seedlings and their nontree competitors. Higher herbaceous cover played a major role in preventing successful seed germination, seedling establishment, growth, and survival [102].

5. Conclusion and Recommendation

The current study delivers important information about the state of woody plant species composition, structures, and regeneration of woody plant species and the impacts of site factors on the natural regeneration of tree species of Majang forest biosphere reserves. The results revealed that the diversity is high, with a total of 158 plant species belonging to 115 genera and 56 families. Among these, the plant species *Dracaena afromontana*, *Celtis zenkeri*, and *Pouteria altissima* were the most frequent and dominant with greater important value index (IVI) in MFBR. The overall height and DBH class distribution of all individuals of different sizes showed more or less an inverted J-shape distribution in MFBR. However, a few numbers of species showed an unhealthy population structure or poorly represented either in the lower or higher DBH and height classes. Considering seedling, sapling, and tree densities, the regenerating status of all the woody plant species were categorised as "not regenerate" (9.6%), "poor" (30.7%), "fair" (59.5%), and "good" (10.8%) in all sites. The correlation result between natural regeneration of trees, saplings, and seedlings and site factors revealed both positive and negative relationships. However, the main threat to the biosphere reserve is the illegal logging of some tree species for different purposes. Therefore, awareness creation on sustainable forest management, utilisation, conservation of priority species, and livelihood diversification to the local community and encouraging community and private woodlot plantation in the transitional zone of the biosphere reserves are recommended.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors thank the Center of Environmental Sciences, Addis Ababa University, for their contribution. This study was funded by Addis Ababa University.

Supplementary Materials

Appendix 1: list of species in MFBR. Appendix 2: stand structure and IVI of species in all the sites of the MFBR. Appendix 3: stand structure and IVI of species in site I of the MFBR. Appendix 4: stand structure and IVI of species in site II of the MFBR. Appendix 5: stand structure and IVI of species in site III of the MFBR. Appendix 6: stand structure and IVI of species in site IV of the MFBR. Appendix 7: seedlings, saplings, and trees per hectare of woody species in MFBR. Appendix 8: seedlings, saplings, and trees per hectare of woody species with regeneration status in study site I. Appendix 9: seedlings, saplings, and trees per hectare of woody species with regeneration status in study site II. Appendix 10: seedlings, saplings, and trees per hectare of woody species with regeneration status in study site III. Appendix 11: seedlings, saplings, and trees per hectare of woody species with regeneration status in study site IV. Appendix 12: Dominant trees with their percentage basal area of MFBR. Appendix 13: basal area per ha in site I of the MFBR. Appendix 14: basal area per ha in site II of the MFBR. Appendix 15: basal area per ha in site III of the MFBR. Appendix 16: basal area per ha in site IV of the MFBR. (*Supplementary Materials*)

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