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

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 400 m² (20 m × 20 m) 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 m² ha⁻¹, respectively. The majority of the species fell 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
<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

\[ H' = -\sum_{i=1}^{s} p_i \ln p_i, \]  

(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.

\[ N_1 = e^H, \]  

(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

\[ J = \frac{H'}{H_{\text{max}}} = \frac{H'}{\ln S \text{ or } \ln N_0}. \]  

(3)

where \( J \) = is Shannon equitability, \( H'_{\text{max}} = S \), 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:

\[ E_1 = e^E = \frac{1D}{S} = \frac{N_1}{N_0}. \]  

(4)

Simpson’s diversity Index (\( D \)) is calculated as

\[ D = 1 - \sum p_i^2, \]  

(5)

where \( D \) = is a Simpson’s diversity index and \( p_i \) is described in equation (1).

True Simpson has been done by inverting the result of Simpson entropy.
\[
N_2 = \frac{1}{D} \approx 2D = \left[ \frac{1}{1 - \left( \sum_{i=1}^{s} P_i^2 \right)} \right] = \frac{1}{\sum_{i=1}^{s} P_i^2}. \tag{6}
\]

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:

\[
\text{frequency} = \frac{\text{the total number of quadrats in which a species occurred}}{\text{total number of sampled quadrats}} \times 100. \tag{7}
\]

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].

\[
\text{abundance} = \frac{\text{the total number of individuals of a species}}{\text{the total number of quadrats in which the species occurred}} \tag{8}
\]

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:

\[
\text{important value index (IVI)} = RD + RDo + RF, \tag{11}
\]

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.

2.3.1. 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:

\[
\text{basal area (DO)} = \frac{\pi DBH^2}{4}. \tag{10}
\]
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. Lamiacae 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 N0) of the Harego forest was 50, while the True Shannon, effective number of species (Hill’s N1), and True Simpson, the richness of abundant species (Hill’s N2), 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 integrigfolia, 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, Ocinum lamifolium, Olinia rochetiana, Pinus patula, Senega 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 m2 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 contributed 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 m2 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 ethbaica Schweinf.  | Dere        | Tree         |
|                 | Calyptrinia aerea (Ait.) Benth. | Diga       | Shrub        |
|                 | Pterolobium stellatum (Forssk.) Brenan | Kentafa   | Climber     |
|                 | Clerodendrum myricoides (Hochst.) Vatke | Misirich  | Shrub        |
|                 | Ocimum lamifolium Hochst. Ex. Benth. | Dama kese | Shrub        |
| Lamiaceae       | Prema schimperi Engl.      | Choco       | Shrub        |
|                 | Otostegia integrofisla Benth. | Tinjut     | Shrub        |
|                 | Rhus glutinosa A. Rich.    | Embs        | Shrub        |
|                 | Rhus retrinorrhoea Oliv.   | Tilem       | Shrub        |
|                 | Clatia abyssinica Jaub. and Spach. | Fyele fej  | Shrub        |
| Euphorbiaceae   | 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    | Juniperus procera hochst. ex Endl. | Yehabesha tsid | Tree |
|                 | Jasmum grandiflorum P.S.Green | Tembelel   | Climber     |
| Oleaceae        | Olea europaea L. subsp. cuspidata | Weira    | Tree         |
|                 | Prunus africana (Hook.F.) Kalkm. | Tiqur inchet | Tree |
| Rosaceae        | Rosa abyssinica Lindley.   | Kega       | Shrub        |
| Loganiaceae     | Buddleja polystachya Fresen. | Atquar    | Shrub        |
| Apiceae         | 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        |
|                 | Opuntia ficus-indica (L.) Miller. | Kulkual | Tree         |
| Capparidaceae   | Crapeva adansonii Gilg.    | Dingay seber | Tree        |
| Ebenaceae       | Euclea racemosa Murr. (subsp. chimperi) | Dedeho | Shrub        |
| Eriaceae        | Erica arborea L.           | Asta       | Tree         |
| Malvaceae       | Abutilon longicuspe Hochst. ex A. Rich. | Nechlo | Shrub        |
| Meliaceae       | Ekebergia capensis Sparrm. | Sembo       | Tree         |
| Myrsineaceae    | Myrsine africana L.        | Qechomo     | Shrub        |
| Myrtaceae       | Eucalyptus globulus Labill | Nech bahir zaf | Tree |
| Oliniaceae      | Olinia rochitana A. Juss. | Beye       | Tree         |
| Pinaceae        | Pinus patula Schiede ex Schtdl | 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. | Kitkitia     | Shrub        |
| Sapotaceae      | Mimusops kummel A. DC.     | Ishie       | Tree         |
| Solanaceae      | Solanum marginatun Lam.    | Embuayu     | Shrub        |
| Sterculiaceae   | Dombeya torrida (J. F. Gmel.) P. Bamps | Wulkfa | Tree |
| Tilaceae        | Grewia farruginea 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.
two and three, but none of the species had a basal area of >1 m² 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 viridisflorum 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 quadripartita, 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 4529 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 showed fair regeneration, 1 (2.86%) species showed no regeneration, and 8 (22.86%) species showed poor regeneration status. Eight 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 ethiica, Mimusops kummel, Pittosporum viridisflorum, 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 abyssinia, Buddleia poly-stachya, 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...
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
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 Kirslos 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 1: Cumulative DBH (a) and height (b) class of woody species in the Harego dry Afromontane forest.](image-url)

### Table 4: Basal area (m² ha⁻¹) classes of species in the Harego forest.

| BA class | Class interval | Density (stems ha⁻¹) | RD | No. of Species | BA per class (m² 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            |

### Table 6: Basal area (m² ha⁻¹) classes of species in the Harego forest.
or due to both [93]. Therefore, sound conservation and management should be given for species susceptible to extinction 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 forest, 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$^{-1}$ | Mature | Sapling | Seedling | Status   |
|--------------------------------------------|-----------------|--------|---------|----------|----------|
| Clerodendrum myricoides                    | 3.36            | 298.51 | 641.79  | 1        | 1        |
| Heteromorpha arborescens                  | 8.96            | 955.22 | 1791.04 | 2        | 1        |
| Jasminum grandiflorum                      | 49.63           | 2313.43| 5044.78 | 3        | 2        |
| Calpurnia aurea                           | 67.16           | 492.54 | 835.82  | 1        | 1        |
| Carissa spinarum                          | 240.67          | 2417.91| 3507.46 | 1        | 1        |
| Dodonaea angustifolia                      | 458.58          | 4641.79| 7582.09 | 1        | 1        |
| Euclea racemosa                           | 89.55           | 925.37 | 1656.72 | 1        | 1        |
| Grewia ferruginea                         | 29.48           | 119.40 | 253.73  | 1        | 1        |
| Juniperus procera                         | 61.57           | 194.03 | 582.09  | 1        | 1        |
| Myrtus communis                           | 57.84           | 910.45 | 2179.10 | 1        | 1        |
| Myrmecodia seneagalensis                  | 44.03           | 388.06 | 865.67  | 1        | 1        |
| Myrsine Africana                          | 159.33          | 5208.96| 9313.43 | 1        | 1        |
| Osyris quadrifoliata                      | 104.85          | 628.47 | 1925.37 | 1        | 1        |
| Rhus glutinosa                            | 53.36           | 74.63  | 268.66  | 1        | 1        |
| Rhus natansalis                           | 398.13          | 3179.10| 4985.07 | 1        | 4        |
| Rosa abyssinica                           | 10.82           | 134.33 | 208.96  | 1        | 1        |
| Acca aethiopica                           | 11.57           | 14.93  |        | 1        | 1        |
| Euphorbia candelabrum                     | 117.54          | 44.78  | 74.63   | 1        | 1        |
| Euphorbia tirucalli                       | 0.75            | 0.00   | 59.70   | 1        | 1        |
| Mimusops kummel                           | 4.10            | 0.00   | 28.85   | 1        | 1        |
| Olea europaea subsp.                       | 264.18          | 1358.21| 2179.10 | 1        | 1        |
| Pittosporum viridiflorum                  | 77.99           | 0.00   | 89.55   | 1        | 1        |
| Premna schimperi                           | 11.94           | 119.40 | 119.40  | 2        | 1        |
| Prunus africana                           | 10.82           | 0.00   | 29.85   | 1        | 1        |
| Rhus retinorhoea                          | 6.72            | 0.00   | 44.78   | 1        | 1        |
| Crateva adansoni                          | 23.13           | 104.48 | 0.00    | 3        | 1        |
| Acacia abyssinica                         | 8.21            | 0.00   | 0.00    | 4        | 1        |
| Buddleja polystachya                      | 7.46            | 0.00   | 0.00    | 4        | 1        |
| Cupressus lusitanica                      | 11.94           | 0.00   | 0.00    | 4        | 1        |
| Dombeya torrida                           | 46.27           | 0.00   | 0.00    | 4        | 1        |
| Ekebergia capensis                        | 4.48            | 0.00   | 0.00    | 4        | 1        |
| Erica arborea                             | 0.37            | 0.00   | 0.00    | 4        | 1        |
| Opuntia ficus-indica                      | 17.16           | 0.00   | 0.00    | 4        | 1        |
| Oliba rochetiana                          | 2.61            | 0.00   | 0.00    | 4        | 1        |
| Acacia seyal                              | 0.00            | 0.00   | 14.93   | 5        | 1        |
| 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]; Zenga, 50 species [88]; Shello Giorgis, 50 species [101]; Gennemar, 55 species [94]; Amoro, 57 species [102]; Ambo state forest, 58 species [83]; and Gelaoldie, 59 species [89], but higher than the Munessa-Shashemene forest, 32 species [103]; Yemrehane Kirots 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 Kaffa 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]; Denkor forest, 65 species [26]; Woywnuha forest, 69 species [86]; Hugumburda forest, 70 species [31]; Yegeo 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]; Menfeskius Monastery forest, 97 species [66]; and Sirso forest, 74 species [76]. Church forests of Dangila, 73 species [110]; Wurig Forest, 70 species [77]; Kumuli forest, 113 species [96]; Alemaga forest, 101 species [111]; Geshmat forest, 60 species [90]; Brandi forest, 71 species [85]; and Aro 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 adoesis, Maytenus arbuthofia, Rhus glutinosa, and Solanum marginatum were found in the study area. Of these, Lippia adoesis 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 Yegeo forest, 9 species [41]; but comparable to Tarad Dam and Abebaye forests, 6 species [108] and Boda forest [118] and Bradiforest [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 Zenga forest [88], Debra-libanos Monastery forest [97], Ambo state forest [83], and Woywnuha 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 ethbaica  | Clerodendrum myricoides |
| Buddleia polystachya | Euphorbia tirucalli | Heteromorpha arborescens |
| Cupressus lusitanica | Mimusops kummel | Jasminum grandiflorum |
| Dombeya torrida | Pittosporum viridiflorum | Calpurnia aurea |
| Ekbergia capensis | Prunus africana | Carissa spinarum |
| Erica arborea | Rhus retinorhoea | Dodonaea angustifolia |
| Olinia rochetiana | Acacia seyal | Euclia racemosa |
| Opuntia ficus-indica | Crateva adansonii | Grewia ferruginea |

((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 (N0), true Shannon (N1), and true Simpson (N2) 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 N1 is less than N0 and N2 is less than N1 [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 Yeqof 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 Bradri 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], Dangilfo forest (H’ = 3.8 and E = 0.92) [102], 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. Cupidata, and Jasminum grandiflorum) were also reported in Yeqof 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], Yeqof 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 canadelaebraum and Juniperus procer was due to the high basal area. The high value of Dodonaea angustifolia, Myrsine africana Rhus natalensis Carissa spinarum, Jasminum grandiflorum, Olea europaea 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 Monastery forest [66], Sirso forest [76], Wurg forest [77], Ambo State forest [83], Dello Mena forest [84], Brandi forest [85], Woynuwuha forest [86], Gelawoldie forest [89], Gennemar dry Afromontane Forest [94], Kumuli forest [96], Wanzaye forest [100], Amoro forest [102], and Sesa Mariam Monastery 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,
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 *Scopolia 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

| Forest                  | A     | B     | A/B   | Source                  |
|-------------------------|-------|-------|-------|-------------------------|
| Harego                  | 197.39| 36.19 | 5.45  | Present study           |
| Denkoro                 | 526   | 285   | 1.85  | [26]                    |
| Zenga                   | 206   | 96    | 2.15  | [80]                    |
| Yegef                   | 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.
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 Wol-Washa forest [105] and Ambo state forest [83] ecologically and economically important species were less represented in the regeneration stage. Explanations for hampered 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, Asea et al. [116] identified grazing as one of the dominant ecological drivers that affected the vegetation structure of dry Afrotomante 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, I were grouped under priority class I; species 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 Afrotomante 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 Recommendations 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 strategy 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.
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 enclosure 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 worried, Oromia, Ethiopia," International Journal of Financial Research, vol. 2021, Article ID 8834892, 10 pages, 2021.

[40] L. Kidane, S. Nenomissa, and Z. Woldu, “The effects of disturbance on the population structure and regeneration potential of five dominant woody species—in Hugumburda-Gratkassu 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 Graftanhu natural vegetation, southern Tigray of Ethiopia," Helyon, vol. 5, no. 1, 2019.

[43] A. Mohammed 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. Annons, "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 Komolcha areas, Komolbcha, Ethiopia, 2017.

[53] D. C. Powell, Density Management Field Exercise, Forest Silviculturist Umailla 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: Gentianaceae 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, 2003.

[58] S. Edwards, M. Tadesse, and S. Demissew, Flora of Ethiopia and Eritrea, Volume 2, Part 1: Magnoliaceae to Flacourtiaeae, The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopia and The Department of Systematic Botany, Uppsala University, Addis Ababa, Ethiopia, 1995.

[59] I. Hedberg, S. Edwards, and S. Nenomissa, Flora of Ethiopia and Eritrea, Volume 4, Part 1: Apiaceae to Dipsaceae, Dipsacaceae, Addis Ababa, Ethiopia, 1999.

[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: Cactaceae 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. Batcheler 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
International Journal of Forestry Research

[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 gojam 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 Meneessa-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 of Drylands*, vol. 1, pp. 134–147, 2006.

[105] G. Fisaha, K. Hundera, and G. Dalle, "Woody plants’ diversity, structural analysis and regeneration status of Wol-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 North Shoa Zone*, Debre Birhan, Debre Birhan University, Ethiopia, 2004.

[107] T. Soromessa and E. Kelbessa, "Diversity and endemicity of Shello Giorgis dry afromontane forest, farita district, west amhara, Ethiopia," *Biodiversity: International Journal*, vol. 4, pp. 59–65, 2020.

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

[109] T. Hundera, T. Bekele, and E. Kelbessa, "Floristic and 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.

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

[111] G. Woldu, N. Solomon, H. Hishe, H. Gebrewahid, M. A. Gebremedhin, 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 of Natural Science: Research*, vol. 8, pp. 16–31, 2018.

[112] 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.

[113] 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.

[114] 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.

[115] F. Senbeta, T. Woldemariam, S. Demissew, and M. Denich, "Macrophyllancton da zona económica exclusiva do nordeste do Brasil (segunda expedición oceanográfica - revizee/Nell) com ênfase em Copepoda (Crustacea)," *Revista Brasileira de Zoologia*, vol. 21, no. 3, pp. 467–475, 2004.

[116] M. A. Gebremedhin, and E. Birhane, "Topographic variables influencing plant species diversity and forest structure in Arero dry Afromontane forest of Borena zone, South Ethiopia," *Advances in Life Science and Technology*, vol. 34, pp. 87–99, 2018.

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

[118] K. Hundera, T. Bekele, and E. Kelbessa, "Floristic and 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.

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

[120] 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.

[121] T. Soromessa 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.

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

[123] G. Mushesha, 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.

[124] G. G. Woldu, N. Solomon, H. Hishe, H. Gebrewahid, M. A. Gebremedhin, and A. Birhane, "Status and species diversity of Alemsaga forest, Northwestern Ethiopia," *Advances in Life Science and Technology*, vol. 34, pp. 87–99, 2015.

[125] G. G. Woldu, N. Solomon, H. Hishe, H. Gebrewahid, M. A. Gebremedhin, and A. Birhane, "Topographic variables influencing plant species diversity in the esclosure of Northern Ethiopia," *Heliovon*, vol. 6, 2020.

[126] T. Soromessa and E. Kelbessa, "Diversity and regeneration status of komto afromontane moist forest, east wollega zone, west Ethiopia," *Journal of Forest Research*, vol. 23, no. 2, pp. 205–216, 2012.

[127] 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.

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

[129] G. Gebeeyehu, 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.
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.