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Research Article

Woody Species Composition, Structure, and Diversity of Dindin Natural Forest, South East of Ethiopia

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Information on species composition, structure, and diversity is essential to introduce and select different management activities to improve the forest productivity. Accordingly, species composition, structure, diversity, and regeneration status of trees were assessed in the Dindin natural forest. In this forest, trees or shrubs having ≥2.5 cm diameter at breast height and height >1.5 m were identified and measured in 35 quadrats of 20 m × 20 m. Regeneration status was assessed in 5 m × 5 m subplots that were laid within each main plot to sample seedling and sapling. Woody species diversity, density, basal area, and importance value index were calculated. To prioritize conservation efforts, the study utilized factors such as the importance value index, seedling and sapling densities, and population structure. A total of 42 woody tree species representing 30 families were recorded in the forest. The diversity and evenness of woody species in the Dindin forest were 2.66 and 0.70, respectively. Woody species density was 1403 individual ha^{-1}, and the total basal area was 35.54 m^2ha^{-1}. About 480 seedlings per hectare were recorded in the Dindin forest. The research yielded practical insights into the dominance, population structure, importance value, and regeneration status of tree species. The analysis of population structure indicates that certain dominant species are experiencing inadequate regeneration. In addition, multiple nondominant shrubs and tree species within the forest are also at risk of extinction due to insufficient regeneration. Therefore, these important findings play a crucial role in the formulation and implementation of effective strategies to restore and rehabilitate the studied forest.

1. Introduction

Ethiopia is located in the Horn of Africa, distinguished by a diverse range of landscapes, including rugged mountains, river valleys, flat-topped plateaus, deep gorges, and rolling plains [1]. As a result of its extensive variations in altitude and climate [2], Ethiopia is the richest country in biological resources (flora and fauna) [3]. Ethiopia is home to approximately 6,027 species of higher vascular plants, with around 10% of them being endemic to the country [4]. Furthermore, about 544 endemic plant taxa which represent 10% of the overall flora [4] and 16.7% of the flora represents woody plants, of which 30% are mainly indigenous [5].

Tropical deforestation ranges from 69 million ha $year^{-1}$ in the early 1980s to 165 million ha $year^{-1}$ in the late 1980s [6]. Forest cover and biodiversity loss due to anthropogenic activities is a growing concern in many parts of the world [7, 8]. Approximately 650 million hectares of land in Africa are believed to be covered by forests, accounting for roughly 17 percent of the global forest area [9]. A total of 340 million ha of woody vegetation in dry land zones of Africa have become degraded through human activities [10]. Environmental degradation manifested in the form of land and water resource degradation as well as loss of biodiversity is the major challenge in Ethiopia [11]. Rapid human population growth, poverty, forest clearing, overgrazing, and lack of a proper policy framework are the major underlining causes for loss of forest resources and land degradation in Ethiopia [12, 13]. Due to the aforementioned reasons, the forest cover of Ethiopia has been declining from 15.11 million hectares in the 1990s to 12.9 million hectares in 2010, which means about 18.6% of the forest was cleared [14]. Besides, approximately 141,000 hectare of the forest was deforested every year [15]. Increasing population size, a shortage of farmland, and a high energy requirement could be the possible reasons for the conversion of forest lands to other land use types [16].

The dry evergreen montane forest is the second largest flora, next to Acacia Commiphora, constituting about 460 species in Ethiopia [17]. The most common species in this vegetation type are *Juniperus procera* (Endl.), *podocarpus falcatus* (Thunb.), *O. europaea* L. subsp. *cuspidata,* and *Eucalyptus* [18]. However, overgrazing is the most dominant threat to dry Afromontane vegetation structure though there is no evidence on how grazing patterns shape the overall forest system [17]. Besides, deforestation and agricultural land expansion are the major cause for degradation of dry land vegetation [19, 20]. These have led to a decline in the size, productivity, diversity of forest, and woodland and bush land resources [21].

Thus, management intervention in the dry Afromontane forest is imperative to reverse the deforestation and forest degradation. So far, conservation efforts such as traditional community-based forest management practices [22], plantation forests [23], area ex-closure [23, 24], and participatory forest management [25] are being carried out by the Ethiopian government and local communities to restore degraded forests. However, additional measures are required specifically for the restoration of the Dindin forest to enhance its productivity.

The Dindin forest priority area is one of the remaining dry Afromontane forests in the eastern part of Ethiopia [26] which is important for its protective function and conservation of woody plant genetic resources [27]. The forest is also the main niches for *Juniperus procera* and home for many endemic species. A study on the remnant forest patches of the Dindin forest is thus urgently needed as baseline information for ensuring sustainable use of natural vegetation, its conservation, and ecological management practices. Information on species composition, structure, and diversity is essential to introduce and select different management activities to improve the forest productivity. Studies on woody species population structure and density might help to understand the regeneration status of species [28]. Moreover, regeneration is a central component to understand the forest conditions [29]. Utilization of forest resources in a sustainable way is possible if and only if adequate information on regeneration status is available for a given forest ecosystem [28]. A forest can be regarded as healthy when it has a sufficient number of seedlings and samples, characterized by an inverted J-shaped pattern in species distribution cohorts [12, 29–31]. As a conservation approach, scientific studies on woody species composition, structure, and diversity of a given forest patch are desirable to determine the status of the forest and take appropriate conservation measures. Unfortunately, there is a lack of recent and updated information regarding the woody tree species of the Dindin forest, which is crucial for effective management interventions. Thus, the current work on woody tree species composition, diversity, structural analysis, and regeneration status of the vegetation in the study area is believed to contribute a lot to the effective conservation and management of this forest priority area. Thus, the overall objective of this study was to determine the woody species composition, structure, diversity, and regeneration status of the Dindin forest priority area.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Dindin forest priority area in the west Hararghe zone, Oromia region. It is part of the south-eastern highlands and located in the western part of the Ahmar mountain range. The total area is estimated to 19,000 ha [27]. The forest is located at f 8°31′30″ to 8°38′30″ N and 40°12′30″ to 40°19′30″ E (Figure 1). The altitude ranges between 2150 and 3000 m above sea level [26]. The Dindin forest is nationally recognized for its abundant variety of plant and animal species. This particular type of Afromontane forest is characterized by the prevalence of *Juniperus procera* and *Podocarpus falcatus*, alongside various other broad-leaved trees, in mixed stands [26]. According to data from the District Agricultural Bureau in 2003, the average monthly temperature of the area fluctuates between 15°C in December and 25°C in June. The primary rainy season occurs during the summer months of June, July, and August, with an average annual rainfall of up to 1500 mm.

2.2. Sampling Design. A systematic sampling design was used to collect vegetation data from the study site. Five transect lines at 300 m interval were laid following the altitudinal gradient, and a total of 35 sample plots that measure $20\,m \times 20\,m$ $(400\,m^2)$ were established proportionally along transect lines at every 100 m interval within a transect line to record vegetation data.

2.3. Data Collection. To assess woody species diversity and dominance of the Dindin forest, biometric parameters such as diameter at breast height (DBH) and height (ht) were measured from all trees and shrubs within each plot. For this study area, trees and shrubs were defined as woody plants with DBH greater than 2.5 cm and ht exceeding 1.5 m [32]. Specifically, trees were defined as a woody perennial plant with a single main stem and have a definite crown. While shrubs were woody perennial plants, often without a definite crown and several stems growing from the same root. The saplings and seedlings were counted from five $5\,m \times 5\,m$ $(25\,m^2)$ subplots nested within the main plots, four from the corners and one at the middle of the main plots [33, 34].

Key informants and literatures were used for the identification of the species at the field [35]. Plants were identified in the field using the published volumes of the Flora of Ethiopia as well as the Flora of Ethiopia and Eritrea. Specimens were collected for those difficult to identify in the field, processed, and identified through comparing them with already identified specimens placed in the National Herbarium of Ethiopia.

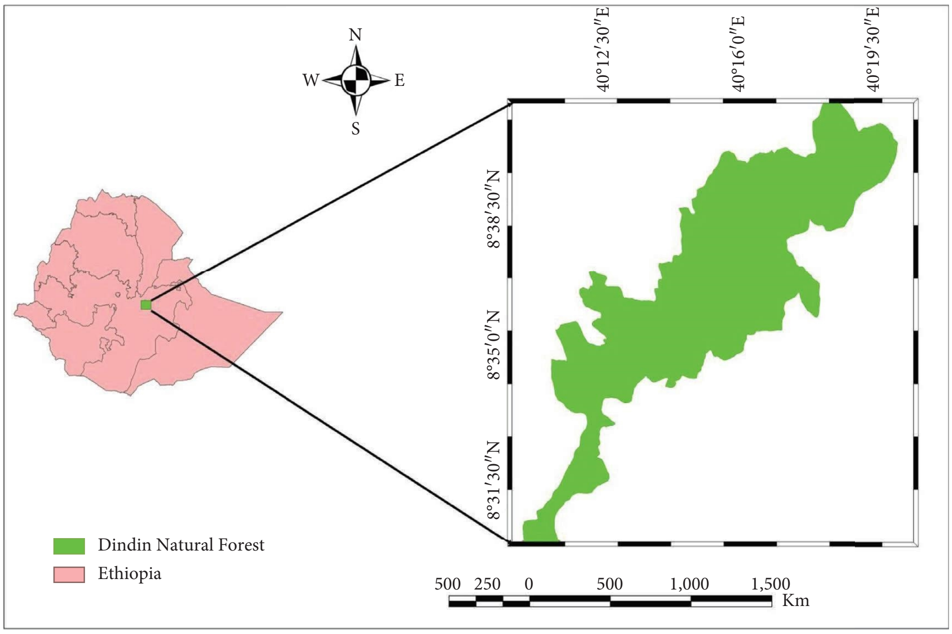

Figure 1: Locational map of the Dindin forest.

3. Methods of Data Analysis

3.1. Diversity. Shannon–Wiener diversity index (H') was used to calculate the diversity indices of different community types because it accounts both for species richness and evenness, as well as it is not affected by the sample size. Shannon–Wiener diversity index and evenness were calculated using the following formula:

$$H' = -\sum_{i=1}^{S} \text{pi} \ln \text{pi}, \quad (1)$$

where H' represents Shannon–Wiener diversity index and pi represents proportion of individuals found in the i^{th} species.

Species richness (S), equitability/evenness (J), and species dominance using the Simpson dominance index [36, 37] were used to analyze species distribution, diversity, evenness, and species dominance, respectively.

Species richness (S) was calculated as

$$S = \sum \text{ni}, \quad (2)$$

where ni is the number of species in a community.

Shannon equitability or evenness is measured as the relative abundance of the different species that make up the richness of a forest area.

Shannon equitability (J) or evenness was calculated using the following formula:

$$J = \frac{H'}{H' \max} = \frac{-\sum_{i=1}^{S} \text{pi} \ln \text{pi}}{\ln S}, \quad (3)$$

where J is the evenness, H' is the Shannon–Wiener diversity index, and $H\text{max}' = \ln S$, in which ln is the natural logarithm and S is the total number of species in the sample.

Simpson's diversity index is a measure of diversity which takes into account the number of species present as well as the relative abundance of each species.

Simpson's diversity index was calculated using the following formula:

$$D = 1 - \sum_{i=1}^{S} \text{pi}^2, \quad (4)$$

where D = Simpson's index of species diversity; S = number of species; and pi = proportion of total sample belonging to the i^{th} species.

3.2. Structural Analysis. Stand characteristics such as stem density, basal area, mean diameter, diameter class distribution, and height class distributions were computed for each plot and averaged per stand unit for all tree/shrubs individuals with a DBH >2.5 cm and a height of >1.5 cm [32]. Woody species were clustered using a 10 cm diameter and 3.5 m height interval.

Basal area (BA), density (D), frequency (F), dominance (DO), and importance value index (IVI) data were calculated using the formula developed [38, 39] to describe woody species structure in the forest. Basal area was calculated as follows:

$$\text{BA} = \pi \frac{d^2}{4}, \quad (5)$$

where BA is the basal area in square meter per hectare, d is the diameter at breast height in meter, and $\pi = 3.14$.

The importance value index (IVI) for each woody species were calculated as: importance value index (IVI) (%) = % relative dominance (RDo) + % relative density (RD) + % relative frequency (RF)

$$\text{where relative dominance (RDo) (\%)} = \left(\frac{\text{Relative dominance of species ith}}{\text{The sum of dominance of all species}}\right) \times * 100,$$

$$\text{dominance (Do)} = \frac{\text{Basal area of ith species}}{\text{Basal area of quadrates in hectare}},$$

$$\text{frequency (\%)} = \frac{\text{Number of plots in which species i occurs}}{\text{Total number of plots laid down}} * 100,$$

$$\text{relative frequency (\%)} = \frac{\text{Frequency of species i}}{\text{The sum of frequency of all species}} * 100, \quad (6)$$

$$\text{density (\%)} = \frac{\text{Total number of all trees}}{\text{Sample size in hectare}} * 100,$$

$$\text{relative density (\%)} = \left(\frac{\text{Density of species i}}{\text{The sum of density of all species}}\right) \text{x } 100.$$

3.3. Regeneration Status of the Forest. Since the study was designed to enhance the future conservation of the forest, determining the regeneration status of the forest is imperative. The regeneration status of our forest was determined based on the population size of seedling, sapling, and mature tree/shrub. If the number of seedling > sapling > tree/shrub the regeneration is at good status, whereas if seedling = sapling = adults, we consider it as fair regeneration. But if seedling is < sapling < adults, we consider it as poor regeneration [30].

4. Results

4.1. Species Composition. The species, family, and life form of each recorded tree and shrub species are summarized in Table 1. A total of 42 woody species representing 30 families were identified in the study area (Table 1). Among the woody species, trees constituted 67% (28 species), shrubs 14% (6 species), and tree/shrubs 19% (8 species) of species encountered indicating that tree species are the most diverse as compared to shrubs and tree/shrubs. The study revealed that seedlings accounted for 30.15% of the total tree population, while saplings and mature trees comprised 36.30% and 33.55%, respectively. Thus, it can be concluded that the study area exhibits a higher abundance of saplings compared to seedlings and mature trees.

4.2. Woody Species Diversity. Diversity, richness, and evenness of woody tree species at seedling, sapling, and adult trees level are presented in Table 2. The diversity indices result showed that a higher value of diversity index was recorded for mature trees than seedling and sapling. Similarly, mature trees were more evenly distributed as compared with seedling and sapling. Shannon–Wiener and Simpson's indices were estimated to be 2.40 and 0.86 for seedling, 2.37 and 0.87 for sapling, and 2.62 and 0.89 for mature trees, respectively.

4.3. Densities of Trees and Shrubs. Table 3 provides a summary of the density of woody tree species across various classes. In the Dindin forest, the density of trees with a diameter at breast height (DBH) equal to or greater than 2.5 cm was 1403.57 individuals per hectare. Out of the total density, 382.14, 492.14, and 529.28 individuals per hectare represented adult trees, saplings, and seedlings, respectively. Trees in the first DBH class (2.5–16 cm) accounted for 36.4% of the total woody species density, followed by the second DBH class (16.1–26 cm) at 23.3%. These two DBH classes together contributed more than 49.70% of the total woody species density in the forest. The density of woody species with DBH greater than 10 cm and DBH greater than 20 cm were 320.71 individuals per hectare and 211.43 individuals per hectare, respectively. The ratio of the density of trees and shrubs with DBH greater than 10 cm to DBH greater than 20 cm was measured as 1.52, indicating the size class distribution.

4.4. Diameter and Height Distribution of the Forest. The distribution of diameter and height classes among all individuals exhibited an inverted J-shaped pattern, as depicted in Figure 2. A significant proportion of individuals were grouped in the first two classes. The DBH class distribution revealed that approximately 68.5% of individuals were categorized in the DBH class <30 cm (classes 1, 2, and 3), while only a small percentage (4%) reached a DBH greater than 60 cm. Similarly, approximately 84% of individuals were less than or equal to 30 m in height, encompassing height classes 1, 2, 3, 4, 5, and 6, as illustrated in Figure 2. This pattern indicated that a majority of species had the highest concentration of individuals within the lower DBH and height classes.

4.4.1. Basal Area. The total basal area of the Dindin forest was 35.54 m^2ha^{-1}. The highest basal area (13.25 m^2ha^{-1}) was recorded for *podocarpus falcatus* and the lowest (0.01 m^2ha^{-1}) was for *Brucea antidysenterica*.

4.4.2. Importance Value Index (IVI). The IVI showed that *podocarpus falcatus* (49.98%), *Juniperus procera* (41.66%), and *Bersama abyssinica* (25.81%) were the top

Table 1: List of plant species recorded from Dindin natural forest. *T* denotes trees, while *S* represents shrubs.

Species	Family	Life form	Abundance (individuals (ha))			
			Mature T/S	Seedlings	Saplings	Total
Allophylus abyssinicus (Hochst.) Radlk	*Sapindaceae*	T/S	46	5	7	58
Allophylus macrobotrys Gilg	*Sapindaceae*	T/S	2	3	2	7
Antiaris toxicaria Lesch.	*Moraceae*	T	2	0	0	2
Barbeya oleoides Schweinf.	*Barbeyaceae*	T	1	4	1	6
Bersama abyssinica Fresen.	*Melianthaceae*	T/S	13	46	40	99
Bersama spss (hade jelo)	*Melianthaceae*	T	43	4	9	56
Bridelia micrantha (Hochst.) Baill.	*Phyllanthaceae*	T	1	0	0	1
Brucea antidysenterica J.F.Mill.	*Simaroubaceae*	S	1	142	90	233
Cassipourea malosana (baker) Alston.	*Rhizophoraceae*	T	3	5	1	9
Celtis africana burm. f.	*Cannabaceae*	T	0	2	1	3
Clerodendrum myricoides (Hochst.) R. Br. ex Vatke	*Verbenaceae*	T	2	1	2	5
Croton macrostachyus (Hochst. ex Delile)	*Euphorbiaceae*	T/S	31	6	2	39
Dombeya torrida (J.F.Gmel.) Bamps	*Sterculiaceae*	T	3	0	0	3
Dovyalis caffra (Hook. f. et Harv.) Warb.	*Flacourtiaceae*	T	1	11	22	34
Ehretia cymosa Thonn.	*Boraginaceae*	T	0	1	1	2
Embelia schimperi Vatke	*Myrsinaceae*	L	3	1	6	10
Euclea racemosa L.	*Ebenaceae*	T/S	0	0	2	2
Ficus sur forssk.	*Moraceae*	T	2	0	0	2
Hagenia abyssinica (Bruce) J.F. Gmel.	*Rosaceae*	T	8	0	0	8
Heteromorpha arborescens (Spreng.) Cham. & Schltdl.	*Apiaceae*	T/S	0	20	9	29
Hippocratea africana (Willd.) Loes. ex Engl.	*Celastraceae*	T	1	7	4	12
Juniperus procera Hochst. ex Endl.	*Cupressaceae*	T	95	26	21	142
Maesa lanceolata forssk.	*Primulaceae*	T	63	26	35	124
Maytenus arbutifolia (Hochst. ex A.Rich.) R.Wilczek	*Celastraceae*	T	29	41	45	115
Myrsine africana L.	*Primulaceae*	T	1	0	0	1
Myrsine melanophloeos (L.) R.Br. ex sweet	*Myrsinaceae*	T	13	101	124	238
Olea capensis L.	*Oleaceae*	T/S	0	2	1	3
Olea europaea subsp. africana (Mill.) P.S.Green	*Oleaceae*	T	21	9	3	33
Olea spss (yedega woira)	*Oleaceae*	T	6	0	1	7
Olinia rochetiana A.Juss.	*Penaeaceae*	T	9	4	2	15
Osyris quadripartita Salzm. ex Decne.	*Santalaceae*	T/S	0	4	1	5
Podocarpus falcatus (Thunb.) R.Br. ex Mirb.	*Podocarpaceae*	T	116	155	146	417
Polyscias fulva (hiern) harms	*Araliaceae*	T	2	0	0	2
Prunus africana (Hook. f.) kalkman	*Rosaceae*	T	18	35	34	87
Rhamnus prinoides L'Herit	*Rhamnaceae*	T	2	0	0	2
Rhus glutinosa Hochst. ex A.Rich.	*Anacardiaceae*	S	6	2	1	9
Rosa abyssinica R.Br. ex Lindl.	*Rosaceae*	S	0	8	9	17
Schefflera abyssinica (Hochst. ex A.Rich.) Harms	*Araliaceae*	T	6	0	0	6
Schefflera volkensii (Engl.) harms	*Araliaceae*	T	7	0	0	7
Urera hypselodendron (Hochst. ex A.Rich.)	*Urticaceae*	T	2	0	0	2
Vernonia amygdalina Del.	*Asteraceae*	S	0	1	0	1

Table 2: Diversity of seedling, sapling, trees/shrubs, and the whole forest of the Dindin forest.

Woody species	*N*	Richness	Shannon–Wiener diversity (H')	Simpson's diversity (D)	Evenness (H'/Hmax)
Seedling	35	30	2.400	0.86	0.71
Sapling	35	29	2.37	0.87	0.70
Mature trees	35	33	2.62	0.89	0.75
The whole forest	35	42	2.66	0.89	0.70

three important species in the Dindin natural forest (Table 4). The lowest IVI was recorded for *Brucea antidysenterica* (0.91%).

4.5. Population Structure of Trees and Shrubs. The analysis of population structure for tree and shrub species in Dindin natural forest unveiled a specific pattern, as illustrated in

Table 3: Density distribution of trees and shrubs in DBH classes in the forest.

DBHDBH classes (cm)	Density (no of trees per class)	Percentage
2.5–16	145.0	36.4
16.1–26	92.9	23.3
26.1–36	62.9	15.8
36.1–46	35.0	8.8
46.1–56	26.4	6.6
56.1–66	12.9	3.2
66.1–76	7.9	2.0
76.1–86	5.7	1.4
>86	9.3	2.3

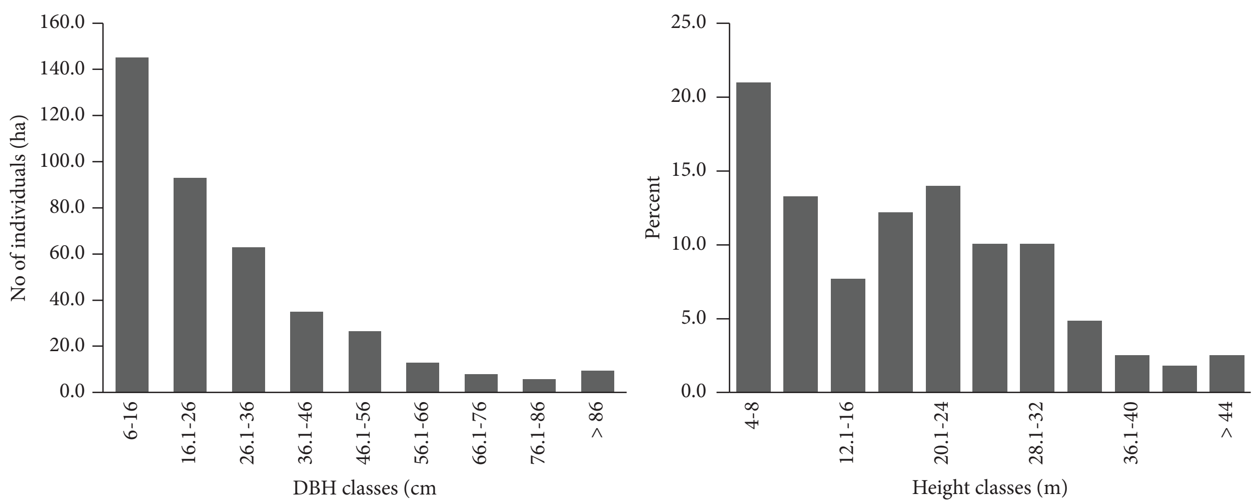

Figure 2: DBH and height class distribution of trees and shrubs in the Dindin forest.

Figures 3(a)–3(f). This pattern exhibited a bell-shaped distribution characterized by a lower number of individuals in both the lower and higher DBH classes compared to the middle DBH classes.

4.6. Regeneration Status. The density of seedlings, saplings, and mature individuals was 481, 444, and 399 individuals per hectare, respectively. Accordingly, the regeneration status of the forest is found to be good. Among the identified woody species, 11 species had no seedlings, while another 11 and 7 species had no saplings and mature trees or shrubs, respectively. Table 5 provides a list of these species that did not have individual seedlings, saplings, or mature trees/shrubs.

Generally, an individual tree/shrub's regeneration status was depicted through three distribution patterns, as illustrated in Figures 4(a)–4(f). The first pattern showcased woody species with a high number of seedlings, including *Allophylus macrobotrys, Barbeya oleoides, Brucea antidysenterica, Cassipourea malosana, Celtis africana, Ehretiacymosa, Heteromorpha arborescens, Hippocratea africana, Osyris quadripartita, Podocarpus falcatus, Prunus africana, Vernonia amygdalina, and Vernonia amygdalina*. The second pattern exhibited woody species with a significant number of saplings, such as *Bridelia micrantha, Dovyaliscaffra, Embelia schimperi, Ficus sur, Maytenus arbutifolia, Myrsine melanophloeos, Polyscias fulva,* and *Rosa abyssinica*. The third pattern highlighted woody species with a substantial presence of mature trees or shrubs, including *Allophylus abyssinicus, Antiaristoxicaria, Bersama abyssinica, Croton macrostachyus, Dombeya torrida, Hagenia abyssinica, Juniperus procera, Maesa lanceolata, Olea capensis, Olea europaea, Oliniarochetiana, and Rhamnus prinoides.*

5. Discussion

Our findings suggest that the species richness in our study area is lower compared to the woody species composition observed in certain dry Afromontane forests, such as Gra-Kahsu natural forest (64 species, [40]), Gelawoldie community forest (59 species, [41]), Gennemar (55 species, [42]), and Wof-Washa (62 species, [43]). In contrast, the following dry Afromontane forests exhibited a lower number of species compared to our study area: had 32 species at Weiramba forest [44], 38 species at four forest patches in the Awi zone [29], and 31 species at Yerer forest [45].

The species compositions of Gara Ades forest (with 40 woody species) and Menagesha Suba forest (with 41 woody species) [46], as well as the Arero forest (with 39 woody species) [47] other, show a relatively similar pattern to the

Table 4: IV contribution of woody species in the Dindin forest.

Species	RD (%)	RDO (%)	RF (%)	IVI (%)
Podocarpus falcatus	25.6	17.4	7.0	49.9
Juniperus procera	17.5	17.2	7.0	41.7
Bersama abyssinica	*11.5*	*2.6*	*11.7*	*25.8*
Allophylus abyssinicus	7.6	3.3	7.0	17.8
Maesa lanceolata	8.1	2.7	6.2	17.1
Maytenus arbutifolia	7.6	1.1	6.2	15.0
Croton macrostachyus	5.5	2.0	6.2	13.6
Schefflera abyssinica	2.0	7.7	3.9	13.6
Prunus africana	3.2	1.3	5.4	10.0
Olea capensis	1.3	2.6	3.9	7.8
Olea africana	2.3	3.3	1.6	7.1
Hagenia abyssinica	1.4	2.5	3.1	7.0
Olea europaea	1.4	1.0	3.1	5.5
Olinia rochetiana	2.2	1.7	1.6	5.5
Myrsine melanophloeos	0.9	0.4	3.9	5.1
Polyscias fulva	0.4	2.3	1.6	4.3
Myrsine africana	2.5	0.3	0.8	3.6
Cassipourea malosana	0.7	0.5	2.3	3.5
Schefflera volkensii	0.2	0.9	2.3	3.4
Dombeya torrida	0.5	1.1	1.6	3.1
Antiaristoxicaria	0.4	1.1	1.6	3.0
Rhus glutinosa	0.8	0.1	1.6	2.5
Ficus sur	0.3	0.4	1.6	2.2
Embelia schimperi	0.6	0.03	1.6	2.2
Allophylus macrobotrys	1.2	0.2	0.8	2.1
Rhamnus prinoides	0.3	0.1	1.6	1.9
Clerodendrum myricoides	0.4	0.2	0.8	1.3
Urera hypselodendron	0.3	0.2	0.8	1.3
Dovyalis caffra	0.3	0.02	0.8	1.1
Barbeya oleoides	0.2	0.1	0.8	1.0
Bridelia micrantha	0.1	0.03	0.8	0.9
Hippocratea africana	0.2	0.01	0.8	0.9
Brucea antidysenterica	0.1	0.01	0.8	0.9

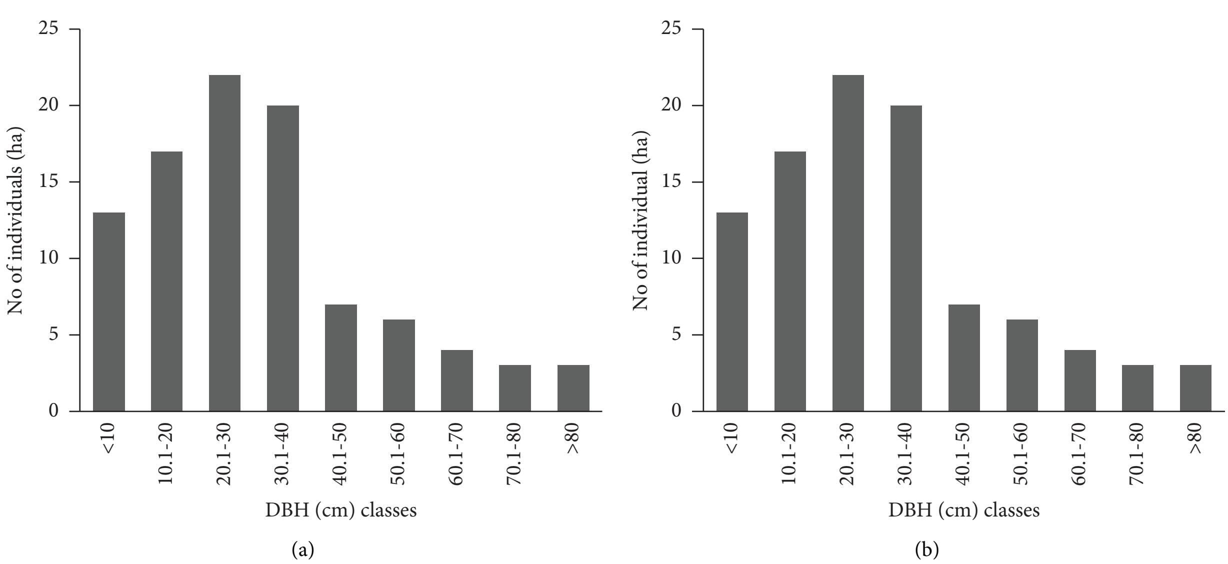

Figure 3: Continued.

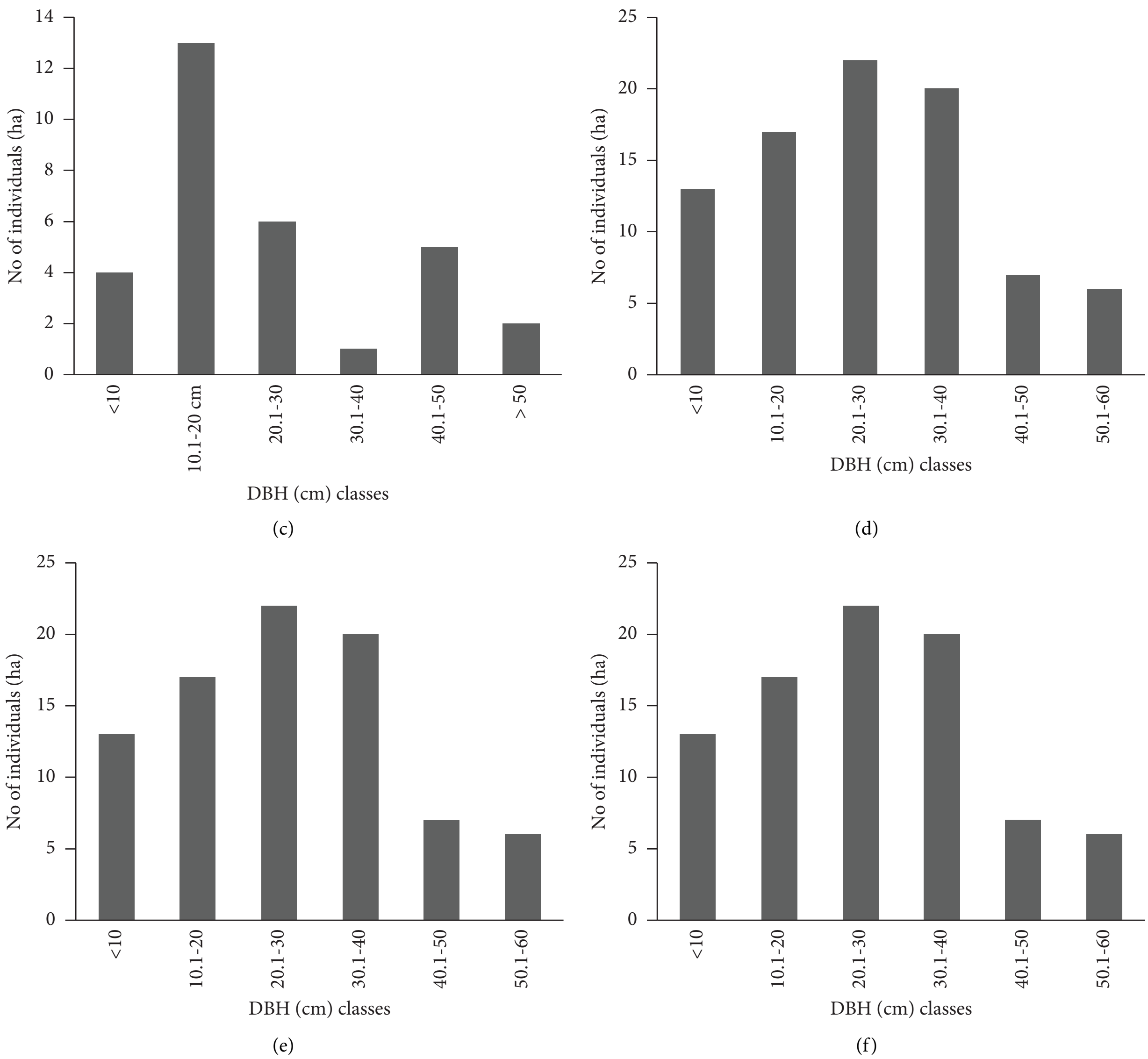

Figure 3: (a–f) Representative patterns of species population structures in the Dindin forest. (a) *Podocarpus falcatus*. (b) *Juniperus procera*. (c) *Croton macrostachyus*. (d) *Maytenus arbutifolia*. (e) *Maesa lanceolata*. (f) *Prunus africana*.

Table 5: List of species with no seedling, sapling, and mature trees or shrubs in the Dindin forest.

Species with no seedling	Species with no sapling	Species with no mature trees or shrubs
Antiaris toxicaria	*Hagenia abyssinica*	*Ehretia cymosa*
Bridelia micrantha	*Schefflera volkensii*	*Vernonia amygdalina*
Dombeya torrida	*Urera hypselodendron*	Vernonia amygdalina
Ficus sur	*Ehretia cymosa*	*Celtis africana*
Hagenia abyssinica	*Vernonia amygdalina*	*Osyris quadripartite*
Myrsine africana	*Vernonia amygdalina*	*Heteromorpha arborescens*
Polyscias fulva	*Celtis africana*	*Rosa abyssinica*
Rhamnus prinoides	*Rhus glutinosa*	
Schefflera abyssinica	*Osyris quadripartita*	
Schefflera volkensii	*Heteromorpha arborescens*	
Urerahypselodendron	*Prunus africana*	

species composition observed in the Dindin forest. Our findings also revealed a higher abundance of woody tree species compared to other plant habits. This observation aligns with the findings of Bboz and Maryo [30], who reported that the majority of species in the study area were predominantly tree species. Moreover, the dominant species in the vegetation of the study area were from the families *Araliaceae*, *Rosaceae*, and *Oleaceae*.

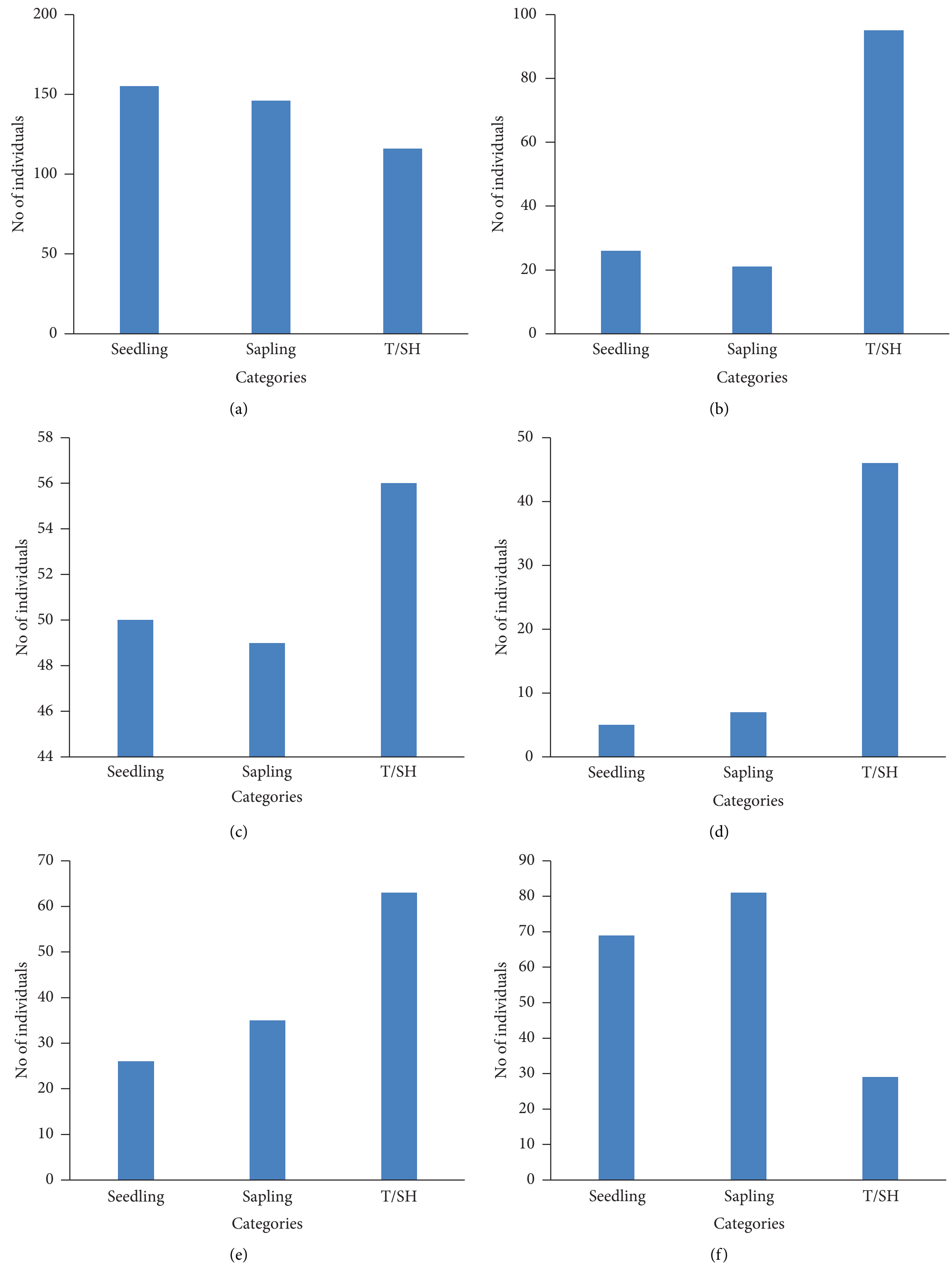

FIGURE 4: (a–f) Seedling, sapling, and tree/shrub distribution of some selected woody species in the Dindin forest. (a) *Podocarpus falcatus*. (b) *Juniperus procera*. (c) *Bersama abyssinica*. (d) *Allophylus abyssinicus*. (e) *Maesa lanceolata*. (f) *Maytenus arbutifolia*.

The diversity of woody species plays a crucial role in conservation efforts, as it reflects important ecological processes for forest management and conservation [48]. In the study forest, the average Shannon–Weiner diversity index (H) was calculated to be 2.66, and the average evenness (E) value was 0.7. These values are lower than those reported for Chilimo forest ($H' = 2.72$) ($H = 2.7$) [49]. Zegie Peninsula ($H' = 3.72$), Tara Gedam forest ($H = 2.9$), but higher than Abebaye ($H = 1.31$) [50]. Yerer mountain forest ($H = 2.17$) [45], and Alemsaga forest ($H = 2.51$) [51]. According to Cavalcanti et al. [52], the diversity of a forest is considered as high, medium, low, or very low when the value of the Shannon–Weiner diversity index is above 3.0 between 2.0 and 3.0, between 1.0 and 2.0, and below 1.0, respectively. Therefore, the woody species diversity of the Dindin forest falls within the medium category, as the estimated value is between 2 and 3. The medium value of the Shannon diversity index suggests that there are various factors contributing to this result, including illegal harvesting, agricultural expansion, overpopulation, and livestock intervention. Zewdie [53] and Esubalew [54] have highlighted that human intervention, overgrazing, and illegal activities pose threats to the diversity and distribution of woody species in forests. In addition, density and importance value index (IVI) are important parameters used to characterize forest systems. However, these parameters can vary among different species within the forest. Stem densities within the forest can vary based on species, diameter size classes, and forest characteristics [29]. In the Dindin forest, the total density of individual tree species with a diameter at breast height (DBH) of ≥2.5 cm was recorded as 1404 individuals per hectare. Comparatively, the density in the Dindin forest is relatively higher than that of other dry Afromontane forests such as Aba Sena Forest (819 individuals per hectare) [54], Gelawoldie community forest (631 individuals per hectare) [41], Yemrehane Kirstos Church Forest (250 stems per hectare) [12], and Tsahare Kan and Dabkuli forest (664 stems per hectare and 364 stems per hectare, respectively) [29]. However, the density in our study area is lower compared to Amoro forest (2860.5 stems per hectare) [55] and the Zegie Peninsula (3318 stems per hectare) [56].

The importance value index (IVI) provides insight into the structural significance of a species within a mixed-species stand. It serves as a means of comparing the ecological importance of different species, with a higher IVI indicating a greater sociological structure of the species within the community. This measure is crucial for understanding the ecological significance of species [57], particularly identifying the leading dominant species in a specific vegetation type [26]. The woody species with the highest IVI are considered to have the greatest impact on the forest community. Basal area is another valuable input for conservation strategies [58] and reflects the abundance of species within a given forest [51]. In our study area, ecologically important tree species include *P. falcatus, J. procera, B. abyssinica, A. abyssinicus, M. lanceolata,* and *M. arbutifolia*. Species with lower IVI values were *E. schimperi, A. macrobotrys, R. prinoides, C. myricoides, U. hypselodendron, D. caffra, B. oleoides, B. micrantha, H. africana,* and *B. antidysenterica*. These species require conservation measures to enhance their importance within the forest.

The significance of basal area as a measure of species importance is evident. It serves as a crucial metric for evaluating forest resources [30]. In the Dindin forest, the total basal area of trees and shrubs, calculated based on diameter at breast height (DBH), was determined to be 35.54 m^2/ha. It is worth noting that the reported basal area in the Chilimo-Gaji dry Afromontane forest [1] and Yemrehane Kirstos Church Natural Forest [12] exceeded that of our study area. In addition, Simon and Girma [26] reported a higher basal area for the Dindin forest compared to the current measurement. Conversely, the basal area reported for Weiramba forest [44] and Wanzaye natural forest [59] was lower than that of the Dindin forest. The differences in climate conditions, along with the extent and type of disturbance, could potentially account for this variation. According to Bboz and Maryo [30], variations in basal area can be attributed to climate conditions. The distribution of DBH reveals that a higher number of individuals were observed in lower DBH classes compared to larger DBH classes. Similarly, most individual trees and shrubs were concentrated in the first ht class. These findings further validate the observation that the number of individuals decreases as both DBH and ht class of the trees increase. This finding aligns with the results of previous studies [29, 32, 51, 60].

The overall characteristics of the Dindin forest stand provide insights into the regeneration status of the forest. The distribution of tree species across different size classes based on DBH exhibits a broken J-shaped pattern, as demonstrated by *C. macrostachyus*, as well as a bell-shaped distribution, indicating a higher number of individuals in the middle size classes and a decrease towards both lower and larger diameter classes. This bell-shaped distribution pattern is exemplified by species such as *P. falcatus, J. procera, M. arbutifolia, M. lanceolata,* and *P. africana*. These findings suggest a less favorable recruitment process and population dynamics of woody species in the study area, which is consistent with the observations made by Tesfaye et al. [61].

The examination of the forest's regeneration status involved comparing various attributes, such as adult density, with the populations of saplings and seedlings. The total number of seedlings in the forest exceeded that of saplings and adults, displaying an inverted J-shaped pattern. However, the densities of seedlings, saplings, and adult tree/shrub species at the species level exhibited three general patterns. The first pattern, illustrated by *P. falcatus*, was an inverted J-shape, characterized by a higher number of individual seedlings. The second pattern, exemplified by *J. Procera*, *M. lanceolata*, *B. abyssinica,* and *A. abyssinicus,* displayed a J-shape, indicating a higher number of adult trees/shrubs in the study area. The third pattern, demonstrated by *M. arbutifolia*, exhibited a bell shape, reflecting a higher number of individuals at the sapling stage.

Eleven woody tree species in the forest lacked a seedling stage, while another eleven woody species lacked a sapling stage. The absence of seedlings and saplings in these species indicated a discontinuity in their population structures [29]. Additional studies have also shown that a lack of regeneration at the stand level is common in Ethiopian forests [43, 62]. Therefore, species with few or no seedlings and saplings should receive priority in terms of management and conservation efforts.

6. Conclusion

The study provides useful information on the present condition of the woody species diversity, structure, and regeneration status of the Dindin forest. As compared with other dry Afromontane forest, it has a relatively small number of woody species bound with a medium diversity. The forests harbor 42 woody species belonging to 30 families. The woody species of the Dindin forest were dominated by *Podocarpus falcatus* which is the most economical and ecologically important tree species in the forest. The overall distribution of DBH classes of woody plants had an inverted J-shape pattern that indicates the potential source of recruitment and ensures sustained regeneration of the forest if it is properly managed. However, the number of individuals in the higher diameter class declines considerably, suggesting that there is intervention that can be attributed to the exploitation of woody species in the forest by surrounding communities. The density of seedling, sapling, and matured woody plants of these forests showed the need for conservation priority for most woody plant species of poor regeneration status. Among woody species in the forest, about 24% woody species had no seedling and sapling. Hence, special attention should be directed towards the conservation of *H. abyssinica, S. volkensii, U. hypselodendron, E. cymose, V. amygdalina, C. africana R. glutinosa, O. quadripartita, H. arborescens*, and *P. africana* which exhibit a lack of seedlings.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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