Hindawi
International Journal of Forestry Research
Volume 2022, Article ID 7475999, 20 pages
https://doi.org/10.1155/2022/7475999

Research Article

Diversity, Structural, and Regeneration Analysis of Woody Species in the Afromontane Dry Forest of Harego, Northeastern Ethiopia

Belachew Bogale Worku[1], **Emiru Birhane Hizkias**[2] and **Seid Muhie Dawud**[1]

[1]*Department of Forestry, Wollo University, P.O.Box 1145, Dessie, Ethiopia*
[2]*Department of Land Resources Management and Environmental Protection, Mekelle University, P.O.Box 231, Mekelle, Ethiopia*

Correspondence should be addressed to Belachew Bogale Worku; beboge22@gmail.com

Received 19 February 2022; Revised 4 August 2022; Accepted 20 August 2022; Published 14 September 2022

Academic Editor: Ranjeet Kumar Mishra

Copyright © 2022 Belachew Bogale Worku et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The study was conducted in the Harego dry Afromontane forest, Northeastern Ethiopia, to analyze woody species composition, diversity, structure, and regeneration status. To collect the vegetation data, a total of 67 sample plots measuring $400m^2$ ($20m \times 20m$) were laid systematically. Species identity, abundance, height, and diameter at breast height (DBH) were recorded for each sample plot. Diversity, structural, and regeneration status were analyzed for the forest. A total of 50 woody species representing 35 families and 44 genera were identified and recorded. According to the IUCN Red List Category, *Rhus glutinosa* A. Rich and *Prunus africana* (Hook.f.) Kalkm. are vulnerable species. Fabaceae was the dominant family, and of the total species, 27 were shrubs, 19 were trees, and 4 were climbers. The species accumulation curve indicates that the majority of plant species in the study area were captured by our sampling efforts. The values of true Shannon ($N1 = 17$) and true Simpson ($N2 = 11$) indicate that species in the Harego forest are more or less evenly distributed. The abundance-frequency ratio of all woody species (WI = >0.05) indicates the heterogeneity of species composition. The total density and basal area were 4400 stems ha^{-1} and 9.66 m^2 ha^{-1}, respectively. The majority of the species fallen into the lower IVI classes. The diameter and height class distribution revealed an inverted *J*-shape. The increase in population demand and disturbance shows a high variation in stand structure and hampered natural regeneration, which needs immediate conservation actions.

1. Introduction

Covering about thirty-one percent of Earth's land surfaces, forest ecosystems contain a considerable amount of the world's terrestrial biodiversity [1]. Tropical forests, particularly tropical dry forests [2], are among the most species-rich ecosystems on the Earth and comprise exceptional species richness and high concentrations of endemic species [3]. About three-fourths of this dry forest ecosystem is found in Africa and the world's tropical islands [3]. The dry Afromontane forests of Ethiopia in particular are diverse in structure and composition due to their wide distribution in diverse climatic types and over a large altitudinal range [4]. Nevertheless, a continuous clearing of vegetation for agriculture, fuel, and construction [5, 6] altogether influenced the vegetation cover of the dry Afromontane forest [6, 7]. Almost all forests have been converted to agricultural land [4, 5], except for small fragments that are left in the most inaccessible areas and around churches [8–11].

In the tropics, several studies have been conducted about forest composition, diversity, structure [9, 12–32], and regeneration [13, 20, 33–38]. The results of these studies revealed that the use of the forest area as pasture may limit the regeneration capacity [20, 23, 39]. In most of the studies, the population structure showed the presence of excessive cutting of selected diameter classes of ecologically, economically, and medically important tree species for various purposes [21, 22, 30, 40–43]. However, tropical forests vary in species richness from site to site and within plant communities [44], suggesting the influence of spatial environmental variations [24]. In brief, the problems of one forest site might not be the problems of other sites, which leads to studying each site specifically. Documenting scientific information on the forest composition, diversity, structure, and distribution of the species [16, 17, 39] is, therefore, an important activity in areas where this has not been undertaken [26].

Harego forest is among these small fragmented forests, which are found in Northeastern Ethiopia. It was previously disturbed and degraded but protected in 1974 during the Dergue regime [45]. According to local elders, since protection, the area has been increasing in vegetation cover and species composition, and it conserves the hillside from erosion by increasing water infiltration. It also serves as a habitat for different plants and animals. Moreover, the forest provides edible fruits for humans and cultural and recreational services. However, human pressure, grazing, and illegal logging of trees for construction, timber, and fuelwood collection still exist. The ever-increasing demand for forest products and forest land, together with the increased population growth has put this remaining patch of forest on the margin of extinction [43]. For all these reasons, the conservation of biodiversity needs to be at the forefront of regional sustainable development [23, 46]. Therefore, an undertaking of vegetation analysis and the regeneration status of the remaining forests are essential as they form the foundation for plans to manage sustainably [47].

In the study area (Harego forest), only the dynamics of *Olea europaea* subsp. *cuspidata* seedlings, and juveniles have been studied by Bekele [45]. Therefore, the present study is significant in generating useful baseline data to conserve and manage the native flora and fauna of these forest ecosystems and elsewhere in the forest of Northeastern Ethiopia. To achieve this objective, the following studies were carried out: (i) measurement and description of the plant species diversity and richness of the Harego secondary forest; (ii) study of the pattern of vegetation and population structure of the forest and selected species; and (iii) study the regeneration status of the forest and selected species. Therefore, this study is going to answer the following research questions: (1) how are the species composition and diversity of the Harego forest? (2) What looks like the distribution pattern of the Harego forest in terms of diameter and height classes? (3) Does the regeneration status of Harego forest good, fair, or poor?

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Harego dry Afromontane forest South Wollo Zone, Northeastern Ethiopia. Geographically, it is situated between 11° 4′ 12″ to 11° 6′ 0″ latitude and 39° 38′ 53″ to 39° 41′ 24″ longitude (Figure 1). Harego forest is characterized by rugged topography that consists of high mountains, valleys, and a plateau with an altitude range from 2079 to 2516 meters above sea level and covers an area of 341.67 ha. Cenozoic volcanic rocks (mainly basalts of tertiary age) and some sedimentary rocks are the main geological formations [48]. The Cenozoic volcanic rocks have developed from tertiary flood basalt sequences with the intercalation of felsic lava and pyroclastic rocks up to 3 km thick [49]. The major soil types are cambisols, arenosols, lithosols, and vertisols [48, 50, 51]. The mean annual temperature of the Harego forest was 17.7°C, with a mean minimum and maximum of 7.7°C and 27.6°C, respectively [52]. The mean annual rainfall of the Harego forest was 1040 mm, which varied greatly from year to year. The study area has, in general, a bimodal rainfall pattern, with low rainfall from November to February and the main rainy season being from July to August.

2.2. Vegetation Sampling. A reconnaissance survey was conducted from July 15 to September 30, 2017, in and around the forest area to gather relevant information concerning the study area. Actual field data were collected from October 15 to January 30, 2018. A system of systematic sampling using a grid line on the geographical map was initially employed. Points indicating the positions of the sample plots were systematically marked and recorded on the intersection line with the topographic map of the study area, with 500 m and 100 m of distance between and within the grid line, respectively. A total of 6 vertical grid lines and 27 horizontal grid lines on the map and 72 sample plots were obtained. The points on the map were later located on the ground using the handy GPS (GARMIN 72) navigation system, and square sample plots with 20 m × 20 m have been laid down as the main plot. During the determination of plot size, the slope factor was corrected using a slope correction table [53, 54]. Based on the accessibility of the area and other factors like roads, 67 quadrats (2.68 ha) were used as sample plots to document species composition and study woody species diversity and determine the vegetation structure, the pattern of population structure, and regeneration status of the forest.

All woody species in each plot were recorded. Specimens were collected, numbered, pressed, and dried for identification of plant species that were not identified onsite. Local people and Wollo University forestry experts were involved in species identification using local names, and the corresponding scientific names were followed by the published volumes 1–7 of Flora of Ethiopia and Eritrea [55–61] and useful trees and shrubs for Ethiopia [62]. In each main plot, woody plant species with a diameter at breast height, DBH ≥2 cm, and height ≥2 m were measured using a caliper and Suunto clinometer, respectively, starting from the edge and working inwards and marking each tree and shrub to prevent accidentally measuring and counting it twice. Plants with multiple stems below 1.3 m in height were treated as a single individual, and the DBH of all stems was measured and averaged [63]. For the trees which were buttressed and abnormal at 1.3 m, the diameter was measured just above the buttress where the stem assumes a nearly cylindrical shape. The height of short trees and shrubs was measured using a calibrated stick. In places where topographic features make it difficult to measure, the height of trees and shrubs was visually estimated. Seedlings and saplings were determined in five 1 m × 1 m (four at the corners and one at the centre) subplots. Individual stem with DBH <2 cm and a height

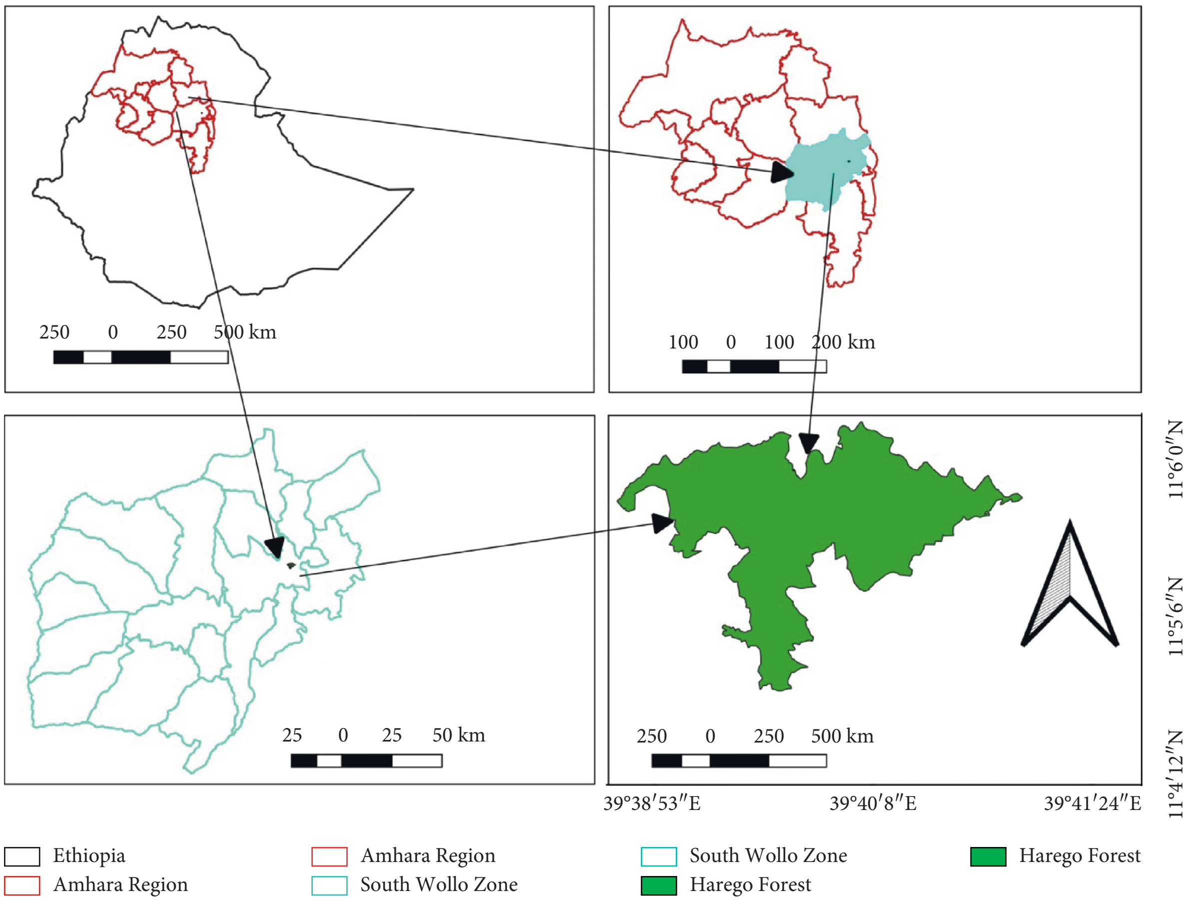

Figure 1: Map of the study area, Harego forest, South Wollo, Northeastern Ethiopia.

<1.5 m was counted by species as a seedling, while individuals with DBH <2 and height between 1.5 and 2 m were counted as saplings, and individuals with DBH ≥2 cm with height ≥2 m were considered as mature (tree and shrubs) as described by Temesgen and Werkineh [18], Sighal [64], Dibaba et al. [65], Negesse and Woldearegay [66].

2.3. Data Analysis. Normality distribution of data on abundance, diameter, and height was checked, and data on abundance and diameter were log-transformed. Analysis of diversity indices and true diversity was computed using PAST software version 2.17 [67–69]. The Shannon diversity index is computed as

$$H' = -\sum_{i=1}^{s} p_i \ln p_i, \quad (1)$$

where H′ = Shannon–Wiener diversity index, S = the number of species existed in the study site, p_i = the proportion of individuals in the i^{th} species, and ln = natural logarithm = logarithm of the base e.

The true Shannon is computed by exponentially transforming the results obtained from the Shannon entropy equation.

$$N_1 = e^H, \quad (2)$$

where ${}^1D$ or N_1 = is true Shannon, e = is the inverse of ln, the natural logarithm of a number.

Evenness (Shannon equitability index) is calculated as

$$J = \frac{H'}{H\max} = \frac{H'}{\ln_S \text{ or } \ln N_0}, \quad (3)$$

where J = is Shannon equitability, $H'_{max} = S$, and N_0 = is the number of species that existed at the study site.

True evenness (E′) is also obtained by the exponential transforming of the evenness result which is obtained from the Shannon equitability index. Then, true evenness (E′) [70] was obtained from the exponential result of evenness:

$$E_1 = e^E = \frac{{}^1D}{S} = \frac{N_1}{N_0}. \quad (4)$$

Simpson's diversity Index (D) is calculated as

$$D = 1 - \sum Pi^2, \quad (5)$$

where D = is a Simpson's diversity index and pi is described in equation (1).

True Simpson has been done by inverting the result of Simpson entropy.

$$N_2 = \frac{1}{D} = {}^2D = \left[\frac{1}{1-\left(1-\sum_{i=1}^{S} Pi^2\right)}\right] = \frac{1}{\sum_{i=1}^{S} Pi^2}, \quad (6)$$

where $(1/\lambda)={}^2Dx = N_2 =$ true Simpson diversity index.

The reason behind the computing of true diversity (effective numbers of species) [71, 72] was that the Shannon–Wiener and Simpson diversity indices are not diverse by themselves but rather an index of entropy. Transforming the indices or entropy to effective numbers of species creates a steady, plausible, and sensitive general similarity measure [73].

Structural analysis of the vegetation was described based on the analysis of species abundance [74], frequency, abundance-frequency ratio (WI) [75], density and basal area [74], important value index (IVI), and DBH and height [67].

Frequency is the percentage of the total number of quadrats in which a given species was present and is a measure of the uniformity of distribution of a species within a stand [75]. Therefore, to know each species' distribution at the study site, the frequency was calculated as a percentage of the total quadrats in which a species occurred with the total number of quadrats encountered:

$$\text{frequency} = \frac{\text{the total number of quadrats in which a species occurred}}{\text{total number of sampled quadrats}} * 100. \quad (7)$$

The abundance of any individual species is expressed as the total number of species present in all the quadrats divided by the total number of quadrats in which a species occurred. Therefore, the abundance of any individual species collected was calculated following the methodology of Lamprecht [74].

$$\text{abundance} = \frac{\text{the total number of individuals of a species}}{\text{the total number of quadrats in which the species occurred}}. \quad (8)$$

The abundance frequency ratio (A/F) refers to the spatial distribution of trees and shrubs and was determined following Whitford's study: WI = abundance/frequency (A/F ratio). A value <0.025 would imply a regular distribution, values between 0.025 and 0.05 would mean a random distribution, and a value >0.05 would mean a contagious distribution.

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied [74]. This is an indicator of the numerical dominance of a species in a given forest area. Therefore, it is calculated as

$$\text{density} = \frac{\text{the total number of individuals of a species}}{\text{the total number of quadrats studied}}. \quad (9)$$

2.3.1. Basal Area (BA). The dominance can be expressed either by density (numerical dominance) or basal area using diameter measurement. However, the basal area provides a better measure of the relative importance of the species than a simple stem count [67]. Therefore, the basal area was calculated using the diameter of each individual of the species as follows:

$$\text{basal area (DO)} = \frac{\pi DBH^2}{4}, \quad (10)$$

where $\pi = 3.14$ and DBH = diameter measured at breast height.

The important value index (IVI) is a composite index based on the relative measures of species frequency, abundance, and dominance [67]. It indicates the significance of species in the system. Therefore, the important value index (IVI) was computed for all woody species based on relative density (RD), relative dominance (RDo), and relative frequency (RF) to determine their dominant position as follows:

$$\text{important value index} (IVI) = RD + RDo + RF, \quad (11)$$

where RD is relative density, RDo is relative dominance, and RF is relative frequency.

The stand structure of the forest and the population structure of selected species were analyzed using DBH and height data and classified into six and five classes, respectively, following Mewded et al. [76] and Boz and Maryo [77], respectively. The DBH class were as follows: 1 = 2–6; 2 = 6.1–10; 3 = 10.1–15; 4 = 15.1–20; 5 = 20.1–25; and 6 = >25 cm, while the height class were as follows: 1 = 2–6; 2 = 6.1–10; 3 = 10.1–15; 4 = 15.1–20; and 5 = >20 m. The diameter and height frequency distribution pattern was drawn using a histogram.

2.3.2. Regeneration Structure Analysis. Natural regeneration is a process by which the forest is renewed naturally due to the emergence of young plants from seeds or seedlings. The density value of seedlings and saplings considered as regeneration potential of the species [78–80] provides information on the status of regeneration when compared to their corresponding matured species [33]. As a result, the regeneration status of the forest area in general and selected representative species, in particular, was categorized as (1) good: when the density of seedlings was less than the density of saplings > the density of mature (trees and shrubs); (2) fair regeneration: when the density of seedlings was > or ≤ saplings ≤ mature; (3) poor regeneration: when the species survives only in sapling stage, but no seedlings (density of saplings may be <or ≥ mature); (4) no regeneration: when a species is present only in a mature form; (5) new regeneration: when a species has no mature, but only sapling and/or seedling stages [78–80].

3. Results

3.1. Species Composition and Diversity of the Study Area. A total of 50 woody species representing 35 families and 44 genera were identified and recorded between 2079 and 2516 meters above the sea level (Table 1). Fabaceae was the richest family represented by 5 species in three genera. Lamiaceae has four species in four genera. Anacardiaceae and Euphorbiaceae had three species each in one and two genera, respectively. Similarly, four families (Celastraceae, Cupressaceae, Oleaceae, and Rosaceae) were represented by 2 species each, while the rest of the 27 were represented by a single species each. Of the total species recorded, 27 (54%) species were shrubs, 19 (38%) were trees, and 4 (8%) species were climbers. Five (10%) of the total species recorded were endemic to Ethiopia. All of the endemic species were shrubs in their growth habit. The IUCN Red List category indicates that two of the endemic species were least concerned, while one species was categorized as vulnerable. On the other hand, one of the endemic species was categorized as not threatened (Table 2).

The shape of the species accumulation curve (Figure 2) indicates the expected pattern of the initial exponential increase in species with increasing sampling and then gradually slowing as more samples are added to the curve flattens out. Hence, the 50 plant species recorded in the study area were considered within the third quartile of total richness. The total species richness (Hill's N_0.) of the Harego forest was 50, while the True Shannon, effective number of species (Hill's N_1), and True Simpson, the richness of abundant species (Hill's N_2), were 17 and 11, respectively. The Shannon–Wiener diversity index (H□), Simpson diversity index (*D*), and evenness (*J*) were 2.85, 0.91, and 0.73, respectively. The effective number of species obtained from the exponential transformation of Shannon entropy was higher than the inverse of the Simpson index (true Simpson). The value of true evenness was 0.34.

3.2. Vegetation Structure

3.2.1. Frequency. The inventory showed that shrubs are the most frequently occurring species in the Harego forest. The five most frequent species were *Rhus natalensis,* found in 88.06% of the quadrats, followed by *Dodonaea angustifolia*, 83.58%, *Carissa spinarum*, 82.09%, *Olea europaea* subsp. *cuspidata*, 80.60%, and *Jasminum grandiflorum,* in 68.66% of all the quadrats (see Table 3). The five most frequently observed species together contributed to 35.48 of the total relative frequency of the forest. This shows that these species are the most widespread and significant members of the community in the forest. On the other hand, *Acacia seyal*, *Erica arborea*, *Otostegia integrifolia*, *Pinus patula*, *Rumex nervosus,* and *Solanum marginatum* rarely occurred and contributed to 0.78 of the total relative frequencies. The frequency distribution displayed some sort of pattern, and the woody species were classified into five frequency classes expressed in percentage. The result showed an inverted J-shape (Figure 3) in which most of the species fell into the lower frequency class and abruptly decreased towards the higher classes. This implies that the study forest had a high degree of floristic heterogeneity. Similarly, the abundance-frequency ratio of all woody species (Whitford index = WI > 0.05) showed a clumped or contagious pattern of distribution (Table 3).

3.3. Density of Woody Species. The density of all woody species collected in the study area was 4400.37 stems ha^{-1} (Table 3), of which the five largest contributors were *Dodonaea angustifolia*, 764.18 stems ha^{-1}; *Rhus natalensis*, 602.24 stems ha^{-1}; *Myrsine africana*, 522.39 stems ha^{-1}; *Carissa spinarum*, 388.81 stems ha^{-1}; and *Olea europaea* subsp. *cuspidata*, 352.61 stems ha^{-1} of the total individuals. More than 59% of the total forest cover was occupied by these five species. In contrast, *Acacia seyal*, *Berberis holstii*, *Clutia abyssinica*, *Erica arborea*, *Euphorbia tirucalli*, *Ocimum lamiifolium*, *Olinia rochetiana*, *Pinus patula*, *Senra incana*, and *Solanum marginatum* were found to be the rarest species representing less than 1% of the forest. Furthermore, the density of individuals with a DBH ≤10 cm was 4167.00 stems ha^{-1} and those individuals with a DBH between 10 and 20 cm and with a DBH >20 cm were 197.39 stems ha^{-1} and 36.19 stems ha^{-1}, respectively. The ratio between 10 and 20 cm (a) and DBH >20 cm (b) was 5.45. This indicates that the proportion of medium-sized individuals' (DBH between 10 and 20 cm) was highly greater than the large-sized DBH class (DBH >20 cm), but lower than the lower DBH class (DBH ≤10 cm).

3.4. Basal Area. The total basal area of all woody species was found to be 9.66 m^2 ha^{-1} (Table 3). The five species with the largest basal area were *Euphorbia candelabrum* (22.15%), *Olea europaea* subsp. *cuspidata* (20.85%), *Juniperus procera* (10.01%), *Eucalyptus globulus* (8.65%), and *Rhus natalensis* (8.19%). These species constituted to 75.37% of the total basal area of the study site. The remaining 24.63% was constituted by the rest of the 33 species. The basal area distributions of woody species were classified into five classes. The basal areas of two-thirds of species were fallen in the first class (BA = 0.001–0.1 m^2 ha^{-1}), followed by classes

Table 1: List of woody species recorded in the Harego dry Afromontane forest.

Family	Scientific Name	*Local name	Growth habit
Fabaceae	*Acacia abyssinica* Hochst.	Bazra girar	Tree
	Acacia etbaica Schweinf.	Dere	Tree
	Acacia seyal Del.	Nech girar	Tree
	Calpurnia aurea (Ait.) Benth.	Digta	Shrub
	Pterolobium stellatum (Forssk.) Brenan	Kentafa	Climber
Lamiaceae	*Clerodendrum myricoides* (Hochst.) Vatke	Misirich	Shrub
	Ocimum lamiifolium Hochst. Ex. Benth.	Dama kese	Shrub
	Premna schimperi Engl.	Chocho	Shrub
	Otostegia integrifolia Benth.	Tinjut	Shrub
Anacardiaceae	*Rhus glutinosa* A. Rich.	Embs	Shrub
	Rhus natalensis Krauss	Taquama	Shrub
	Rhus retinorrhoea Oliv.	Tilem	Shrub
Euphorbiaceae	*Clutia abyssinica* Jaub. and Spach.	Fyele fejj	Shrub
	Euphorbia candelabrum Kotschy.	Kulkual	Tree
	Euphorbia tirucalli L.	Kinchib	Tree
Celastraceae	*Maytenus* arbutifolia (A. Rich.) Wilczek	Wend atat	Shrub
	Maytenus senegalensis (Lam.)	Sete atat	Shrub
Cupressaceae	*Cupressus lusitanica* Mill.	Yeferenj tsid	Tree
	Juniperus procera hochst. ex Endl.	Yehabesha tsid	Tree
Oleaceae	*Jasminum grandiflorum* P.S.Green	Tembelel	Climber
	Olea europaea L. *subsp. cuspidata*	Weira	Tree
Rosaceae	*Prunus africana* (Hook.f.) Kalkm.	Tiqur inchet	Tree
	Rosa abyssinica Lindley.	Kega	Shrub
Loganiaceae	*Buddleja polystachya* Fresen.	Atquar	Shrub
Apiaceae	*Heteromorpha arborescens* (Spreng.)	Yejib mirkuz	Shrub
Apocynaceae	*Carissa spinarum* L.	Agam	Shrub
Asparagaceae	*Asparagus africanus* Lam.	Yeset kest	Climber
Asteraceae	*Echinops macrochaetus* Fresen.	Kosheshila	Shrub
Berberidaceae	*Berberis holstii* Engl.	Zinkila	Shrub
Cactaceae	*Opuntia ficus-indica* (L.) Miller.	Kulkual	Tree
Capparidaceae	*Crateva adansonii* Gilg.	Dingay seber	Tree
Ebenaceae	*Euclea racemosa* Murr. (*subsp. chimperi*)	Dedeho	Shrub
Ericaceae	*Erica arborea* L.	Asta	Tree
Malvaceae	*Abutilon longicuspe* Hochst. ex A. Rich.	Nechlo	Shrub
Meliaceae	*Ekebergia capensis* Sparrm.	Sembo	Tree
Myrsinaceae	*Myrsine africana* L.	Qechemo	Shrub
Myrtaceae	*Eucalyptus globulus* Labill	Nech bahir zaf	Tree
Oliniaceae	*Olinia rochetiana* A. Juss.	Beye	Tree
Pinaceae	*Pinus patula* Schiede ex Schltdl	Patula	Tree
Pittosporaceae	*Pittosporum viridiflorum* Sims.	Kefetaa	Tree
Poaceae	*Festuca simensis* Hochst ex. A. Rich.	Lancha	Shrub
Polygonaceae	*Rumex nervosus* Vahl	Embuacho	Shrub
Ranunculaceae	*Clematis hirsuta* Perr. and Guill.	Nech yeazo hareg	Climber
Santalaceae	*Osyris quadripartita* Decn.	Keret	Shrub
Sapindaceae	*Dodonaea angustifolia* L. f.	Kitkita	Shrub
Sapotaceae	*Mimusops kummel* A. DC.	Isheh	Tree
Solanaceae	*Solanum marginatum* Lam.	Embuay	Shrub
Sterculiaceae	*Dombeya torrida* (J. F. Gmel.) P. Bamps	Wulkfa	Tree
Tiliaceae	*Grewia ferruginea* Hochst. ex A. Rich.	Alenkoza	Shrub
Verbenaceae	*Lippia adoensis* Hochst. ex Walp.	Kese	Shrub

*Local name = Amharic.

Table 2: List of endemic woody species and their IUCN Red List Categories in the Harego dry Afromontane forest.

Botanical name	Family	Growth habit	IUCN Red List category
Rhus glutinosa A. Rich.	Anacardiaceae	Shrub	Vulnerable
Clematis hirsute Perr. and Guill.	Ranunculaceae	Shrub	—
Maytenus arbutifolia (A. Rich.) Wilczek	Celastraceae	Shrub	Not threatened
Lippia adoensis Hochst. Ex walp.	Verbenaceae	Shrub	Least concerned
Solanum marginatum L.f.	Solanaceae	Shrub	Least concerned

IUCN = International Union for Nature Conservation.

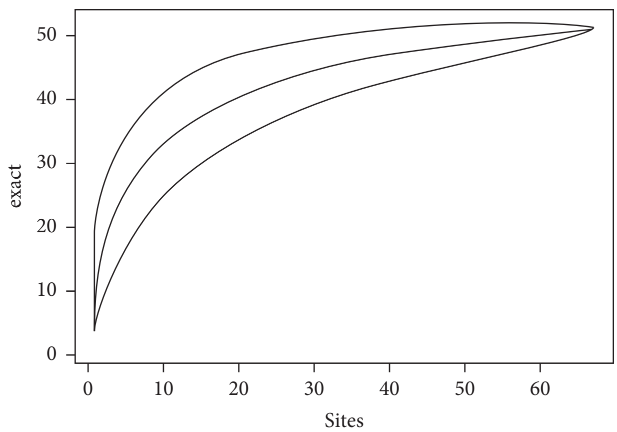

Figure 2: Species accumulation curve in Harego dry Afromontane forest (where the word Exact represents the number of species).

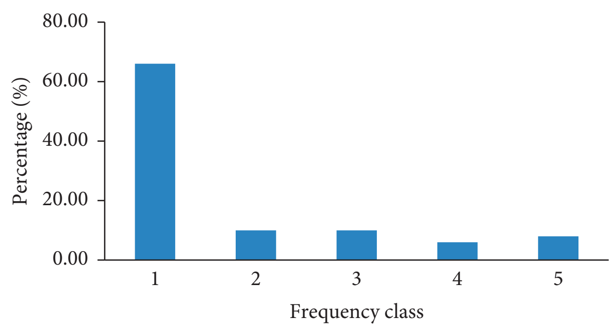

Figure 3: Frequency (%) class distribution of woody species in the Harego forest. Frequency class: 1 = 0–20; 2 = 20.1–40; 3 = >40.1–60; 4 = >60.1–80; and 5 = >80.1–100%.

two and three, but none of the species had a basal area of >1 m^2 ha^{-1} (Table 4).

3.5. Important Value Index (IVI). In the study area, the 10 most important woody species that accounted for 69.54% of the total IVI value, in descending order, were *Olea europaea* subsp. *cuspidata* (35.96%), *Dodonaea angustifolia* (30.24%), *Rhus natalensis* (29.63%), *Euphorbia candelabrum* (28.30%), *Myrsine africana* (18.62%), *Carissa spinarum* (18.24%), *Juniperus procera* (15.53%), *Jasminum grandiflorum* (12.18%), *Euclea racemosa (10.25%)*, and *Osyris quadripartita* (9.75%) (Table 3). Species with the lowest IVI% were *Rumex nervosus* (0.23), *Solanum marginatum* (0.17), *Erica arborea,* and *Acacia seyal* (0.14 each). The percentage of IVI of each species was categorized into five classes (Table 5). The high value of IVI was in class 4 followed by classes 3, 1, and 2, respectively. They accounted for about 97.60% of the total IVI value.

3.6. Diameter and Height Class Distribution of Trees and Shrubs. In the study area, DBH and height class distribution of all individuals in different size classes showed an inverted J-shaped distribution (Figures 4(a) and 4(b)) in which the majority of the species had the highest number of individuals at lower DBH and height classes with high decrease towards both high DBH and height classes. The diameter class distribution of selected representative woody species revealed various patterns of population structure. The first pattern was an inverted J-shaped distribution which is represented by *Olea europaea* subsp. *cuspidata* and *Juniperus procera* (Figures 5(a) and 5(g)). In this pattern, the high number of individuals was in the lower DBH classes, and abruptly decreased towards the higher classes. Species like *Rhus natalensis* and *Pittosporum viridiflorum* also shown an inverted J-shape (Figures 5(c) and 5(k)), but individuals existed only in the first three lower DBH classes. The second pattern was L-shaped, which is represented by *Dodonaea angustifolia*, *Osyris quadripartite*, and *Calpurnia aurea* (Figures 5(b), 5(j), and 5(l)). In this pattern, a very high number of individuals were observed in the first lower DBH class, followed by a few individuals in the second lower class, but none of the individuals fallen into the higher classes. The third pattern was bell-shaped, which is exhibited by *Euphorbia candelabrum* (Figure 5(d)). The fourth pattern was *I*-shaped, in which individuals were found only in the first DBH class, but not in other classes. This pattern was represented by *Myrsine africana*, *Carissa spinarum*, *Jasminum grandiflorum,* and *Euclea racemosa* (Figures 5(e), 5(f), 5(h), and 5(i)).

3.7. Regeneration Status of Woody Species. The total seedling, sapling, and mature density of 35 representative woody species in the study area were 45299 stems ha^{-1}, 24507 stems ha^{-1}, and 2465 stems ha^{-1}, respectively (Table 6). The density distribution of the seedling population was higher than that of the saplings, and the density of saplings was also higher than that of mature density. This indicates that the overall regeneration status of the forest is good. However, all species were not shown to have a good regeneration status. About 16 (45.71%) species showed good regeneration, 9 (25.71%) species had shown fair regeneration, 1 (2.86%) species showed poor regeneration, and 8 (22.86%) species showed no regeneration, while 1 (2.86%) species were newly regenerated. Five species, namely, *Myrsine africana, Dodonaea angustifolia, Rhus natalensis, Carissa spinarum,* and *Jasminum grandiflorum*, with their respective relative densities, represented 72.47% of the saplings. Economically or ecologically important species (*Euphorbia candelabrum*, *Juniperus procera,* and *Olea europaea* subsp. *cuspidata*) were less represented, while *Acacia etbaica*, *Mimusops kummel*, *Pittosporum viridiflorum,* and *Prunus africana* were not represented by saplings. Only 26 seedling species were represented from 35 woody species found in the understory. Seedlings of five species, with their respective relative density (*Myrsine africana, Dodonaea angustifolia, Jasminum grandiflorum*, *Rhus natalensis,* and *Carissa spinarum*) made up about 69.39% of the total seedlings counted in the study area. Eight species, namely, *Acacia abyssinica*, *Buddleja polystachya*, *Cupressus lusitanica*, *Dombeya torrida*, *Ekebergia capensis*, *Erica arborea*, *Opuntia ficus indica,* and *Olinia rochetiana* species, existed without saplings and seedlings. The only species which newly regenerated in Harego forest

Table 3: Woody species structures and important value indices in the Harego forest.

Species	F	A	WI	D	DO	RF	RDO	RD	IVI
Olea europaea subsp. *Cuspidate*	80.60	17.50	17.50	352.61	2.01	7.10	20.85	8.01	35.96
Dodonaea angustifolia	83.58	36.57	36.57	764.18	0.53	7.36	5.51	17.37	30.24
Rhus natalensis	88.06	27.36	27.36	602.24	0.79	7.75	8.19	13.69	29.63
Euphorbia candelabrum	38.81	12.42	12.42	120.52	2.14	3.42	22.15	2.74	28.30
Myrsine Africana	64.18	32.56	32.56	522.39	0.11	5.65	1.10	11.87	18.62
Carissa spinarum	82.09	18.95	18.95	388.81	0.21	7.23	2.17	8.84	18.24
Juniperus procera	41.79	7.75	7.75	80.97	0.97	3.68	10.01	1.84	15.53
Jasminum grandiflorum	68.66	15.07	15.07	258.58	0.03	6.04	0.26	5.88	12.18
Euclea racemosa	65.67	9.39	9.39	154.10	0.09	5.78	0.96	3.50	10.25
Osyris quadripartita	52.24	12.91	12.91	168.66	0.13	4.60	1.31	3.83	9.75
Eucalyptus globulus	10.45	1.86	1.86	4.85	0.84	0.92	8.65	0.11	9.69
Pittosporum viridiflorum	41.79	7.68	7.68	80.22	0.21	3.68	2.21	1.82	7.71
Calpurnia aurea	41.79	9.61	9.61	100.37	0.06	3.68	0.60	2.28	6.56
Maytenus arbutifolia	26.87	20.11	20.11	135.07	0.05	2.37	0.50	3.07	5.94
Rhus glutinosa	44.78	5.53	5.53	61.94	0.06	3.94	0.59	1.41	5.94
Maytenus senegalensis	26.87	11.22	11.22	75.37	0.04	2.37	0.45	1.71	4.53
Acacia abyssinica	13.43	2.44	2.44	8.21	0.25	1.18	2.59	0.19	3.96
Heteromorpha arborescens	23.88	13.00	13.00	77.61	0.00	2.10	0.04	1.76	3.91
Dombeya torrida	20.90	8.86	8.86	46.27	0.10	1.84	1.01	1.05	3.91
Grewia ferruginea	19.40	8.00	8.00	38.81	0.09	1.71	0.93	0.88	3.52
Opuntia ficus-indica	7.46	9.20	9.20	17.16	0.23	0.66	2.40	0.39	3.45
Clerodendrum myricoides	25.37	4.47	4.47	28.36	0.03	2.23	0.35	0.64	3.23
Cupressus lusitanica	13.43	3.56	3.56	11.94	0.17	1.18	1.77	0.27	3.22
Acacia etbaica	16.42	2.91	2.91	11.94	0.10	1.45	1.01	0.27	2.73
Pterolobium stellatum	16.42	7.00	7.00	28.73	0.01	1.45	0.15	0.65	2.25
Crateva adansonii	10.45	9.86	9.86	25.75	0.06	0.92	0.57	0.59	2.08
Prunus africana	7.46	6.20	6.20	11.57	0.10	0.66	1.05	0.26	1.97
Lippia adoensis	5.97	34.25	34.25	51.12	0.00	0.53	0.00	1.16	1.69
Ekebergia capensis	2.99	6.00	6.00	4.48	0.11	0.26	1.16	0.10	1.53
Premna schimperi	8.96	8.00	8.00	17.91	0.02	0.79	0.18	0.41	1.38
Clematis hirsute	8.96	9.50	9.50	21.27	0.01	0.79	0.09	0.48	1.36
Echinops macrochaetus	8.96	10.17	10.17	22.76	0.00	0.79	0.00	0.52	1.31
Rosa abyssinica	7.46	10.40	10.40	19.40	0.01	0.66	0.06	0.44	1.16
Asparagus africanus	7.46	10.00	10.00	18.66	0.00	0.66	0.00	0.42	1.08
Buddleja polystachya	7.46	4.00	4.00	7.46	0.01	0.66	0.07	0.17	0.89
Festuca simensis	5.97	9.00	9.00	13.43	0.00	0.53	0.00	0.31	0.83
Rhus retinorrhoea	5.97	5.25	5.25	7.84	0.01	0.53	0.07	0.18	0.77
Mimusops kummel	2.99	6.50	6.50	4.85	0.03	0.26	0.36	0.11	0.73
Pinus patula	1.49	5.00	5.00	1.87	0.05	0.13	0.51	0.04	0.69
Senra incana	4.48	3.33	3.33	3.73	0.00	0.39	0.00	0.08	0.48
Clutia abyssinica	4.48	3.00	3.00	3.36	0.00	0.39	0.00	0.08	0.47
Olinia rochetiana	2.99	3.50	3.50	2.61	0.01	0.26	0.07	0.06	0.39
Berberis holstii	2.99	3.50	3.50	2.61	0.00	0.26	0.00	0.06	0.32
Otostegia integrifolia	1.49	22.00	22.00	8.21	0.00	0.13	0.00	0.19	0.32
Euphorbia tirucalli	2.99	3.00	3.00	2.24	0.00	0.26	0.00	0.05	0.32
Ocimum lamiifolium	2.99	3.00	3.00	2.24	0.00	0.26	0.00	0.05	0.31
Rumex nervosus	1.49	12.00	12.00	4.48	0.00	0.13	0.00	0.10	0.23
Solanum marginatum	1.49	5.00	5.00	1.87	0.00	0.13	0.00	0.04	0.17
Erica arborea	1.49	1.00	1.00	0.37	0.00	0.13	0.00	0.01	0.14
Acacia seyal	1.49	1.00	1.00	0.37	0.00	0.13	0.00	0.01	0.14
Total	1135.82	500.37	500.37	4400.37	9.66	100	100	100	300

WI = abundance-frequency ratio; D = density (stems ha^{-1}); DO = basal area (m^2 ha^{-1}); RF = relative frequency; RD = relative density; RDO = relative basal area; and IVI = important value index.

was *Acacia seyal*. Generally, based on the availability of seedlings and saplings, plant species were grouped into three conservation priority classes (Table 7): class (1) species with no seedlings and saplings, (2) species with either seedlings or saplings, and (3) species with both seedlings and saplings.

4. Discussion

4.1. Floristic Composition and Species Diversity. According to the Atlas vegetation map of Ethiopia [81], the floristic composition of Harego forest is dry single-dominant Afromontane forest of the dry evergreen Afromontane forest and grassland

Table 4: Basal area (m^2 ha^{-1}) classes of species in the Harego forest.

BA class	Class interval	Density (stems ha^{-1})	RD	No. of Species	BA per class (m^2 ha^{-1})	BA (%)
1	0.01–0.1	1140.30	26.72	24	0.96	9.91
2	0.1–1	2654.10	62.19	12	4.55	47.09
3	>1–5	473.13	11.09	2	4.15	43.00
4	>5–10	0.00	0	0	0.00	0.00
5	>10	0.00	0	0	0.00	0.00
Total		4267.54	100	38	9.66	100

Basal area (BA) class (1 = 0.01–0.1; 2 = >0.1–1; 3 = >1–5; 4 = >5–10; and 5 = >10); RD = relative density; BA (%) = basal area in per cent.

Table 5: Importance value index (IVI) proportion of species belonging to each class in the Harego dry Afromontane forest.

IVI Class	Class interval (%)	No. of species	Sum of IVI	Percentage (%)
1	<1	16	7.21	2.40
2	1.0–10	25	93.84	31.28
3	10.1–20	5	74.81	24.94
4	20.1–30	2	57.94	19.31
5	(>30)	2	66.20	22.07
Total		50	300	100

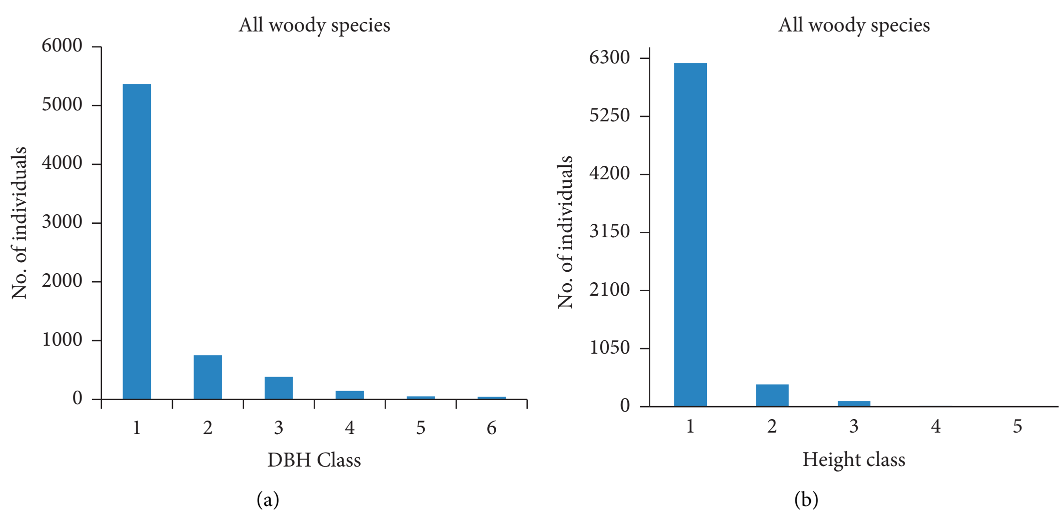

Figure 4: Cumulative DBH (a) and height (b) class of woody species in the Harego dry Afromontane forest.

complex types in Northeastern Ethiopia. The dry evergreen Afromontane forest represents a complex system of succession involving extensive grasslands rich in legumes, shrubs, and small to large-sized trees in a closed forest with a canopy of several strata [82]. Among the emergent species listed in the Atlas of Ethiopia by *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, *Acacia abyssinica*, *Prunus africana*, and *Euphorbia candelabrum* were found in the Harego forest. *Pittosporum viridiflorum, Ekebergia. capensis, Mimusops kummel,* and *Olinia. rochetiana* were found in the canopy layer. The third story is known as the shrub layer, and some of the species found in the study area were Carissa *spinarum*, *Calpurnia aurea*, *Dodonaea angustifolia*, *Dombia torrida*, *Grewia ferruginea*, *Maytenus* spp., *Osyris quadripartita*, *Premnia schimperi*, *Rhus natalensis,* and *Clutia abyssinica*. Climbers are also found, and some of them were *Myrsine africana* and *Heteromorpha arborescens.* Fabaceae was the most species-rich family in the study area, consisting of five species. Similar findings at Ambo state forest, 17 species [83], Kafta Sheraro National Park, 16 species [18], Menfeskidus Monastery forest, 14 species [66], Dello Mena forest, 13 species [84], Gra-Kahsu forest, 12 species [42], Yegof mountain forest, 9 species [41], Bradi forest, 9 species [85], Woynwuha forest, 9 species [86], Wof-Washa forest, 6 species [87], Zengena forest, 5 species [88], Gelawoldie forest, 5 species [89], Gemshat forest, 4 species [90], Yemrehane Kirstos Church Forest, and 4 species [91] were reported the dominance of the Fabaceae in the vegetation stands. The highest representation of species from the family Fabaceae could be related to the fact that it is the second largest family in the vascular plants of Ethiopia and Eritrea [60, 92]. This could also be attributed to its competent and successful dispersal strategies as well as its sound adaptation potential to the diverse ecologies of the country. In the study forest, about 46.38% of the families had only one species each. Families with only one species are susceptible to extinction either due to anthropogenic activities or due to unsuitable environmental conditions

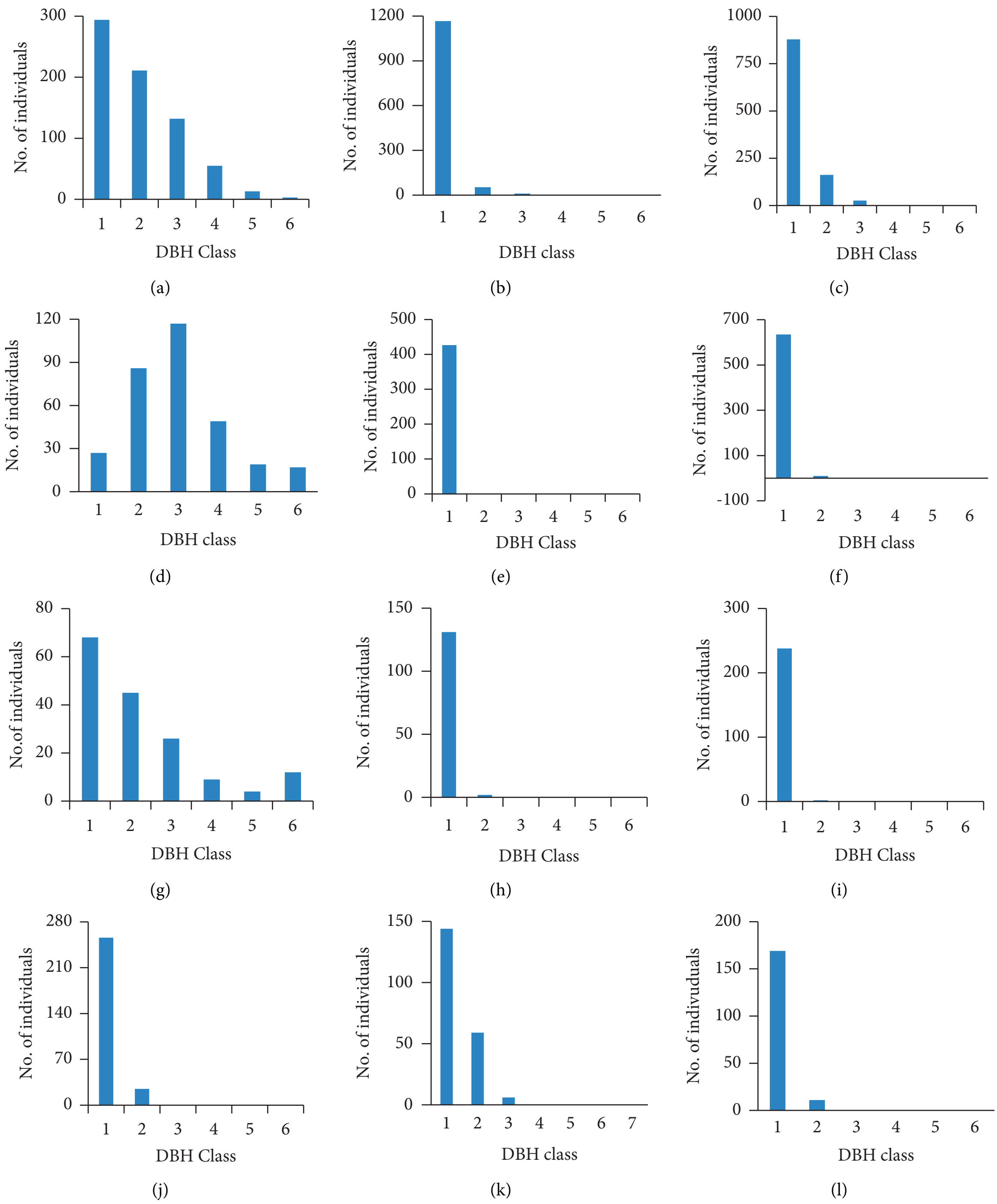

Figure 5: (a–i) Population structure of selected representative woody species in the Harego dry Afromontane forest. (a) Olea europaea subsp. cuspidata. (b) Dodonaea angustifolia. (c) Rhus natalensis. (d) Euphorbia candelabrum. (e) Myrsine africana. (f) Carissa spinarum. (j) Osyris quadripartita. (k) Pittosporum viridiflorum. (l) Calpurnia aurea.

or due to both [93]. Therefore, sound conservation and management should be given for species susceptible to extinction in in situ conditions. In the present study, shrubs had the largest proportion (54%) of growth habits. Similar finds were also reported at Gennemar dry Afromontane forest, 56.4% [94]; Yegof mountain forest, 51.3% [95]; Gelawoldie forest, 50.8% [89]; Zengena fores, 46% [88]; Kumuli forest, 44% [96]; and Gra-Kahsu natural vegetation, 39.53% [42], of the total growth habits of the species. The cause of the low tree species composition is due to intensive logging of useful species for timber and fuelwood [97], which in turn significantly altered their species composition with the dominance of pioneers and shrubs [4, 31]. Besides, shrub species have the capability to establish early success in the disturbed area [41].

The number of species recorded in the Harego forest (50 woody species) is more or less comparable with other dry

Table 6: Regeneration status of representative woody species in the Harego dry Afromontane forest.

Species	Stems ha^{-1}			Status
	Mature	Sapling	Seedling	
Clerodendrum myricoides	3.36	298.51	641.79	1
Heteromorpha arborescens	8.96	955.22	1791.04	1
Jasminum grandiflorum	49.63	2313.43	6044.78	1
Calpurnia aurea	67.16	492.54	835.82	1
Carissa spinarum	240.67	2417.91	3507.46	1
Dodonaea angustifolia	458.58	4641.79	7582.09	1
Euclea racemosa	89.55	925.37	1656.72	1
Grewia ferruginea	29.48	119.40	253.73	1
Juniperus procera	61.57	194.03	582.09	1
Maytenus arbutifolia	57.84	910.45	2179.10	1
Maytenus senegalensis	44.03	388.06	865.67	1
Myrsine Africana	159.33	5208.96	9313.43	1
Osyris quadripartite	104.85	626.87	1925.37	1
Rhus glutinosa	53.36	74.63	268.66	1
Rhus natalensis	398.13	3179.10	4985.07	1
Rosa abyssinica	10.82	134.33	208.96	1
Acacia etbaica	11.57	0.00	14.93	2
Euphorbia candelabrum	117.54	44.78	74.63	2
Euphorbia tirucalli	0.75	0.00	59.70	2
Mimusops kummel	4.10	0.00	29.85	2
Olea europaea subsp. *Cuspidate*	264.18	1358.21	2179.10	2
Pittosporum viridiflorum	77.99	0.00	89.55	2
Premna schimperi	11.94	119.40	119.40	2
Prunus africana	10.82	0.00	29.85	2
Rhus retinorrhoea	6.72	0.00	44.78	2
Crateva adansonii	23.13	104.48	0.00	3
Acacia abyssinica	8.21	0.00	0.00	4
Buddleja polystachya	7.46	0.00	0.00	4
Cupressus lusitanica	11.94	0.00	0.00	4
Dombeya torrida	46.27	0.00	0.00	4
Ekebergia capensis	4.48	0.00	0.00	4
Erica arborea	0.37	0.00	0.00	4
Opuntia ficus-indica	17.16	0.00	0.00	4
Olinia rochetiana	2.61	0.00	0.00	4
Acacia seyal	0.00	0.00	14.93	5
Total	2465	24507	45299	

1 = good regeneration; 2 = fair; 3 = poor; 4 = no regeneration; and 5 = newly regenerated.

Afromontane forests of the region, such as Metema, 45 species [98]; Achera Natural Forest, 48 species [99]; Wanzaye, 49 species [100]; Zengena, 50 species [88]; Shello Giorgis, 50 species [101]; Gennemar, 55 species [94]; Amoro, 57 species [102]; Ambo state forest, 58 species [83]; and Gelawoldie, 59 species [89], but higher than the Munessa-Shashemene forest, 32 species [103]; Yemrehane Kirstos Church forest, 39 species [91]; the dry land of eastern Tigray, 39 species [104]; and small Afromontane forest fragments in Tigray, 40 species [9]. On the other hand, the total number of species in the study area was much lower than the species recorded in Kafta Sheraro forest, 70 species [18]; *Agama* forest, 72 species [19]; Wof-Washa forest, 62 species [105]; Gra-Kahsu forest, 62 species [42]; Sirso forest, 74 species [76]; Oda forest, 62 species [14]; Denkoro forest, 65 species [26]; Woynwuha forest, 69 species [86]; Hugumburda forest, 70 species [31]; Yegof forest, 76 species [95]; Wof-Washa forest, 103 species [106, 107]; Abebaye and Tara Gedam forest, 88 species and 111 species, respectively [108]; Dello menna forest, 112 species [84]; Tana Zegie peninsula forest, 113 species [27]; and Sesa Mariam Monastery forest, 113 species [109]; Menfeskidus Monastery forest, 97 species [66]; and Sirso forest, 74 species [76]. Church forests of Dangila, 73 species [110]; Wurg Forest, 70 species [77]; Kumuli forest, 113 species [96]; Alemsaga fores, 101 species [111]; Gemshat forest, 60 species [90]; Brandi forest, 71 species [85]; and Arero dry Afromontane forest, 84 species [112]. Possible reasons for these differences may be due to forest size and landscape fragmentation as a result of human and environmental influence, age, and management activities. Generally, variations in altitude, which govern temperature and rainfall [42, 87, 113], slope and aspect [114, 115], anthropogenic disturbance and size of the forest area [9, 31, 40] are a factor in the difference in species richness in the different forest areas [116]. Prolonged grazing and illegal logging of trees for construction, timber, and fuel wood collection leads the study forest to have less species richness than most of the dry Afromontane forest if Ethiopia.

Among the endemic plant species listed in the dry evergreen Afromontane forest, *Clematis hirsute*, *Lippia adoensis*, *Maytenus arbutifolia*, *Rhus glutinosa,* and *Solanum marginatum* were found in the study area. Of these, *Lippia adoensis* and *Rhus glutinosa* are found on the IUCN Red List. Endemic species in the study area were few in numbers compared to Chilimo forest, with 18 species [117]; Borena saint national park, 11 species [26]; and Yegof forest, 9 species [41]; but comparable to Tara Gedam and Abebaye forests, 6 species [108] and Boda forest [118] and Bradi forest [85], which consisted 5 endemic species each. The few numbers of endemic species in the Harego forest, compared to other dry Afromontane forests, is an indicator of its stage of secondary succession after disturbance, where pioneer shrub species are densely populated. Endemic plant species are not found elsewhere in the world and need immediate conservation measure. Therefore, identifying and knowing these species supports us in giving conservation priority and effective management.

The species-area curve is a cumulative curve that relates the occurrence of species with the area sampled; curves that increase and flatten at the end indicate that the number of plots used is sufficient [74]. The species accumulation curve of the Harego forest indicates that the majority of plant species in the study area were captured by our sampling efforts. The species diversity curve of the vegetation richness across quadrats was good, and the diversity curve increased and plateaued, showing that an acceptable number of quadrats were used. Almost all similar patterns were observed around Lake Zengena forest [88], Debra-libanos Monastery forest [97], Ambo state forest [83], and Woynwuha forest [86].

According to Kent and Coker [67], the Shannon–Wiener diversity index normally varies between 1.5 and 3.5 and rarely exceeds 4.5. The Shannon–Wiener diversity index is high when it is above 3.0, medium when it is between 2.0 and 3.0, low between 1.0 and 2.0, and very low when it is smaller than 1.0 [119]. The studied forest had medium diversity

Table 7: Priority classes for conservation of woody species in the Harego dry Afromontane forest.

Priority class 1	Priority class 2	Priority class 3
Acacia abyssinica	*Acacia etbaica*	*Clerodendrum myricoides*
Buddleja polystachya	*Euphorbia tirucalli*	*Heteromorpha arborescens*
Cupressus lusitanica	*Mimusops kummel*	*Jasminum grandiflorum*
Dombeya torrida	*Pittosporum viridiflorum*	*Calpurnia aurea*
Ekebergia capensis	*Prunus africana*	*Carissa spinarum*
Erica arborea	*Rhus retinorrhoea*	*Dodonaea angustifolia*
Olinia rochetiana	*Acacia seyal*	*Euclea racemosa*
Opuntia ficus-indica	*Crateva adansonii*	*Grewia ferruginea*
		Juniperus procera
		Maytenus arbutifolia
		Maytenus senegalensis
		Myrsine Africana
		Osyris quadripartite
		Rhus glutinosa
		Rhus natalensis
		Rosa abyssinica
		Euphorbia candelabrum
		Olea europaea subsp. *Cuspidate*
		Premna schimperi

(($H' = 2.85$) and a more or less even ($E = 0.73$) representation of individuals of all species encountered in the studied quadrats, except for a few dominant species. The medium Shannon–Wiener diversity index of the forest may be due to the continuous harvesting of fuel wood and timber and the clearing of shrubs/trees for agriculture [83]. Similarly, the species richness (N_0), true Shannon (N_1), and true Simpson (N_2) in the study area indicated that species in the Harego forest were more or less evenly distributed. There was a minimum degree of dominance of a few species, as N_1 is less than N_0 and N_2 is less than N_1 [72]. This is because the Harego forest is densely populated by small-sized trees and shrubs, which in turn indicates that the woody plants of the forest are under secondary succession. The comparative analysis of Harego forest with other dry Afromontane forests demonstrated higher diversity and evenness than the Yegof forest ($H' = 2.26$ and $E = 0.57$) [95], Weiramba forest ($H' = 2.3$ and $E = 0.66$) [120], Ambo state forest ($H' = 2.73$ and $E = 0.67$) [83], and Zengena forest ($H' = 2.74$ and $E = 0.7$) [88], but lower than Bradi forest ($H' = 3.84$ and $E = 0.89$) [85], Amoro forest ($H' = 3.29$ and $E = 0.92$) [102], Gelawoldie forest ($H' = 3.8$ and $E = 0.9$) [89], Dangila Church forests ($H' = 3.5$ and $E = 0.82$) [110], Wanzaye forest ($H' = 3.15$ and $E = 0.81$) [100], and Woynwuha forest ($H' = 3.24$ and $E = 0.76$) [86]. Local climatic variations and a high rate of forest disturbance due to human encroachment and livestock grazing, which are common in the study area, are among the factors most responsible for variations in species diversity and evenness in a given forest. As a result, diversity and evenness indices imply the need to conserve the forest to restore its floristic diversity as well as to reduce and/or avoid human pressure.

4.2. Frequency and Density. Frequency is an important parameter of vegetation analysis, which reflects the spread, distribution, or dispersion of a species in a given area and an approximate indication of the heterogeneity of a stand [75]. The most frequently occurred species in the study forest (*Rhus natalensis*, *Dodonaea angustifolia*, *Carissa spinarum*, *Olea europaea* subsp. *cuspidata*, and *Jasminum grandiflorum*) were also reported in Yegof forest [95] which is found relatively in the same geographical location. In these forests, there is a high anthropogenic disturbance. In support of this, the dominance of shrubs has been evident in Gra-Kahsu [42], Amoro [102] and Zengena forests [88], Gelawoldie forest [89], Kumuli forest [96] where habitat fragmentation due to human encroachment is identified as a major threat. The high values in lower frequency classes and low values in the higher frequency class on the other hand indicate a high degree of floristic heterogeneity existed in the forest [74]. The high frequency could indicate the regular horizontal distribution of the species in the forests [108], while a low frequency could indicate that a species is either irregularly distributed or rare in a particular stand [75]. In the present study, the high values for lower frequency classes and the low values for the higher frequency classes show that Harego forest is floristically heterogeneous. Similar results were also observed, for example, at Gra-Kahsu [42], Ambo state forest [83], Zengena forests [88] Gelawoldie forest [89], Yegof forest [95], Kumuli forest [96], Amoro [102], Church forests of Dangila [110], and Menfeskidus Monastery forest [66]. Variation in the frequency of species might be attributed to habitat preferences among species, species characteristic for adaptation, degree of disturbance, and availability of suitable conditions for regeneration [121]. Besides a clumped pattern of distribution of species was observed which depicts the Harego forest is natural vegetation [122], and most seedlings were adapted to grow close to the mother plants [123].

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied. The total density of woody species (DBH >2 cm and height >2 m) in the Harego forest, 4400.75 stems ha^{-1} was high compared to other dry Afromontane forests like Zengena forest (2,202 stems ha-1) [88], Bradi forest (1838 stems ha^{-1}), Amoro forest (2860.49 stems ha^{-1}) [102], Dangila Church forests (2181 stems ha^{-1}) [110], Wof-Washa forest (664.4 stems ha^{-1}) [87], Gelawoldie forest (2016 stems ha^{-1}) [89], and Menfeskidus Monastery forest (395.83 stems ha^{-1}) [66], but lower than Kumuli forest (7791 individuals ha^{-1}) [96]. The possible reason for these variations might be due to differences in topographic gradients and habitat preferences of species forming the forest [42, 113] and the degree of anthropogenic disturbances [31, 87]. According to Grubb et al. [124], the ratio of individuals' ha^{-1} with DBH in between 10 and 20 cm (a) to individuals with DBH >20 cm (b) is taken as a measure of the size class distribution. Compared to other dry Afromontane forests (Table 8), the ratio (a/b) of the Harego forest, 5.45, was greater than that of the Denkoro forest (1.9) [26], Yegof forest (1.5) [41], Menagesha Amba Mariam forest (0.8), [125], Berber forest (1.5) [33], and Menfeskidus Monastery forest (1.49) [66]. The very high a/b ratio of the study area compared to others is an indicator of its stage of secondary succession and high contribution of the density of shrub species in which large and medium-size trees have been continuously removed.

4.3. Basal Area and IVI. The dominance can be expressed either by density (numerical dominance) or basal area (diameter measurement). However, the basal area provides a better measure of the relative importance of the species than a simple stem count [74]. The total basal area of the Harego forest (9.66 m^2 ha^{-1}) was much less than reported for other dry Afromontane forests such as Shello forest (132 m^2 ha^{-1}) [101], Dangila Church forests (98.4 m^2 ha^{-1}) [110], Ambo state forest (95.83 m^2 ha^{-1}) [83], Gelawoldie forest (93.8 m^2 ha^{-1}) [89], Bradi forest (91.03 m^2 ha^{-1}) [85], Menagesha Amba forest (84.17 m^2 ha^{-1}) [125], Wof-Washa forest (55.99 m^2 ha^{-1}) [87], Menfeskidus Monastery forest (56.30 m^2 ha^{-1}) [66], Weiramba forest (32.10 m^2 ha^{-1}) [120], Kumuli forest (30.16 m^2 ha^{-1}) [96], Zengena forest (22.3 m^2 ha^{-1}) [88], Amoro forest (18.5 m^2 ha^{-1}) [102], and Yegof forest (15.85 m^2 ha^{-1}) [95]. The normal basal area value for virgin tropical forests in Africa is 23–37 m^2 ha^{-1} [74]. However, the basal area of the Harego forest was low compared to tropical forests in Africa including dry Afromontane forests found in Ethiopia. The studied forest is at the stage of secondary succession after disturbance, and the high density of shrub species led it to lower in the basal area of the stand. In line with this, Senbeta [23] reported that site productivity, competition (successional stage), and/or density affect the basal area of forests and stands. Particularly, the higher density of species and the lower mean basal area is an indicator of the dominance of shrub species in forest areas [63] and an indicator of its secondary succession [126]. In general, the basal area classes indicate species with the larger basal area in the Harego forest were selectively harvested, and its current status led none of the individuals to be recommended for timber harvesting.

Importance value index is a useful parameter to compare the ecological significance of species in which a high IVI value indicates that the species ecological structure in a community is high [67, 74]. Besides, the IVI gives a more realistic assessment of dominance from a structural standpoint. The species having highest IVI is identified as dominant, and the second highest IVI is defined as co-dominant species. According to Lamprecht [74], stands that yield more or less the same IVI for the characteristic species indicate the existence of the same or at least similar stand composition and structure, site requirements, and comparable dynamics among species. In contrast to this idea, most of the species in this study showed variation in terms of their important value index. This was due to the difference in density, frequency, and basal area of species. If we have seen the top 10 species with IVI, the high value for *Olea europaea sub spp. cuspidata* was attributed to its high frequency and basal area, while for *Euphorbia candelabrum* and *Juniperus procera* was due to the high basal area. The high value of *Dodonaea angustifolia*, M*yrsine africana Rhus natalensis Carissa spinarum*, *Jasminum grandiflorum*, *Euclea racemosa,* and *Osyris quadripartita* was attributed to their high frequency and density. Generally, in the present study, the high value in the basal area for tree species, while the high values in frequency and density for shrub species were the major contributors of the IVI value. Similar results were also reported in other dry Afromontane forests, for example, at Ambo state forest [83], Yegof forest [95], Church forests of Dangila [110], and Bradi forest [85]. IVI is also used as a criterion to prioritize species for conservation actions. Species with the highest IVI value need lower conservation efforts than those having the lowest IVI value [108]. Because of species with the highest IVI value has to be considered as more resilience and resistance to the high pressure of disturbance than the lowest classes. As a result, immediate protection and conservation action is needed to the species which were categorized under the lowest (first and second) IVI class of the study area.

4.4. DBH and Height Class Distribution. The population structure refers to the distribution of individuals in systematically defined height or diameter classes of plants [36]. DBH and height of plant species are, therefore, the two most commonly used size measures in the analysis of plant population structure [34], and it will provide a rough idea about the regeneration of woody plants [36]. The DBH and height class distribution of the Harego forest have shown the dominance of small-sized individuals in the forest. Similar findings have been reported in other dry Afromontane forests such as Menfeskidus Monastry forest [66], Sirso forest [76], Wurg forest [77], Ambo State forest [83], Dello Mena forest [84], Brandi forest [85], Woynwuha forest [86], Gelawoldie forest [89], Gennemar dry Afromontane Forest [94], Kumuli forest [96], Wanzaye forest [100], Amoro forest [102], and Sesa Mariam Monastry forest [109]. This revealed a healthy regeneration but low in recruitment [34, 103, 127]. Such a result is an indicator of the history of selective cutting of large-sized individuals [19, 99, 128] for construction,

Table 8: Comparison of tree density (stems ha^{-1}) of Harego forest with other dry Afromontane forests of Ethiopia;

Forest	A	B	A/B	Source
Harego	197.39	36.19	5.45	Present study
Denkoro	526	285	1.85	[26]
Zengena	206	96	2.15	[88]
Yegof	338.75	82.5	1.95	[41]
Gelawoldie	170	73	2.3	[89]
Menagesha Amba Mariam	155.46	197.46	0.80	[125]
Berber	216.58	138.62	1.56	[33]
Menfeskidus Monastery	288.64	193.94	1.49	[66]
Shello	173.5	68	2.55	[101]

a = individuals >10 cm DBH; *b* = individuals >20 cm DBH; a/*b* = ratio between a and *b*.

farming materials, and income generation [26, 33, 83, 108] and the dominance of the shrub species density in the forest [103]. In general, in an area where the density of shrub species is high, the diameter class distribution would be reversed J-shape [129] since bigger tree species are selectively removed [33]. Contrary to the present study, Shiferaw et al. [112], Teshager et al. [120], and Gebeyehu et al. [130] have found bell-shaped and irregular J-shaped woody plant population frequency distribution patterns. The variations among these forests might be attributed to the different management practices and anthropogenic activities in and around the forests.

However, the diameter class distribution of selected species demonstrated various patterns of population structure, implying different population dynamics among species. The first pattern was a reversed J-shaped distribution. Similar distribution pattern was reported by Menagesha Amba Mariam forest [125] for *Olea europaea* subsp. *cuspidata*, Negesse, and Woldearegay [66] for *Podocarpus falcatus*, *Juniperus procera*, and *Erica arborea* at Menfeskidus Monastery forest. This pattern indicates healthy regeneration potential but low recruitment, and it might be due to the overexploitation of higher-class individuals for construction, farming, and income generation. Because of logging, it has been enormously selective and has alarmed only a few highly valuable timber tree species in Ethiopia [131]. The second pattern was L-shaped, with a very high individual in the first class and only a few individuals in the second class, but not across other classes. A similar pattern was reported for *Calpurnia aurea*, *Euclea racemosa,* and *Maytenus arbutifolia* at Yegof forest [95]. This is an indicator of good regeneration but bad recruitment, which in turn implies their early succession in disturbed areas [103]. This could also be attributed to unfavourable environmental conditions such as rocky land and poorly developed soil [19] and human disturbance [41, 108]. The third pattern was bell-shaped in which individuals were high in the middle classes but decreased towards the higher and lower DBH classes. A similar pattern were reported for *Nuxia congesta*, *Acokanthera schimperi*, and *Allophylus abyssinicus* at Menfeskidus Monastery forest [66], *Acokanthera schimperi*, *Olea europaea* subsp. *cuspidata*, and *Scolopia theifolia* at Arero forest [112]. This pattern indicates poor regeneration and recruitment [33] which might be due to the history of overexploitation of seed-bearing individuals [23]. The hampered regeneration could also be attributed to grazing or trampling by livestock that was a common phenomenon in the dry Afromontane forest [84]. The fourth pattern was I-shaped, which indicates the species were newly regenerated in the disturbed area. A similar pattern was reported for *Erythrina bruci* at Zengena forest [88]. This pattern suggested good reproduction potential and healthy regeneration status but poor recruitment status [13, 88, 108, 125]. This might be due to the early successional stage of shrub species in the disturbed area [26, 41] and cutting off the higher diameter class for fence and firewood. Generally, variations in the population structure of plant species might be attributed to environmental and anthropogenic factors that can interrupt natural regeneration. These are indicators of the need to take appropriate conservation measures by the relevant authorities at various levels, giving due attention to those species with poor reproduction and recruitment status, as well as reducing human pressure on medium and large-sized individuals that would serve as seed sources for the regeneration of woody species in the forest and restoration of the surrounding degraded areas.

4.5. Natural Regeneration of Harego Forest. The density values of seedlings and saplings are considered as the regeneration potential of the species [80]. The studied forest had shown good regeneration status, in which the density of seedlings was higher than the density of saplings, and saplings were higher than mature individuals. The presence of more seedlings than saplings and saplings than mature trees was also reported in similar vegetation studies in Ethiopia, such as Yemrehane Kirstos Church forest [91], Yegof mountain forest [41], Sirso forest [76], and Bradi forest [85], and Ambo state forest [83]. However, a few species (*Myrsine africana, Dodonaea angustifolia, Jasminum grandiflorum*, *Rhus natalensis,* and *Carissa spinarum*) were the most abundant in the regeneration stage, which covered about three-fourths of the total regenerating population. This shows the future status of the forest will be covered by a few dominant species, which leads to less diversification of the forest [105]. In contrary, fair regeneration at Berber [33] and Gelawoldie forest [89] and poor regeneration at

Menagesha Amba Mariam Forest [125] was reported. Possible variation in the regeneration status of the forests might be due to variations in the degree of human encroachment and livestock grazing [116, 132] and also soil seed bank and physical factors [125].

Of the species selected for regeneration analysis, about half of them showed good regeneration status. The presence of good regeneration potential shows the stability of the species to thrive in the environment [105] through different mechanisms like the dispersal of seeds through wind and the drooping of birds and animals [33]. However, about one-fourth of the species were under the poor and no regeneration category, although most of them are economically and ecologically important. A similar report was observed from Wof-Washa forest [105] and Ambo state forest [83] ecologically and economically important species were less represented in the regeneration stage. Explanations for hampering regeneration in the forest could be many, including livestock grazing and trampling, selective maturing stem cuts for construction and market purposes, rockiness, and shallow soil depth. Besides, canopy shade, litter accumulation and herbs, termites, and aphids, and the need for dormancy periods for seeds with certain species were also a factor to either affect the fruiting and/or seed germination or successful conversion of seedlings to the saplings stage. Moreover, individuals in the young stages of any species were more vulnerable to any kind of environmental stress and anthropogenic disturbance [34]. Reports from Northeastern Ethiopia showed that rainfall seasonality, shade, and herbivory are the dominant factors in regulating establishment, recruitment, survival, and growth, particularly during the seedling stage [45]. In support of this, Asefa et al. [116] identified grazing as one of the dominant ecological drivers that affected the vegetation structure of dry Afromontane forests in Ethiopia due to the high cattle population. On the other hand, the growth of *Acacia* species was highly affected by temperature, availability of water, and soil type [133]. Generally, seedling recruitment is a block in the population dynamics of many tree species [134] since it determines the local abundance of mature trees and this calls for urgent conservation measures through prioritization [41, 99]. As a result, those species that did not have seedlings and saplings, l were grouped under priority class I; species those with either seedlings or saplings have grouped under conservation class II; and species existing with both seedlings and saplings were grouped under the III conservation priority class. Therefore, all local and regional stakeholders should participate in conservation activities to prevent these species from local extinction.

5. Conclusions and Recommendations

Harego forest is one of the few naturally regenerated forests found in the dry Afromontane zone of Ethiopia, including endemic species that have been found under the IUCN Red List (grouped under vulnerable, near threatened, and least concern). Most of the species families in the study area were of a single species. Families represented by only one species and endemic species categorized in the IUCN Red List and rare species in this forest will disappear from the forest if comprehensive conservation measure has not been taken. The forest could also be evaded a few species, predominantly by shrubs, unless proper management actions have been taken on rare species. Most species have fallen in the lower frequency, basal area, and IVI classes. The density of species in the forest also decreased with increasing DBH and height classes, which show the history of past disturbance and selective stem cutting of the desired species. In particularly, ecologically or economically significant woody species in forests are poor in regeneration. In general, the increase in population demand and disturbances to indigenous woody species show a high variation in stand structure and hampered natural regeneration. These imply the need for immediate conservation action to ensure the sustainable utilization of the forest. As a result, woody species, which rarely exist, endemic, and listed under in the IUCN Red List, having low IVI value and poor regeneration status in the study area, need a proper conservation mechanism, in situ and ex situ, they disappear. Further studies on herbaceous species, ethnobotany, and soil seed banks are required.

Data Availability

The vegetation-enumerated data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The financial support from Wollo University that covered the living expenses and tuition fees of Mr. Belachew Bogale is gratefully acknowledged. The authors deeply appreciate and are thankful for the administrative and technical support received from colleagues, field workers, and herbarium staffs.

References

[1] FAO, *Global Forest Resources Assessment 2010: Option and Recommendatios for a Global Remote Sensing Survey of Forests*, FAO, Rome, Italy, 2010.

[2] N. Myers, R. A. Mittermeier, C. G. Mittermeier, G. A. B. Fonseca, and J. Kent, "Biodiversity hotspots for conservation priorities," *Nature*, vol. 403, pp. 853–858, 2000.

[3] P. G. Murphy and A. E. Lugo, "Ecology of tropical dry forest," *Annual Review of Ecology and Systematics*, vol. 17, no. 1, pp. 67–88, 1986.

[4] M. Lemenih and F. Bongers, *Dry Forests of Ethiopia and Their Silviculture*, pp. 261–272, Springer, Berlin, Heidelberg, 2011.

[5] B. Bishaw, "Deforestation and land degradation on the Ethiopian highlands: a atrategy for physical recovery," in *Paper. Presentation. International. Conference. Contemporary. Development. Issues Ethiopia. Kalamazoo*, pp. 1–9, Ethiopia Tree Fund Foundation, Michigan, U.S.A, 2001.

[6] I. Backcus, J. Skoglund, Z. Woldu, K. Tekle, and Z. Woldu, "Vegetation on hill slopes i n southern Wello , Ethiopia: degradation and regeneration, Nord," *Journal de Botanique, Le*, vol. 17, pp. 483–493, 1997.

[7] B. Zewde, "Forests and forest management in Wällo in historical perspective," *Journal of Ethiopian Studies*, vol. 31, pp. 87–121, 1998.

[8] A. Wassie, D. Teketay, and N. Powell, "Church forests in north Gonder administrative zone, Northern Ethiopia," *Forests, Trees and Livelihoods*, vol. 15, no. 4, pp. 349–373, 2005.

[9] R. Aerts, K. Van Overtveld, M. Haile, M. Hermy, J. Deckers, and B. Muys, "Species composition and diversity of small Afromontane forest fragments in northern Ethiopia," *Plant Ecology*, vol. 187, no. 1, pp. 127–142, 2006.

[10] S. Demissew, "A study of the vegetation and floristic composition of Southern Wällo, Ethiopia: a special issue on environment and development in Wällo," *Journal of Ethiopian Studies*, vol. 31, pp. 159–192, 1998.

[11] A. Wassie, F. J. Sterck, and F. Bongers, "Species and structural diversity of church forests in a fragmented Ethiopian highland landscape," *Journal of Vegetation Science*, vol. 21, no. 5, pp. 938–948, 2010.

[12] T. Bekele, *Vegetation Ecology of Remnant Afromontane Forest on the Central Plateau of Shewa, Ethiopia*, Acta University, Uppsala, Sweden, 1993.

[13] T. Gemechu, T. Soromessa, and E. Kelbessa, "Structure and regeneration of gendo moist montane forest , east wellega zone , western Ethiopia," *Journal of Environment and Earth Science*, vol. 5, pp. 148–169, 2015.

[14] M. Kuma and S. Shibru, "Floristic composition, vegetation structure, and regeneration status of woody plant species of Oda forest of Humbo carbon project, Wolaita, Ethiopia," *Journal de Botanique, Le*, vol. 2015, Article ID 963816, 9 pages, 2015.

[15] D. Mekonnen, T. Takele, S. Raju, and T. Woldemariam, "Assessment of woody plant species composition of Dilfaqar Regional Park, Ethiopia," *Journal of Nature Conservation*, vol. 24, pp. 33–44, 2012.

[16] S. Tadese, T. Soromessa, T. Bekele, and G. Gebeyehu, "Woody species composition, vegetation structure, and regeneration status of Majang forest biosphere reserves in Southwestern Ethiopia," *International Journal of Financial Research*, vol. 2021, Article ID 963816, 22 pages, 2021.

[17] E. Atinafe, E. Assefa, B. Belay, Y. Endale, and T. Seta, "Floristic diversity and natural regeneration status of Entoto mountain and the surrounding area in Addis Ababa, Ethiopia," *International Journal of Financial Research*, vol. 2020, Article ID 4936193, 10 pages, 2020.

[18] F. Temesgen and B. Warkineh, "Woody species structure and regeneration status in Kafta Sheraro national park dry forest, Tigray region, Ethiopia," *International Journal of Financial Research*, vol. 2020, Article ID 4597456, 22 pages, 2020.

[19] A. Dibaba, T. Soromessa, A. Kefalew, and A. Addi, "Woody species diversity, vegetation structure, and regeneration status of the moist Afromontane forest of Agama in Southwestern Ethiopia," *International Journal of Ecology*, vol. 2020, Article ID 1629624, 10 pages, 2020.

[20] J. O. Maua, H. MugatsiaTsingalia, J. Cheboiwo, and D. Odee, "Population structure and regeneration status of woody species in a remnant tropical forest: a case study of South Nandi forest, Kenya," *Global Ecology and Conservation*, vol. 21, 2020.

[21] P. C. Nath, A. Arunachalam, M. L. Khan, K. Arunachalam, and A. R. Barbhuiya, "Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India," *Biodiversity and Conservation*, vol. 14, no. 9, pp. 2109–2135, 2005.

[22] Z. Zhang, G. Hu, J. Zhu, and J. Ni, "Stand structure, woody species richness and composition of subtropical Karst forests in Maolan, South-West China," *Journal of Tropical Forest Science*, vol. 24, pp. 498–506, 2012.

[23] W. F. Senbeta, *Biodiversity and Ecology of Afromontane Rainforests with Wild Coffea Arabica L. Populations in Ethiopia*, Cuvillier Verlag Göttingen, Göttingen, Germany, 2007.

[24] E. N. Mwavu and E. T. F. Witkowski, "Population structure and regeneration of multiple-use tree species in a semi-deciduous African tropical rainforest: implications for primate conservation," *Forest Ecology and Management*, vol. 258, no. 5, pp. 840–849, 2009.

[25] M. T. Naidu and O. A. Kumar, "Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India," *Journal of Asia-Pacific Business*, vol. 9, no. 3, pp. 328–334, 2016.

[26] T. Bekele, A. Ayalew, and S. Demissew, "The undifferentiated afromontane forest of Denkoro in the central highland of Ethiopia: a floristic and structural analysis," *Sinet: Ethiopian Journal of Science*, vol. 29, no. 1, pp. 45–56, 2006.

[27] A. Alelign, D. Teketay, Y. Yemshaw, and S. Edwards, "Diversity and status of regeneration of woody plants on the peninsula of Zegie, northwestern Ethiopia," *Tropical Ecology*, vol. 48, pp. 37–49, 2007.

[28] E. Lulekal, E. Kelbessa, T. Bekele, and H. Yineger, "Plant species composition and structure of the Mana Angetu moist montane forest, south-eastern Ethiopia," *Journal of East African Natural History*, vol. 97, no. 2, pp. 165–185, 2008.

[29] L. K. Woldemichael, T. Bekele, and S. Nemomissa, "Vegetation composition in hugumbirda-gratkhassu national forest priority area, south Tigray," *Momona Ethiopian Journal of Science*, vol. 2, pp. 27–48, 2010.

[30] H. Yineger, E. Kelbessa, T. Bekele, and E. Lulekal, "Floristic composition and structure of the dry afromontane forest at bale mountains national park, Ethiopia," *Sinet: Ethiopian Journal of Science*, vol. 31, no. 2, pp. 103–120, 2011.

[31] E. B. Aynekulu, "Forest diversity in fragmented landscapes of northern ethiopia and implications for conservation," 2011, https://d-nb.info/1016004389/34.

[32] A. S. Mohammed and S. Giacomo, "A survey on species diversity, abundance and community structure of woody plants in burial sites in Gobeya Rural Administrative of Tehuledere District, South Wollo, Ethiopia," *Journal of Ecology and the Natural Environment*, vol. 9, no. 4, pp. 62–70, 2017.

[33] T. Bogale, D. Datiko, and S. Belachew, "Structure and natural regeneration status of woody plants of Berbere Afromontane moist forest, Bale Zone, South East Ethiopia; implication to biodiversity conservation," *Open Journal of Forestry*, vol. 7, no. 3, pp. 352–371, 2017.

[34] G. Tesfaye, D. Teketay, and M. Fetene, "Regeneration of fourteen tree species in Harenna forest, southeastern Ethiopia," *Flora—Morphology, Distribution, Functional Ecology of Plants*, vol. 197, no. 6, pp. 461–474, 2002.

[35] G. Tesfaye, D. Teketay, M. Fetene, and E. Beck, "Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia," *Flora—Morphology, Distribution,*

Functional Ecology of Plants, vol. 205, no. 2, pp. 135–143, 2010.

[36] D. Teketay, "Seedling populations and regeneration of woody species in dry Afromontane forests of Ethiopia," *Forest Ecology and Management*, vol. 98, no. 2, pp. 149–165, 1997.

[37] E. Aynekulu, M. Denich, and D. Tsegaye, "Regeneration response of Juniperus procera and Olea europaea subsp cuspidata to exclosure in a dry Afromontane forest in Northern Ethiopia," *Mountain Research and Development*, vol. 29, no. 2, pp. 143–152, 2009.

[38] A. Wassie, F. J. Sterck, D. Teketay, and F. Bongers, "Tree regeneration in church forests of Ethiopia: effects of microsites and management," *Forest Ecology and Management*, vol. 257, no. 3, pp. 765–772, 2009.

[39] T. Ereso Denbel, "Woody species diversity and structure of protected woodlands adjacent to free grazing land woodland at Dugda woreda, Oromia, Ethiopia," *International Journal of Financial Research*, vol. 2021, Article ID 8834892, 10 pages, 2021.

[40] L. Kidane, S. Nemomissa, and Z. Woldu, "The effects of disturbance on the population structure and regeneration potential of five dominant woody species—in Hugumburda-Gratkhassu National Forest Priority Area, North-eastern Ethiopia," *African Journal of Ecology*, vol. 54, no. 1, pp. 20–28, 2015.

[41] S. Mohammed and B. Abraha, "Floristic composition and structure of Yegof mountain forest, South Wollo, ethiop," *Journal of Science and Technology*, vol. 6, pp. 33–45, 2013.

[42] T. Atsbha, A. B. Desta, and T. Zewdu, "Woody species diversity, population structure, and regeneration status in the Gra-Kahsu natural vegetation, southern Tigray of Ethiopia," *Heliyon*, vol. 5, no. 1, 2019.

[43] A. Muhammed and E. Elias, "The effects of landscape change on plant diversity and structure in the Bale mountains national park, southeastern Ethiopia," *International Journal of Ecology*, vol. 2021, Article ID 6628282, 13 pages, 2021.

[44] T. Okuda, N. Kachi, S. K. Yap, and N. Manokaran, "Tree distribution pattern and fate of juveniles in a lowland tropical rain forest - implications for regeneration and maintenance of species diversity," *Plant Ecology*, vol. 131, pp. 155–171, 1997.

[45] T. Bekele, "Recruitment, survival and growth of Olea europaea subsp. cuspidata seedlings and juveniles in dry Afromontane forests of northern Ethiopia," *Tropical Ecology*, vol. 46, pp. 113–126, 2005.

[46] E. O. Wilson, "The current state of biological diversity," *Biodiversity*, vol. 52, pp. 3–18, 1988.

[47] P. S. Swamy, S. M. Sundarapandian, P. Chandrasekar, and S. Chandrasekaran, "Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India, Biodivers," *Biodiversity and Conservation*, vol. 9, no. 12, pp. 1643–1669, 2000.

[48] N. Annon, "Atlas of Ethiopia," *Ethiopian mapping authority*, Addis Ababa, Ethiopia, 1988.

[49] FAO, *Ethiopian geomorphology and soils (1:1,000,000 scales)*, Assistance to Land Use Planning, Addis Ababa, Ethiopia, 1984.

[50] K. Tekle, "FORUM: land degradation problems and their implications for food shortage in south wello, Ethiopia," *Environmental Management*, vol. 23, no. 4, pp. 419–427, 1999.

[51] MoPED, *A Preliminary Survey on Utilization and Conservation of Natural Resources in Southern Well*, MoPED, Dessie, Ethiopia, 1993.

[52] NMSAKS, *The Data of Rainfall and Temperature of Ten Years*, Dessie and Kombolcha areas, Kombolcha, Ethiopia, 2017.

[53] D. C. Powell, *Density Danagement Field Exercise*, Forest Silviculturist Umatilla National Forest, Pendleton, USA, 2014.

[54] FAO, *National Forest Inventory Filed Manual Template. A Forest Resources Assessment Programe Working Paper 94/E*, Food and Agriculture Organization of the United Nations, Rome, Italy, 2004.

[55] S. Edwards, S. Demissew, and I. Hedberg, *Flora of Ethiopia and Eritrea, Volume 6: Hydrocharitaceae to Arecaceae*, The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 1997.

[56] I. Hedberg, E. Kelbessa, S. Edwards, S. Demissew, and E. Persson, *Flora of Ethiopia and Eritrea, Volume 5: Gentianceae to Cyclocheilaceae*, The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 2006.

[57] S. Phillips, *Flora of Ethiopia and Eritrea, Volume 7: Poaceae (Gramineae), the National Herbarium*, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 1995.

[58] S. Edwards, M. Tadesse, and S. Demissew, *Flora of Ethiopia and Eritrea, Volume 2, Part 1: Magnoliaceae to Flacourticeae*, The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 2000.

[59] I. Hedberg, S. Edwards, and S. Nemomissa, *Flora of Ethiopia and Eritrea, Volume 4, Part 1: Apiaceae to Dipsacaceae, Dipsacaceae*, Addis Ababa, Ethiopia, 2003.

[60] I. Hedberg and S. Edwards, "Flora of Ethiopia," *Pittosporaceae to Araliaceae, The National Herbarium*, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala, University, Addis Ababa, Ethiopia, 1989.

[61] S. Edwards, M. Tadesse, and I. Hedberg, *Flora of Ethiopia and Eritrea, Volume 2, Part 2: Canellaceae to Euphorbiaceae*, The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 1995.

[62] A. Bekele, *Useful Trees and Shrubs for Ethiopia: Identification, Propagation and Management in 17 Agro-Ecological Zones*, World Agroforestry Centre (ICRAF), Nairobi, Kenya, 2007.

[63] C. L. Batchleler and D. G. Craib, "A Variable area plot method of assessment of forest condition and trend," *New Zealand. Ecological. Society*, vol. 8, pp. 83–95, 1985.

[64] R. M. Sighal, *Soil and Vegetation Studies in Forests*, ICFRC.publication, Debra Dun, India, 1996.

[65] A. Dibaba, T. Soromessa, E. Kelbessa, and A. Tilahun, "Diversity, structure and regeneration status of the woodland and riverine vegetation of Sire Beggo in Gololcha District, Eastern Ethiopia," *Momona Ethiopian Journal of Science*, vol. 6, no. 1, pp. 70–96, 2014.

[66] G. Negesse and M. Woldearegay, "Floristic diversity, structure and regeneration status of Menfeskidus Monastery

forest in berehet district, north shoa, central Ethiopia," *Trees, Forests and People*, vol. 7, pp. 100191–100210, 2022.
[67] M. Kent and P. Coker, *Vegetation Description and Analysis - a Practical Approach*, John Wiley and Sons.Inc, New York, USA, 1992.
[68] C. J. Krebs, *Ecological Methodology*, Addison Wesley Logman, Inc, New York, USA, 2nd edition, 1998.
[69] A. E. Magurran, *Measuring Biological Diversity*, Blackwell Science Ltd. A Blackwell Publishing Company, Melden, Mass, USA, 2004.
[70] L. Jost, "The relation between evenness and diversity," *Diversity*, vol. 2, pp. 207–232, 2010.
[71] M. O. Hill, "Diversity and evenness: a unifying notation and its consequences," *Ecology*, vol. 54, no. 2, pp. 427–432, 1973.
[72] L. Jost, "Entropy and diversity," *Oikos*, vol. 113, no. 2, pp. 363–375, 2006.
[73] H. Tuomisto, "International Association for Ecology A consistent terminology for quantifying species diversity? Yes, it does exist," *Oecologia*, vol. 164, no. 4, pp. 853–860, 2010.
[74] H. Lamprecht, "Silviculture in the tropics: tropical forest ecosystems and their tree species–possibilities and methods for their long-term utilization," 1989, https://agris.fao.org/agris-search/search.do?recordID=DE95R0053.
[75] P. B. Whitford, "Distribution of woodland plants in relation to succession and clonal growth," *Ecology*, vol. 30, no. 2, pp. 199–208, 1949.
[76] B. Mewded, M. Negash, and T. Awas, "Woody species composition, structure and environmental determinants in a moist evergreen Afromontane forest, southern Ethiopia," *Journal. For. Research*, vol. 31, no. 4, pp. 1173–1186, 2020.
[77] G. Boz and M. Maryo, "Woody species diversity and vegetation structure of Wurg forest, Southwest Ethiopia," *International Journal of Financial Research*, vol. 2020, p. 17, 2020.
[78] M. L. Khan, J. P. N. Rai, and R. S. Tripathi, "Population structure of some tree species in disturbed and protected subtropical forests of north-east India," *Acta Oecologica Oecologia Applicata*, vol. 8, pp. 247–255, 1987.
[79] P. Tiwari, K. Tadele, K. Aramde, and S. Tiwari, "Community structure and regeneration potential of Shorea robusta forest in subtropical submontane zone of Garhwal Himalaya, India," *Nature and Science*, vol. 8, pp. 70–74, 2010.
[80] M. Dhaulkhandi, A. Dobhal, S. Bhatt, and M. Kumar, "Community structure and regeneration potential of natural forest site in Gangotri, India," *Journal of Basic and Applied Sciences*, vol. 4, pp. 49–52, 2008.
[81] I. Friis, S. Demissew, and P. van Breugel, *Atlas of the Potential Vegetation of Ethiopia*, Royal Danish Academy of Science and Letters, Copenhagen, Denmark, 2010.
[82] S. Demissew and I. Friis, "Vegetation of the flora area," 2009, https://www.researchgate.net/publication/260079406_Natural_Vegetation_of_the_Flora_area.
[83] S. M. Melese and B. Ayele, "Woody plant diversity, structure and regeneration in the Ambo state forest, south gondar zone, northwest Ethiopia," *Journal. For. Research*, vol. 28, no. 1, pp. 133–144, 2017.
[84] M. Didita, S. Nemomissa, and T. W. Gole, "Floristic and structural analysis of the woodland vegetation around Dello Menna, Southeast Ethiopia," *Journal of Forestry Research*, vol. 21, no. 4, pp. 395–408, 2010.
[85] G. Yemata and G. Haregewoien, "Floristic composition, structure and regeneration status of woody plant species in Northwest Ethiopia," *Trees, Forests and People*, vol. 9, 2022.
[86] T. Mekonen, B. Ayele, and Y. Ashagrie, "Woody plant species diversity, structure and regeneration status of of Woynwuha natural forest, North West Ethiopia," *Asian Journal. Ethnopharmacol. Medical. Foods*, vol. 1, pp. 7–19, 2015.
[87] F. Yirga, M. Marie, S. Kassa, and M. Haile, "Impact of altitude and anthropogenic disturbance on plant species composition, diversity, and structure at the Wof-Washa highlands of Ethiopia," *Heliyon*, vol. 5, no. 8, 2019.
[88] D. Tadele, E. Lulekal, D. Damtie, and A. Assefa, "Floristic diversity and regeneration status of woody plants in Zengena Forest, a remnant montane forest patch in northwestern Ethiopia," *Journal of Forestry Research*, vol. 25, no. 2, pp. 329–336, 2014.
[89] G. Mucheye and G. Yemata, "Species composition, structure and regeneration status of woody plant species in a dry Afromontane forest, Northwestern Ethiopia," *Cogent Food and Agriculture*, vol. 6, pp. 1823607–1823621, 2020.
[90] A. Ayalew, "Floristic composition and vegetation structure of gemehat remnant forest, habru woreda, north eastern, Ethiopia," *Advances in Life Science and Technology*, vol. 67, pp. 24–35, 2018.
[91] A. Ayanaw Abunie and G. Dalle, "Woody species diversity, structure, and regeneration status of Yemrehane Kirstos church forest of lasta woreda, north Wollo zone, amhara region, Ethiopia," *International Journal of Financial Research*, vol. 2018, p. 8, 2018.
[92] E. Kelbessa and S. Demissew, "Diversity of vascular plant taxa of the flora of Ethiopia and Eritrea," *Ethiopian Journal of Biological Sciences*, vol. 13, pp. 37–45, 2014.
[93] M. Kuma, "Diversity of woody plant species of gamuwa and Oda forests of humbo carbon project, wolaita, Ethiopia: for conservation and management of forests," *International Journal of Biodiversity*, vol. 2016, Article ID 7930857, 8 pages, 2016.
[94] S. Ahmed, D. Lemessa, and A. Seyum, "Woody species composition, plant communities, and environmental determinants in Gennemar Dry Afromontane forest, Southern Ethiopia," *Scientific*, vol. 2022, Article ID 7970435, 10 pages, 2022.
[95] M. Woldearegay, Z. Woldu, and E. Luleka, "Species diversity, population structure and regeneration status of woody plants in Yegof dry Afromontane forest, Northeastern Ethiopia," *European. Journal. Advance. Research. Biology. Life Science*, vol. 6, pp. 20–34, 2018.
[96] G. Woldemariam, S. Demissew, and Z. Asfaw, "Woody species composition, diversity and structure of Kumuli dry evergreen Afromontane forest in Yem District, Southern Ethiopia," *Journal of Environment and Earth Science*, vol. 6, pp. 53–65, 2016.
[97] W. Shiferaw, S. Demissew, and T. Bekele, "Vegetation structure of debra-libanos Monastery forest patch of North oromia region, Central Ethiopia," *Species*, vol. 20, pp. 135–150, 2019.
[98] H. A. Wale, T. Bekele, and G. Dalle, "Floristic diversity, regeneration status, and vegetation structure of woodlands in Metema area, amhara national regional state, northwestern Ethiopia," *Journal of Forestry Research*, vol. 23, no. 3, pp. 391–398, 2012.
[99] H. Getaneh and A. Seid, "Floristic composition, structure and regeneration status of Achera natural forest in Chilga District, Northwest Ethiopia," *Ethiopian Journal of Biological Sciences*, vol. 14, pp. 217–231, 2015.

[100] A. G. Asfaw, “Woody species composition, diversity and vegetation structure of Dry Afromontane forest, Ethiopia,” *Journal of Agriculture and Ecology Research International*, vol. 16, no. 3, pp. 1–20, 2018.

[101] T. Ayalew, E. Merawi, and S. Alemu, “Woody plant species diversity of Shello Giorgis dry afromontane forest, farita district, west amhara, Ethiopia,” *Biodiversity. International. Journal*, vol. 4, pp. 59–65, 2020.

[102] B. Liyew, B. Tamrat, and D. Sebsebe, “Woody species composition and structure of Amoro forest in west gojjam zone, north western Ethiopia,” *Journal of Ecology and the Natural Environment*, vol. 10, no. 4, pp. 53–64, 2018.

[103] A. Girma and R. Mosandl, “Structure and potential regeneration of degraded secondary stands in Munessssa-Shashemene Forest, Ethiopia,” *Journal of Tropical Forest Science*, vol. 24, pp. 46–53, 2012.

[104] E. Birhane, D. Teketay, and P. Barklund, “Actual and potential contributions of enclosures to enhance biodiversity of woody species in the drylands of Eastern Tigray,” *Journal. Drylands.*vol. 1, pp. 134–147, 2006.

[105] G. Fisaha, K. Hundera, and G. Dalle, “Woody plants’ diversity, structural analysis and regeneration status of Wof-Washa natural forest, North-east Ethiopia,” *African Journal of Ecology*, vol. 51, no. 4, pp. 599–608, 2013.

[106] A. Tilahun, *Floristic Composition, Structure and Regeneration Status of Wof Washa Forest in Notrth Shoa Zone*, Debre Birhan, Debre Birhan University, Ethiopia, 2004.

[107] G. Tadesse, T. Bekele, and S. Demissew, “Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Welo, Ethiopia,” *Sinet: Ethiopian Journal of Science*, vol. 31, no. 1, pp. 43–54, 2008.

[108] H. Zegeye, D. Teketay, and E. Kelbessa, “Diversity and regeneration status of woody species in Tara Gedam and Abebaye forests, northwestern Ethiopia,” *Journal of Forestry Research*, vol. 22, no. 3, pp. 315–328, 2011.

[109] B. W. Meshesha, B. A. Tsegay, and B. B. Telake, “Survey on composition of perennial vegetation in Sesa Mariam Monastery, northwestern Ethiopia,” *BMC Research Notes*, vol. 8, pp. 622–628, 2015.

[110] T. Birhanu, A. S. Mohammed, and A. B. Mekonnen, “Floristic composition, structure and regeneration status of woody plants in church forests of Dangila, Northwestern Ethiopia,” *Cogent Food and Agriculture*, vol. 7, pp. 1–22, 2021.

[111] G. Masresha, T. Soromessa, and E. Kelbessa, “Status and species diversity of Alemsaga forest, Northwestern Ethiopia,” *Advances in Life Science and Technology*, vol. 34, pp. 87–99, 2015.

[112] W. Shiferaw, M. Lemenih, and T. W. M. Gole, “Analysis of plant species diversity and forest structure in Arero dry Afromontane forest of Borena zone, South Ethiopia,” *Tropical Plant Research*, vol. 5, no. 2, pp. 129–140, 2018.

[113] G. Woldu, N. Solomon, H. Hishe, H. Gebrewahid, M. A. Gebremedhin, and E. Birhane, “Topographic variables to determine the diversity of woody species in the exclosure of Northern Ethiopia,” *Heliyon*, vol. 6, 2020.

[114] E. Yirdaw, M. Starr, M. Negash, and F. Yimer, “Influence of topographic aspect on floristic diversity, structure and treeline of afromontane cloud forests in the Bale Mountains, Ethiopia,” *Journal. For. Research*, vol. 26, no. 4, pp. 919–931, 2015.

[115] M. Kebede, E. Yirdaw, O. Luukkanen, and M. Lemenih, “Plant community analysis and effect of environmental factors on the diversity of woody species in the moist Afromontane forest of Wondo Genet, South Central Ethiopia,” *Biodiversity: Research and Conservation*, vol. 29, no. 1, pp. 63–80, 2013.

[116] M. Asefa, M. Cao, Y. He, E. Mekonnen, X. Song, and J. Yang, “Ethiopian vegetation types, climate and topography,” *Plant Diversity*, vol. 42, no. 4, pp. 302–311, 2020.

[117] T. Soromessa and E. Kelbessa, “Diversity and endemicity of Chilimo forest, Central Ethiopia,” *Bioscience Discovery*, vol. 4, 2013.

[118] E. Fikadu and M. Melesse, “Endemic plant species composition and their status in Boda dry evergreen montane forest, west showa, Ethiopia,” *International Journal of Biodiversity and Conservation*, vol. 6, no. 7, pp. 563–569, 2014.

[119] E. A. H. Cavalcanti and M. E. L. D. Larrazábal, “Macrozooplâncton da zona econômica exclusiva do nordeste do Brasil (segunda expedição oceanográfica - revizee/NeII) com ênfase em Copepoda (Crustacea),” *Revista Brasileira de Zoologia*, vol. 21, no. 3, pp. 467–475, 2004.

[120] Z. Teshager, M. Argaw, and A. Eshete, “Woody species diversity, structure and regeneration status in Weiramba forest of Amhara Region, Ethiopia: implications of managing forests for biodiversity conservation,” *Journal. Natural. Science. Research*, vol. 8, pp. 16–31, 2018.

[121] P. J. Rey and J. M. Alcántara, “Recruitment dynamics of a fleshy-fruited plant (Olea europaea): connecting patterns of seed dispersal to seedling establishment,” *Journal of Ecology*, vol. 88, no. 4, pp. 622–633, 2000.

[122] R. K. Verma, D. K. Shadangi, and N. G. Totey, “Species diversity under plantation raised on a degraded land,” *Malaysian Forester*, vol. 62, pp. 95–106, 1999.

[123] N. Rol, E. E. Andrew, and E. Bechem, “Species composition, diversity and distribution in a disturbed Takamanda rainforest, South West, Cameroon,” *African Journal of Plant Science*, vol. 7, no. 12, pp. 577–585, 2013.

[124] P. J. Grubb, J. R. Lloyd, T. D. Pennington, and T. C. Whitmore, “A Comparison of montane and lowland rain forest in Ecuador I. The forest structure, physiognomy, and floristics,” *Journal of Ecology*, vol. 51, no. 3, p. 567, 1963.

[125] A. Tilahun, “Structure and regeneration status of Menagesha Amba Mariam forest in central highlands of shewa, Ethiopia,” *Agriculture, Forestry and Fisheries*, vol. 4, p. 184, 2015.

[126] M. R. Guariguata, R. L. Chazdon, J. S. Denslow, J. M. Dupuy, and L. Anderson, “Structure and floristics of secondary and old-growth forest stands in lowland Costa Rica,” *Plant Ecology*, vol. 132, no. 1, pp. 107–120, 1997.

[127] F. Gurmessa, T. Soromessa, and E. Kelbessa, “Structure and regeneration status of komto afromontane moist forest, east wollega zone, west Ethiopia,” *Journal of Forestry Research*, vol. 23, no. 2, pp. 205–216, 2012.

[128] K. Hundera, T. Bekele, and E. Kelbessa, “Floristic and phytogeographic synopsis of a dry afromontane coniferous forest in the Bale mountains (Ethiopia): implication to biodiversity conservation,” *SINET Ethiop. Journal. Science.*vol. 30, pp. 1–12, 2007.

[129] C. L. Batcheler, “Note on measurment of woody plant diameter distributions,” *New Zealand Journal of Ecology*, vol. 8, pp. 129–132, 1985.

[130] G. Gebeyehu, T. Soromessa, T. Bekele, and D. Teketay, “Species composition, stand structure, and regeneration status of tree species in dry Afromontane forests of Awi Zone, northwestern Ethiopia,” *Ecosystem Health and Sustainability*, vol. 5, no. 1, pp. 199–215, 2019.

[131] F. Senbeta, T. Woldemariam, S. Demissew, and M. Denich, “Floristic diversity and composition of sheko forest,

southwest Ethiopia," *Ethiopian Journal of Biological Sciences*, vol. 6, no. 1, pp. 11–42, 2009.

[132] A. B. Madalcho, J. Szwagrzyk, and T. Solomon, "Woody species diversity and regeneration challenges in Ethiopia: review article to identify research gaps," *Trees, Forests and People*, vol. 8, pp. 100224–100229, 2022.

[133] F. Sánchez-Bayo and G. W. King, "Ecological factors affecting the early development of seedlings of three Acacia species from Ethiopia," *South African Journal of Plant and Soil*, vol. 11, no. 3, pp. 147–149, 1994.

[134] N. Brokaw, C. D. Canham, J. Thompson et al., "Seedling recruitment in a hurricane-driven tropical forest: light limitation, density-dependence and the spatial distribution of parent trees," *Journal of Ecology*, vol. 93, no. 2, pp. 291–304, 2005.