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Research Article

Plant Community Composition and Structural Pattern Dynamics in Robe-Raya Natural Forest, Southeast Ethiopia

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Due to its fortuitous mix of geography, terrain, and geology, Ethiopia is the home of unique assemblages of rich biodiversity. However, this impressive biological diversity is increasingly threatened by the combined effects of different drivers before they are sufficiently investigated. The present work was carried out in Robe-Raya Natural Forest, located in Southeast Ethiopia, with the intention of examining plant community formation and structural dynamics of the forest species. Sixty (20 m × 20 m) quadrats were placed at 100 m distance along eleven east-west directed transect lines systematically. In order to gather juvenile's data, five subquadrats (2 m × 2 m) were established within the main quadrat, distributed at each corner and middle. In each quadrat, all woody species were recorded and counted; diameter (DBH) and height were measured using tape meter and a hypsometer, respectively, and cover abundance was recorded (in %). Cluster analysis was computed using R-Package to map-out the community types. Species diversity and composition among community types were computed using the Shannon-Wiener index and Sorenson's coefficient, respectively. Frequency, density, height, DBH, basal area, and IVI were used to analyze structural dynamics. Age-class density ratios were used to examine the regeneration status. Ninety-four woody plant species belonging to 39 families were documented. Asteraceae was the most species-rich family (10 species). The common growth form was shrubs (44.7%) followed by trees (41.5%). Cluster analysis produced four community types. In total, the species diversity and evenness were 3.75 and 0.88, respectively. The forest density and basal area were 1183.3 stems/ha and 57.52 $m^2 \cdot ha^{-1}$, respectively. Structural dynamics analyses demonstrated that the forest was composed of, largely, young trees and shrubs and under fair regeneration status. Certain species that have been identified to have low IVI and poor regeneration status should be prioritized for conservation.

1. Introduction

Ethiopia is a land of different terrain and geographical features ranging from moorland (high mountain units) to depressions (land below sea level), rendering it to have variable elevations and climatic conditions [1]. These characteristics contribute to the nation's diverse ecological settings which support organisms' evolution and adaptability favoring it to have a rich biological diversity in east Africa [2].

Several writers have examined Ethiopia's plant biodiversity at various points in time using a variety of methods [3–8]. In Ethiopian highlands [3] recognized two major ecological belts: the Afro-alpine and the Afro-montane. The former is home to succulent, slowly growing, and low-stature plants adapted to cold drought and low temperatures, while the latter is made up of, largely, scattered forest patches with some intact forests in the southwest region of the belt. After reviewing the previous works on Ethiopian vegetation, [4] defined the vegetation types of the country into 15 mapping units based on altitudinal and climate data. Recently, [5] divided Ethiopian diverse vegetation into 12 potential vegetation types ranging from afroalpine to desert and semidesert scrubland with their subtypes. After looking into the previous works, it is disclosed that the lowland semievergreen forest of southwestern Ethiopia had phytogeographical affinity to the Guineo-Congolian vegetation of Africa [6]. By studying Ethiopia's western woodlands, (8) identified three ill-defined clusters: the northern woodlands that stretch across the country's western escarpment; the southern woodlands that follow the Abay River; and the dry woodlands of the upper Tacazze and Abay Rivers.

Despite the fact that these works deepen our knowledge of Ethiopian vegetation, given the country's vast surface area and diverse topographic features, vegetation studies in Ethiopia are far from complete. Thus, further studies to untouched areas are timely endeavors since basic scientific information on the status of forests helps to design appropriate conservation measures. The conservation of forests in Ethiopia contributes to multiple sustainable development goals by addressing climate change, biodiversity conservation, protecting water resources, promoting sustainable livelihoods, reducing disaster risks, and respecting the rights of indigenous and local communities. Regarding forest conservation for sustainable development, Ethiopia has implemented various initiatives, including protected area networks, community-based forest management, and reforestation programs. These efforts aim to balance the conservation of forests with the socioeconomic needs of local communities and the broader sustainable development agenda. Despite these efforts, the nation's biological diversity is still rapidly fragmenting into scattered patches and changing due to unwise anthropogenic activities and climate change [9], suggesting that further studies, like the present ones, are crucial. Through time, the forests have been threatened due to continuous extensive deforestation [10] as a consequence of over and illegal exploitation [11]. The work of [7], after distinguishing eight different vegetation types in Ethiopia that support rich biodiversity and endemism, suggested further research on Ethiopia's vegetation at community and species level in order to meet the target of zero global plant extinctions.

Robe-Raya Natural Forest in the Oromia Regional State, Southeast Ethiopia, is experiencing similar conditions to other parts of the nation where anthropogenic activities are impacting the forest resources to the point where the size, species diversity, and regeneration capacity of the forest are dawdling. Therefore, the purpose of this work was to examine the current status of plant community formation and structural pattern dynamics in order to suggest future directions of management interventions.

2. Materials and Methods

2.1. Study Area Description. The study was carried out in Robe-Raya Natural Forest, Adaba District, Arsi Zone, Oromiya Region, southeast Ethiopia situated in the location stretching from 6.817 to 6.840 N latitude and 39.429–39.439 E longitude degree decimal (Figure 1). The total area of the forest is 245 hectare and the elevation stretches from 2441 to 3190 m.a.s.l. Adaba town, capital of the district, is located about 350 km southeast of Addis Ababa, capital of the nation.

Adaba District's climate falls within Ethiopia's agroecological zones of Weina Dega (midland) and Dega (highland). Analysis of climate data obtained from Ethiopian Meteorological Agency (1996–2022) Adaba District showed heavy precipitation from May through September and minimal precipitation from November to March. During these periods, July had received the highest average annual rainfall (1357 mm), while February had the lowest average (11.2 mm). Over the course of the 26 years, the maximum and minimum average temperatures were 31.1°C and 11.2°C, respectively (Figure 2).

Adaba is one of the districts in Arsi Zone with abundant natural forest and noticeable land marks of Arsi Mountains National Park including Mount Chilalo, Mount Kaka and Mount Gugu peaks. The vegetation of the study area mainly falls into the dry evergreen afromontane forest and grass land complex [12, 13]. Some of the characteristic species of the vegetation are *Juniperus procera, Hagenia abyssinica, Hypericum revolutum, Erica arborea*, Podocarpus falcatus, *Olea europaea* subsp. *cuspidata, Carissa spinarum,* and *Rosa abyssinica*.

2.2. Sampling Design and Vegetation Data Collection. Systematic random sampling procedure was employed for vegetation sampling. By referring the work of [14], a total of sixty 20 m × 20 m quadrats were established at 100 m distance along eleven transect lines that were 200 m apart and oriented in an east-west direction. In each quadrat, all encountered woody species were recorded and counted. Specimens of all woody species were gathered, dried, pressed, and identified in the University of Gondar Herbarium by using the Flora of Ethiopia and Eretria. Recent change in scientific names of plant species was checked and corrected using World Flora online 2023. Seedlings and saplings were counted in five 2 m × 2 m sub quadrats. These sub quadrats were established within the main quadrats, distributed at each corner and center.

To collect data on cover abundance, genuine visual estimation (in %) were carried out on the systematically placed quadrats). Thus, based on the proportion of quadrats' area occupied by the plant species, data on cover abundance was recorded (in %) and later transformed into modified 1–9 Braun-Blanquet Scale [15]. In order to examine DBH, in each quadrat, circumference of every adult woody species was measured at breast height (about 1.3 m) and, hypsometer was used to measure the tree height. According to [16, 17], woody individuals with height >3 m were designated as mature plants; those with height >1.5 m but <3 m were called saplings; and those with height <1.5 m were regarded as seedlings.

2.3. Data Analyses

2.3.1. Community Mapping. For the mapping of community types, hierarchical cluster analysis was computed using R package version 3.5.1. The similarity ratio was used to find the similarity (resemblance) function, and Ward's method was used to increase the within group similarity and between group dissimilarity. The community types recognized from the cluster analysis were further verified by a synoptic table and species occurrences are summarized as a synoptic-cover abundance values. Synoptic values are the product of average

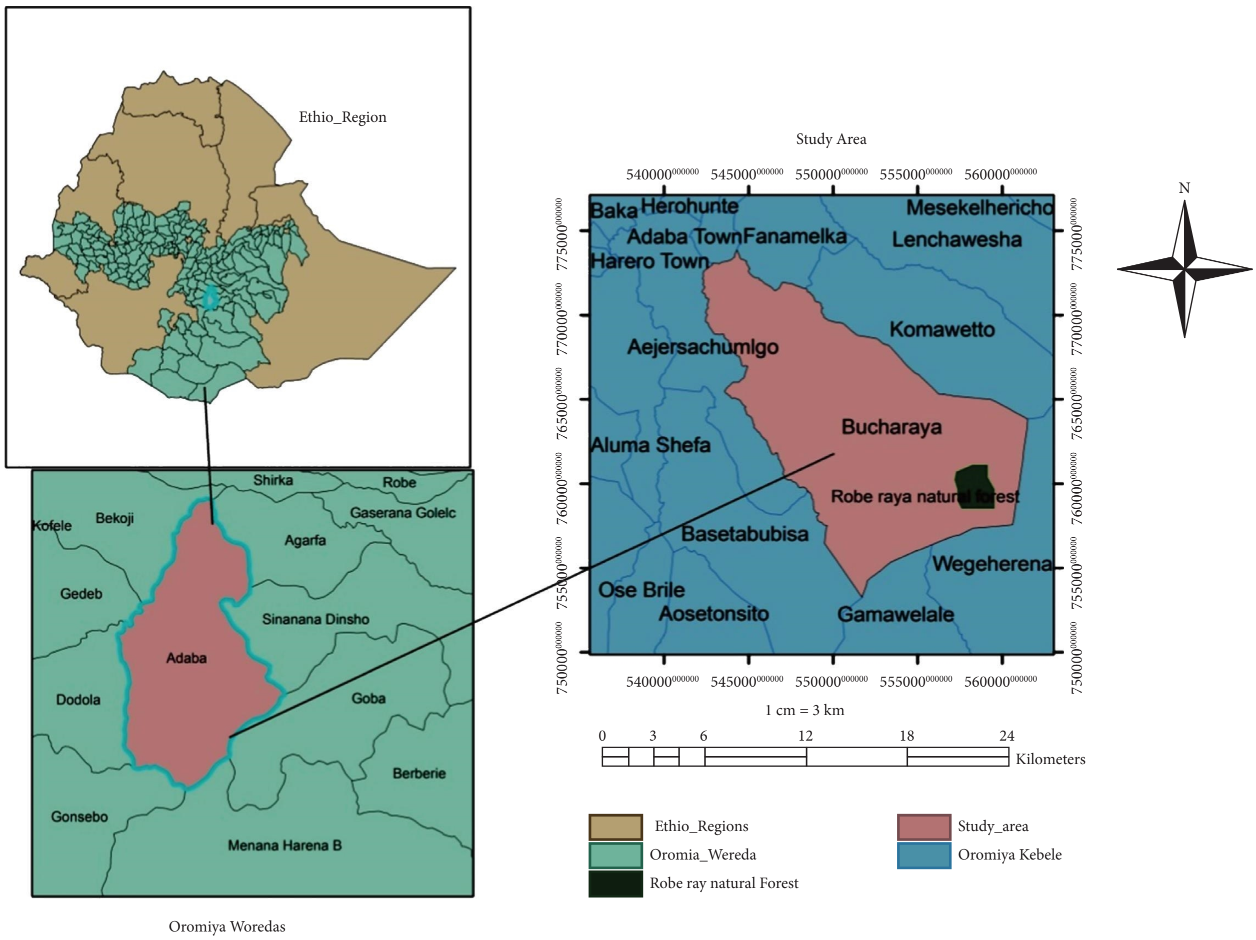

Figure 1: Map of Ethiopia showing the study area.

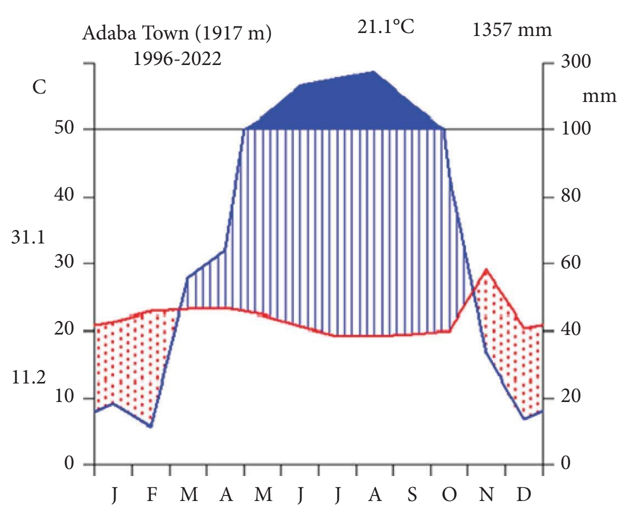

Figure 2: Climate diagram of the study area.

cover abundance value of a species and the species frequency. In each community, species with higher synoptic value was labeled as dominant species which, later, used to designate the community types [14].

2.3.2. Species Diversity Comparisons among Community Types. Shannon-Wiener index (H') was quantified by using the following formula so as to compare species diversity among the community types of the study forest.

$$H' = -\sum_{i=1}^{S} \mathrm{Pi}\,(\ln(\mathrm{Pi})). \tag{1}$$

The species equitability in each quadrat was computed by the formula: Evenness (J) $= H'/H'$ max where, H' = is Shannon-Wiener index, "J" is the species evenness, Pi = the individuals proportion of ith species expressed in terms of total individuals proportion, i = number of individuals of ith species, S = species richness, ln = log base n.

2.3.3. Species Composition Comparisons among Community Types. Sorensen's coefficient (Ss) was employed to evaluate woody species composition and species distribution among the plant communities as well as Robe-Raya forest with similar forests studied previously in the country [14]. $Ss = 2a/(2a + b + c)$, where, Ss = coefficient Sorensen's similarity, a = is number of species common in the two communities b = is the number of species unique to community one c = is the number of species unique second community.

2.3.4. Vegetation Structure Data Analyses. The vegetation structural patterns were analyzed using structural parameters [14] as follows.

(1) Frequency (F). Was calculated as the percentage of all quadrats that were recorded for a species out of all the quadrats.

$$\text{Frequency}\,(F) = \frac{\text{Number of quadrats that a species found}}{\text{The total number of quadrats examined}},$$
$$\text{Relative frequency}\,(\text{RF}) = \frac{\text{Frequency value for a species}}{\text{Sum of frequency value across all species}} \times 100. \tag{2}$$

Each species' frequency was expressed as a percentage, which was, then, arranged in ascending order and categorized into five frequency classes (in %): 1 (≤20), 2 (21–40), 3 (41–60), 4 (61–80), and 5 (81–100). The percentage distribution of individuals of species in each class was used to evaluate and compare the horizontal distribution patterns of species in the forest.

(2) Density (D). Was computed as the number of stem of a given species per unit area [18].

$$\text{Density}\,(D) = \frac{\text{Numberof stems of a species}}{\text{Area studied in ha}},$$
$$\text{Relative density}\,(\text{RD}) = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals in ha}} \times 100. \tag{3}$$

In order to evaluate the density patterns of species across the forest, the densities of each species was arranged in increasing order and categorized into six density classes.

(3) Diameter at Breast Height (DBH). Was generated from the value of circumference of each adult woody plant species by using the formula: DBH = C/π, where C refers circumference and $\pi = 3.14$. The distribution of stems in different DBH classes was evaluated after grouping into eight DBH classes. Tree height of all adult plants was measured, arranged in increasing order, and grouped into seven height classes so as to evaluate the forest developmental stage (maturity).

(4) Basal Area (BA). Was computed depending on the DBH value of each species [18]. Basal area (BA) $= \pi d^2/4$, where BA = basal area in $m^2 \cdot ha^{-1}$, d = DBH in meter, $\pi = 3.14$. For the purpose of evaluating the patterns of the vegetation structure, basal area of woody species of the forest was arranged in increasing order and categorized into basal area classes.

(5) Important Value Index (IVI). Was obtained from the summation of relative dominance (RDO), relative density (RD) and relative frequency (RF) [14].

$$\text{Relative dominance}\,(\text{RDO}) = \frac{\text{Species dominance value}}{\text{dominance value of all species}} \text{x}\,100. \tag{4}$$

According to their IVI values, species were categorized into five IVI groups for conservation priority by following [19].

2.3.5. Regeneration Data Analysis. The regeneration status of the forest species was examined by comparing the density proportion of seedlings with saplings and saplings with adult trees as expressed by [20, 21].

"Good," regeneration, if seedling > sapling > mature tree.

"Fair," regeneration, if seedlings > or ≤ saplings ≤ adults.

"Poor" regeneration, if the species appear only in sapling stage, but no seedlings (saplings may be <, > or = adults); "None," if a species is absent both in sapling and seedling stages, but present as mature and "New," if a species has no mature, but only sapling and/or seedling stages.

3. Results and Discussion

3.1. Floristic Composition. From the study forest, 94 woody plant species spreading in 70 genera and 39 families were documented (Table 1). Though, diversity of given vegetation can be inferred from the overall species number, comparisons of species richness of forests require considering the size and type of the forest as well as the method of the study [22]. Taking these into account, the species richness of the present study is lower than the study disclosed by [13] (114 species) but higher than the report of [23] (74 species) who studied the forest with similar agro-ecology and vegetation formation in Ethiopia. Such difference might result from variation in environmental heterogeneity, disturbance level, stage of ecological succession, and edaphic characteristics of the study area. In this specific case, better species richness was observed due to environmental heterogeneity and the active stage of succession, where species in successive stages overlap, resulting in higher species richness.

Among the identified species of the forest, 42 (44.7%) were shrubs, 39 (41.5%) trees, 5 (5.3%) shrubs/trees (mean found in both tree and shrub habits), and 8 (8.5%) were lianas. Likewise, [24] in Jibat forest, [25] in Menna Angetu forest, [26] in Wonjeta St. Michael forest and [27] in Entota forest reported higher proportion of shrubs among the woody species. Better tolerance and adaptation of shrubs to any form of disturbance might contribute to their higher proportion [28]. In this case, taking the stage of ecological secession and the disturbance level of the forest into account, higher number of shrub species signifies that the forest is secondary.

Asteraceae (10 species) was the family with the highest species richness, followed by Fabaceae (9 species) (Figure 3). The highest species richness of Asteraceae was also documented in earlier works such as Gole forest [26] and Tulu Korma Project Center forest [29]. The success of Asteraceae species is associated with their diaspores equipped with features resembling chute (wing like) that may aid in their adaptation to air dispersal and allow them to travel long distances, particularly in the presence of strong winds [30]. The ability to create viable populations following the introduction of diaspores in various locations, also, aided the successful establishment of the species.

Physiological and/or genetic adaptability such as enhanced germination capacity, resilience to harsh weather, and biotic competition for limited resources, particularly in the early colonization of new environments might make them to establish successfully [31]. Fabaceae, the second most species rich family in the present study, was ranked first in earlier works carried out in Belete Forest [32], Wotagisho forest [33], Bonga forest [34], and Ades forest [35]. Species richness in this family might be linked to their effective reproduction (pollination) and dispersal strategies along with superior adaptation that permits them to have bigger ecological amplitudes.

3.2. Plant Communities. Four communities (clusters) were recognized from the cluster analysis, and these clusters were named after two species with greater synoptic values (Figure 4).

3.2.1. Community I (Hypericum revolutum-Podocarpus falcatus Community). This particular community was located between 2552 and 2871 m a.sl. Compared to the other communities, it included the fewest species (55), as well as the smallest number of quadrats (7) (Table 2). Due to close proximity of quadrats to the edge of the forest, there might be greater human and livestock disturbances, which contributed to the lowest species richness of the community. The two most common trees and indicators of the community were *Hypericum revolutum* and *Podocarpus falcatus*. *Juniperus procera, Myrsine melanophloeos, Erythrina brucie, Nuxia congesta, Schefflera abysinica* and *Vernonia amygdelinawere* frequently occurring tree species. *Gymnosporia arbutifolia, Discopodium penninervium, Discopodium eremanthum, Dovyalis abyssinica, Ehretia cymosa* and *Solanum anguivi* were among the frequently occurring species in the shrub layer. *Asparagus africanus, Cissampelos pareira, Clematis hirsuta*, and *Hippocratea africana* were the commonly occurring lianas (Table 3).

3.2.2. Community II (Olea europaea subsp. Cuspidate-Myrsine melanophloeos Community). This community was dispersed from 2598–2862 m a.s.l. elevation ranges. The community comprised 14 quadrats (0.56 ha) with 74 associated species, which ranked third in terms of the total number of species (Table 2). *Olea europaea* subsp. *cuspidata, Myrsine melanophloeos, Juniperus procera, Hagenia abyssinica, Podocarpus falcatus, Galiniera saxifrage*, and *Ekebergia capensis* were dominant tree species in the community. The four commonly occurring shrubs were *Gymnosporia arbutifolia*, Carissa spinarum, *Lippia abyssinica, Ruta chalepensis*, and *Toddalia asiatica*. *Asparagus setaceus* was the popular liana in the community (Table 3).

3.2.3. Community III (Juniperus procera-Astropanax volkensi Community). Species in the community were distributed between 2518 and 2890 m a.s.l. It was represented by 12 quadrats (0.48 ha) that contained 75 associated species (Table 2). The three most common tree species were *Juniperus procera, Myrsine melanophloeos* and *Astropanax*

Table 1: List of woody plants species collected from study area.

Family	Species	Growth form
Fabaceae	*Vachellia abyssinica* (Hochst. ex Benth.) Kyal. & Boatwr	Tree
Fabaceae	*Vachellia tortilis* (Foressk.) Gal. &Ban	Tree
Acantaceae	*Acanthus sennii* CHiov	Shrub
Aponynaceae	*Acokanthera schimperi* (A.DC) Schweinf	Shrub
Fabaceae	*Albizia schimperiana* Oliv	Shrub
Sapindaceae	*Allophylus abyssinicus* (Hochst.) Radlk	Tree
Asparagaceae	*Asparagus africanus* Lam	Liana
Asparagaceae	*Asparagus setaceus* (Kunth) Jessap	Liana
Melianthaceae	*Bersama abyssinica* Fresen	Tree T
Capparidaceae	*Boscia angustifolia* A. Rich	Shrub
Loganiaceae	*Buddleja davidii* Franch	Shrub
Loganiaceae	*Buddleja polystachya* Fresen	Tree
Fabaceae	*Calpurnia aurea* (Ait.) Benth	Shrub
Rubiaceae	*Canthium oligocarpum* Hiern	Shrub
Asteraceae	*Carduus leptacanthus* Fresen	Shrub
Asteraceae	*Carduus nyassanus* (S.Moore) R.E.Fries	Shrub
Aponynaceae	*Carissa spinarum* L	Shrub
Menispermaceae	*Cissampelos pareira* L	Liana
Ranunculaceae	*Clematis hirsuta* Perr.&Guill	Liana
Euphorbiaceae	*Clutia abyssinica* Janb.& Spach	Shrub
Rubiaceae	*Coffea arabica* L	Tree
Combretaceae	*Combretum adenogonium*Steud, ex A,Rich	Tree
Combretaceae	*Combretum collinum* (Kotschy) Okafor	Shrub
Combretaceae	*Combretum molle* R. Br. Ex G.Don	Tree
Asteraceae	*Conyza spinosa* SCh. Bip.ex Oliv. Hiern,	Shrub
Fabaceae	*Crotalaria agatiflora Schweinf*	Shrub
Fabaceae	*Diospyros abyssinicus* (Hiern) F.White	Shrub
Solanaceae	*Discopodium eremanthum* Choiv	Shrub
Solanaceae	*Discopodium penninervium* Hochest	Shrub
Sapindaceae	*Dodonaea viscosa* subsp. *angustifolia* (L.f.) J.G. West	Shrub
Sterculiaceae	*Dombeya torrida* (J.F.Gmel.) Bamps	Tree
Flacourtiaceae	*Dovyalis abyssinica* (A. Rich.) Warb	Shrub
Dracenaceae	*Draceana afromontana* Mildbr	Shrub
Dracenaceae	*Dracaena steudneri* Engl	Tree
Asteraceae	*Echinops ellenbeckii* O.Hoffm	Shrub
Asteraceae	*Echinops longisetus* A. Rich	Shrub
Boraginaceae	*Ehretia cymosa Thonn*	Shrub
Meliaceae	*Ekebergia capensis* Sparrm	Tree
Ericaceae	*Erica arborea* L	Shrub
Fabaceae	*Erythrina abyssinica* Lam	Tree
Fabaceae	*Erythrina brucei* Schweinf	Tree
Ebenaceae	*Euclea racemosa* subsp. *schimperi* (A,D.C.) Dandy	Tree
Euphorbiaceae	*Euphorbia schimperiana* Scheele	Shrub
Flacourtaceae	*Flacourtia indica* (Burm.f.) Merr	Tree
Rubiaceae	*Galiniera saxifraga* (A.Rich.) Bridson	Tree
Tiliaceae	*Grewia ferruginea* Hochst.ex A. Rich	Tree
Rosaceae	*Hagenia abyssinica* (bruce) J.F.Gmel	Tree
Celasteraceae	*Loeseneriella africana* (Willd.) Loes	Liana
Hypericaceae	*Hypericum revolutum* Vahl	Tree
Asteraceae	*Inula confertiflora* A.Rich	Shrub
Cuppressaceae	*Juniperus procera* L	Tree
Lamiaceae	*Leonotis ocymifolia* (Burm.f.) Iwarsson	Shrub
Verbenaceae	*Lippia abyssinica* (Otto&Adietr.) Cufod	Shrub
Euphorbiaceae	*Macaranga capensis* (Baill.) Sim	Tree
Myrsinaceae	*Maesa lanceolata* Forssk	Shrub
Celasteraceae	*Gymnosporia addat* Loes	Tree
Celasteraceae	*Gymnosporia arbutifolia* (Hochest, ex A. Rich.) Leos	Tree
Celasteraceae	*Gymnosporiagracilipes* (Welw. ex Oliv.) Loes	Shrub
Myrsinaceae	*Myrsine africana* L	Shrub
Myrsinaceae	*Myrsine melanophloeos* (L.) R.Br. Ex.Sweet	Tree

Table 1: Continued.

Family	Species	Growth form
Loganiaceae	*Nuxia congesta* R.Br.ex Fresen	Tree
Oleaceae	*Olea capensis* L	Tree
Oleaceae	*Olea europaea* subsp. *cuspidata* (Wall.ex G. Don.) Cif	Tree
Santalaceae	*Osyris lanceolata* Hoschest. & Steud	Shrub
Myrsinaceae	*Phyllanthus ovalifolius* Forssk	Shrub
Pittosporaceae	*Pittosporum viridiflorum* Sims	Tree
Podocarpaceae	*Podocarpus falcatus* (Thumb.) R.B.ex. Mirb	Tree
Lamiaceae	*Premna schimperi* Engl	Shrub
Rosaceae	*Prunus africana* (Hook.f.) Kakman	Tree
Rhamnaceae	*Rhamnus prinoides* L'Herit	Shrub
Rhamnaceae	*Rhamnus staddo* A. Rich	Tree
Anacardiaceae	*Searsia pyroides* (Burch) Moff	Tree
Rosaceae	*Rosa abyssinica* Lindley	Liana
Rosaceae	*Rubus apetalus* Poir	Liana
Rosaceae	*Rubus steudneri* Schweinf	Shrub
Araliaceae	*Astropanax abyssinicus* (Hochst.ex A.Rich.) Seem	Tree
Araliaceae	*Astropanax volkensii* (Harms) low., Plu., Gost., & Fro	Tree
Rhamnaceae	*Scutia myrtina* (Burm.f.) Kurz	Shrub
Apocynaceae	*Goniostemma acuminatum* Wig	Liana
Malvaceae	*Sida schimperiana* Hochst. Ex. A. Rich	Shrub
Sapotaceae	*Spiniluma oxyacantha* (Baill.) Aubrev	Tree
Asteraceae	*Solanecio gigas* (Vatke) C.Jeffrey	Shrub
Solanaceae	*Solanum aculeatissimum* Jacq	Shrub
Solanaceae	*Solanum anguivi* Lam	Shrub
Solanaceae	*Solanum incanum* Ruiz & Pav	Shrub
Rutaceae	*Vepris nobilis* Del	Shrub
Rutaceae	*Teclea simplicifolia* (Engl.) I.Verd	Shrub
Rosaceae	*Toddalia asiatica* (L.) Lam	Shrub
Meliaceae	*Trichilia prieureana* A.Juss	Shrub
Rubiaceae	*Vangueria apiculata* K. Schum	Tree
Asteraceae	*Vernonia amygdalina* Del	Tree
Asteraceae	*Vernonia auriculifera* A. Rich	Tree
Rhamnaceae	*Ziziphus spina-christi* (L.) Willd	Shrub

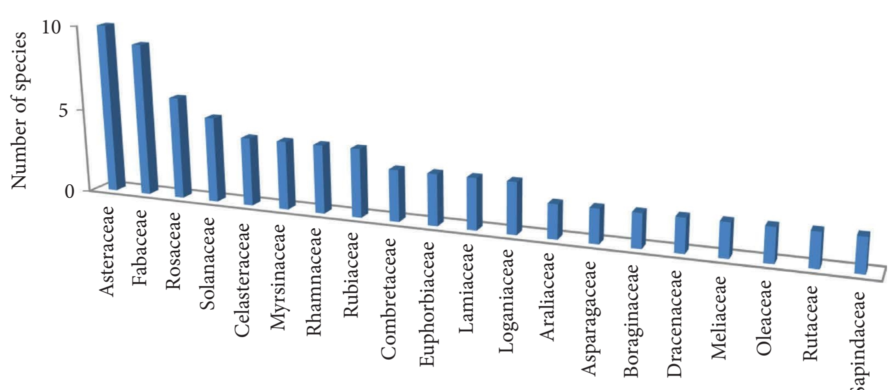

Figure 3: Family representation by species.

volkensi. *Juniperus procera*, *Podocarpus falcatus*, and *Olea europea* subsp. *cuspidata* were emergent tree species. *Dovyalis abyssinica*, *Discopodium penninervium*, *Echinops longisetus*, *Toddalia asiatica*, *Inula confertiflora*, *Lippia abyssinica*, *Rhamnus prinoides*, and *Myrsine africana* were commonly occurring shrubs. *Cissampelos pareira* was the prevalent liana (Table 3).

3.2.4. Community IV (Rubus apetalus-Juniperus procera Community). This community was located in a relatively higher elevation ranging between 2515 and 2914 m.a.s.l. It had a greater number of species and quadrats (27 = 1.08 ha) than the rest of the communities (Table 2). The common tree species were *Juniperus procera*, *Podocarpus falcatus*, *Hypericum revolutum*, *Ekebergia capensis*, *Erythrina brucei*,

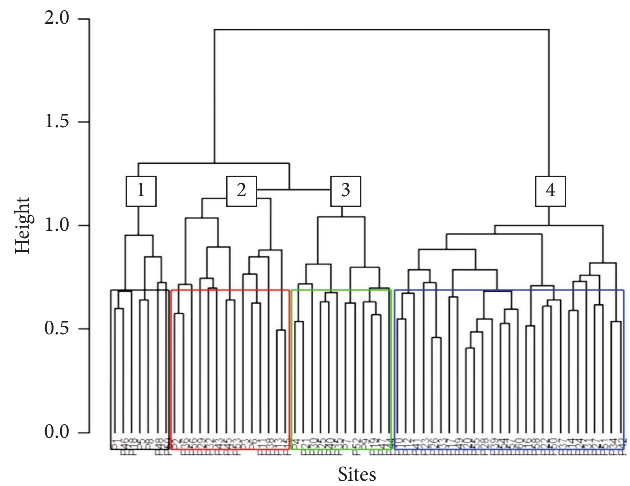

Figure 4: Four community types generated from the cluster analysis.

Galiniera saxifraga, Hagenia abyssinica, Gymnosporia arbutifolia, Nuxia congesta, Astropanax volkensii, Astropanax abyssinicum, Spiniluma oxyacantha, Olea europea subsp. *cuspidata, Rhamnus staddo, Buddleja polystachya,* and *Vernonia amygdalina.* Including *Juniperus procera* and *Podocarpus falcatus*, this community contained several emergent tree species. *Discopodium eremanthum, Premna schimperi, Rhamnus prinoides* and *Toddalia asiatica* were commonly occurring shrub species. Common lianas of the group were *Cissampelos pareira, Hippocratea africana, Clematis hirsuta, Rosa abyssinica* and *Secamone cumpulata* (Table 3). The relatively higher altitude, where the species are distributed, might have higher resource availability and conducive environmental conditions that support higher species richness. In addition, hilly nature and remote location of the area from settlements might reduce anthropogenic and livestock disturbances contributing for the higher species richness and presence of good number of emergent trees in the community [34]. Higher abundance of lianas in the group might also be associated with the presence of large number of tree species that suits for the climbing habit (characteristics) of lianas.

3.2.5. Species Diversity, Richness and Evenness. The woody species diversity (H') and evenness (J) in Robe-Raya Natural Forest were 3.75 and 0.88, respectively. According to [14], the Shannon-Wiener index value typically falls within the ranges of 1.5 to 3.5 and rarely rises above 4.5. The value of the index is considered high when it exceeds 3.0, medium when it falls between 2.0 and 3.0, low when it falls in between 1.0 and 2.0, and extremely low when it falls below 1.0 [36]. Hence, the value of H' (3.75) falls within the normal (high diversity) range, that denotes the forest has a high species diversity. In comparison to Saleda Yohans ($J = 0.84$) [37] and Gosh Beret Forest (0.66) [38], the observed total species evenness ($J = 0.88$) in the forest was also higher, denoting a much more equitable distribution of individuals across various species.

Comparing species richness and diversity amongst the different communities denoted that community 4 had the maximum species richness and diversity, while community 1 had the lowest (Table 4). According to [39], the relative variation among the communities within a given forest is interpreted using species diversity and evenness. Variations in topographic factors, microclimates that lead to the creation of microhabitats, and disturbance levels may all contribute to differences in species richness and diversity throughout community types [40]. In this particular case, for instance, the elevation range in community IV is broader than community I that favors the diversity of more species compared to community I. In addition, quadrats in community I (one) were close to the forest border, an area that is heavily disturbed by anthropogenic activities such as grazing, farming, and trampling. In the end, these variables led to the decrease in species diversity and richness. High species diversity demonstrates ecosystem health, stability, and appropriate species interaction [14], all of which signal the ecological system is operating normally and the opposite is true for a community with low species diversity.

3.2.6. Comparisons of Species Composition. The level of similarity between the species makeup of communities was computed by Sorensen's similarity index. The index quantifies to what extent the species composition of communities are alike. The similarity values in species composition between the communities ranged from 0.39 to 0.66 (39%–66%). Hence, notable dissimilarities had been observed among communities (Table 5). Community III and IV shared the greatest degree of resemblance while the minimum similarity was noted between community I and III (39%) (Table 5). The greater species resemblance between communities III and IV can be attributed to their comparable altitudinal ranges and the environmental variables that arise from their closeness. Conversely, the least similarity between community I and III might be brought as a result of variation in disturbance level, topographic variability and farther distance between the two communities.

Besides, the floristic composition of Robe-Raya Forest is compared with that of other comparable forests that have been previously studied (Table 6). Robe-Raya Forest showed the highest species composition similarity to the Dodola

Table 2: Quadrats in the community and their number.

Community	Number of quadrats	Quadrats
1	7	1, 5, 8, 18, 46, 48, 59
2	14	2, 3, 6, 11, 13, 15, 29, 32, 36, 38, 43, 45, 53, 56
3	12	4, 7, 9, 19, 21, 25, 30, 35, 40, 44, 47, 52
4	27	10, 12, 14, 16, 17, 20, 22–24, 26–28, 31, 33, 34, 37, 39, 41, 42, 49–51, 54, 55, 57, 58, 60

Table 3: Species with a synoptic value ≥ 0.5 in at least one of the clusters.

Species	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Podocarpus falcatus	**3.29**	1.79	2.58	2.52
Hypericum revolutum	**3**	0.29	0.83	1.15
Myrsine melanophloeos	1.43	**1.79**	**2**	1.22
Olea europaea subsp. *cuspidata*	0	**1.71**	1.42	0.74
Juniperus procera	2.43	3.14	**5.42**	**4.11**
Astropanax volkensii	0.57	0	**1.58**	0.15
Rubus apetalus	0	0.21	0.17	**4.93**
Astropanax abyssinicum	1.57	0.57	0.08	0.7
Nuxia congesta	1.57	0	0	0.59
Gymnosporia arbutifolia	1.43	1.5	0.33	0.48
Asparagus africanus	1.43	0.07	0.17	0.07
Vernonia auriculifera	1.14	0.5	0.25	0.93
Discopodium penninervium	1	0.14	0.58	0.15
Coffea arabica	0.57	0.43	0.5	0.59
Discopodium eremanthum	0.57	0.36	0.33	0.56
Combretum adenogonium	0.57	0	0.17	0.15
Dovyalis abyssinica	0.57	0	0	0.3
Ehretia cymosa	0.57	0	0	0.15
Galeria taxifolia	0.43	1.29	0.08	0.37
Toddalia asiatica	0.43	1.14	0.83	0.7
Osyris lanceolata	0.43	0.79	0.83	1.11
Hagenia abyssinica	0.29	1.5	0.83	0.7
Premna schimperi	0.29	0.43	0	0.78
Calpurnia aurea	0.29	0.29	0.08	0.37
Buddleja polystachya	0.29	0.14	1.08	0.7
Vangueria apiculata	0.29	0.07	0.58	0.19
Echinops longisetus	0.29	0	0.5	0.22
Spiniluma oxyacantha	0.14	0.14	0.75	0.44
Carissa spiranum	0	1.36	0.25	0.56
Asparagus setaceus	0	1	0.83	0.26
Dombeya torrida	0	0.29	0.5	0.15
Rhamnus prinoides	0	0.14	0.5	0.48
Inula confertiflora	0	0	0.5	0.11

Values in bold refer to dominant species used to name each community.

Table 4: Species richness (S), diversity index (H') and evenness (J) of plant communities.

Community	Altitudes (m)	S	H'	J
I	2552–2871	55	3.62	0.90
II	2598–2862	71	3.83	0.89
III	2518–2890	75	3.79	0.87
IV	2515–2914	88	3.90	0.87

Forest. The highest species composition similarities between the two forests might stem from their similar altitudinal ranges. Altitude is a proxy variable that indirectly affects the nature of forests by affecting the climate of an area, i.e., the precipitation and temperature of the area.

Conversely, the study forest showed the least species similarity to the Saleda Yohans forest. This could have happened as a result of variations in the degree of disturbance, and other environmental factors that were not assessed in this study may have contributed to this effect.

Table 5: Sorensen's similarity among the plant communities.

Community	I	II	III	IV
I				
II	0.50			
III	0.39	0.57		
IV	0.51	0.64	0.66	

3.3. Vegetation Structural Dynamics

3.3.1. Frequency. From the result it can be inferred that the two most frequently occurring species were trees, *Juniperus procera* (95.0%) and *Podocarpus falcatus* (83.3%) which were observed in 57 and 50 quadrats out of 60, respectively. This would mean the species are able to reproduce successfully and adapted to their habitat, exhibiting regular and uniform horizontal dispersion throughout the entire forest [34]. Conversely, the species with the least frequent occurrences in the study site were *Vachellia tortilis, Ehretia abyssinica, Erythrina abyssinica, Macaranga capensis, Olea capensis* and *Scutia myrtina* occurred in 3 quadrats each out of 60 (Appendix 1). These species failed to disperse regularly and uniformly in the forest which demonstrates that they are unable to withstand the condition under the forest or by nature the species might be rare.

Based on the values of their percentage frequency, the species of woody plants were grouped into five frequency classes (Figure 5). The trend in the frequency classes demonstrated that higher species percentage were represented in frequency class 1 (75.3%) with the continuously declining tendency towards the upper successive frequency classes. A given forest homogeneity and heterogeneity could be inferred from its frequency class distribution; large species percentages in the upper and lower percentage in the lower frequency classes demonstrate greater homogeneity, whereas large species percentages in the lower and small percentages in the upper frequency classes prove greater heterogeneity [41]. Therefore, the finding of the present study proved the heterogeneity of the vegetation in the study area. Earlier studies disclosed similar results [13, 34]. Various species' preferences for different habitats, as well as traits related to adaptability and disturbance tolerance may have contributed to this pattern of species dispersion.

3.3.2. Density. In comparison, Robe-Raya Natural Forest overall adult woody species density (1183.3 stems ha^{-1}) was lower than Wonjeta St. Michael forest (2202.5 stems ha^{-1}) [26], Entoto (3374 stems ha^{-1}) [27], and Gosh Beret (1586.75 stems ha^{-1}) [38] but higher than Jibat (720.3 stems ha^{-1}) [24] forests in Ethiopia. The habitat preferences of the different woody species that make up the forest and the degree of disturbance induced by anthropogenic activities, such as grazing and trampling, can vary, leading to variations in the density of forests [42].

Juniperus procera accounted for the highest density (240.4 stems ha^{-1}) followed by *Myrsine melanophloeos* (210.8 stems ha^{-1}), *Podocarpus falcatus* (204.6 stems ha^{-1}) and *Rubus apetalus* (177.0 stems ha^{-1}) while the least dense species were *Vachellia tortilis* (1.3 stems ha^{-1}), *Gymnosporia addat* (1.8 stems ha^{-1}), *Crotalaria agatiflora* and *Echinops ellenbeckii* (3.3 stems ha^{-1} each) and *Acanthus sennii, Canthium oligocarpum, Conyza spinosa, Diospyros abyssinica, Inula confertiflora, Olea capensis* and *Vepris nobilis* (4.2 stems ha^{-1} each) (Appendix 1). This result illustrates the variation in plant species densities that may occur from variations in the local community's demand for each species as well as the species' resilience to herbivors (grazing and browsing), trampling, and other human disturbances. For instance, species with lower densities may have multiple uses for livelihoods or a poorer capacity to withstand disturbance; on the other hand, species with larger densities may have little demand by the local community. A higher species density usually signifies promising regeneration ability and recruitment under disturbances such as trampling. If the species is found inside the forest (i.e. far from the edge of the forest), it is expected to have higher density since anthropogenic disturbance is particularly prevalent close to the edge of the forest [43].

Density of the forest species were categorized into six density classes (Figure 6). The trend of the density classes demonstrated a sharp drop from the first to the second classes followed by steady downward distribution of species towards the upper consecutive classes. The finding revealed that first and second density classes contained 50.5% and 18.8% of the species, respectively. This demonstrated that a greater number of woody plant species contributed fewer individuals ha^{-1} and vice versa, i.e. species with large number of individuals were fewer. This could be due to targeted harvesting of mature woody plants for making charcoal, building houses, and timber production, or otherwise the species might be rare in nature. Hence, in order to increase the number of individuals within each species, conservation efforts must focus on species in the lower density classes.

3.3.3. Diameter at Breast Height (DBH). After being grouped into seven DBH classes, the percent distribution of individuals of woody species in each class was examined. The distribution of individuals in the lower DBH classes was found to be higher, and the distribution decreased regularly throughout the upper successive DBH classes. The DBH class I contained the greatest proportion of individuals (73.9%), while the other classes - class II, III, IV, V, VI, and VII - contributed 16.7%, 4%, 2.1%, 1.6%, 1.1%, and 0.4% of individuals, respectively. A typical term used for this type of individual distribution is known as the "inverted J-shape pattern" (Figure 7) which was also documented by previous works [34, 37, 38]. This pattern suggests that the forest is primarily composed of shrubs and young trees with good rates of species regeneration and recruitment [1]. *Hypericum revolutum* (3.1%), *Juniperus procera* (5.5%), *Myrsine melanophloeos* (6.9%), *Podocarpus falcatus* (4.9%), *Rubus apetalus* (7.5%), *Rubus steudneri* (3.7%) and *Vernonia auriculifera* (3.8%) were the species that contributed a larger percentage of individuals to DBH class 1. DBH class 6 and 7 (0.4%) were represented by three species only (*Hygenia abyssinica, Juniperus procera* and *Podocarpus falcatus*).

Table 6: Species composition similarity comparisons of Robe-Raya with different dry evergreen afromontane forests of Ethiopia.

Forests	Altitudes	Geographical location	T°C	Rain fall	a	b	c	J (Robe-Raya)	Sources
Gosh-beret	2325–2560	11.90–11.93 N lat 38.15–38.18 E long	15.9	1546	25	27	67	0.33	[38]
Dindin	2150 – 300	7.61–7.68 N lat 40.18–40.26 E long	—	—	36	45	56	0.42	[19]
Entoto	2551–3031	9.13–10.10 N lat 37.78–38.8 E long	14	1226	33	40	59	0.4	[27]
Ades	1600–3100	—	17	>2000	27	21	65	0.39	[35]
Dodola	2500–3500	6.83–7.16 N lat 39.08–39.26 E long	12	>1500	36	23	56	0.48	[22]
Tulu Kurma	2163–2267	9.04–9.12 N lat 38.33–38.45 E long	16.9	1099	48	99	44	0.40	[29]
Saleda yohans	—	—	16.2	1134.5	23	27	69	0.27	[37]
Robe-Raya	2441–3190	6.81–6.84 N lat 39.42–39.43 E long	21.1	1357	93	—	—	1	

J = Jaccard's Coefficient of Similarity.

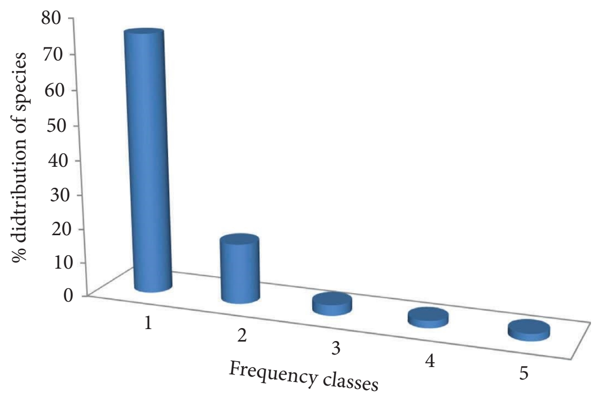

Figure 5: Woody plant species distribution across frequency classes.

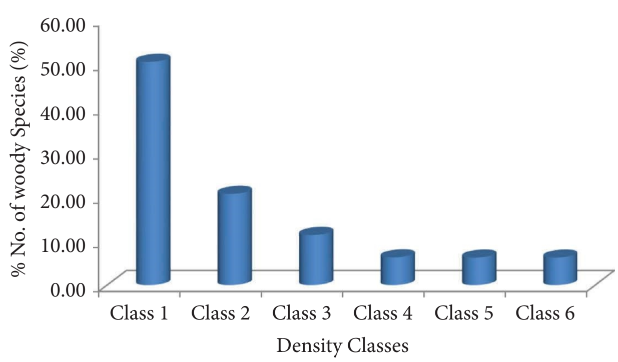

Figure 6: Density distribution of mature woody species across density the classes per ha.

3.3.4. Height. Similar to DBH, the height class distribution of individuals of species exhibited a downward trend towards higher subsequent classes (Figure 8). Thus, height class I included the highest percentage of individuals (78.3%). The remaining height classes: class II, III, IV, V, VI, and VII accounted for 10.1%, 3.9%, 3.5%, 2.3%, 1.1%, and 0.2% individuals, respectively. Similar trends between DBH and height classes were also reported in earlier works [23, 38] that the patterns for DBH and height classes were comparable.

Hypericum revolutum (3.1%), *Juniperus procera* (5.5%), *Myrsine melanophloeos* (6.9%), *Podocarpus falcatus* (4.9%) were among the species that contributed a larger percentage of individuals to height class I. *Juniperus procera* (2.5 ha^{-1} = 59.5%) and *Podocarpus falcatus* (1.7 ha^{-1} = 40.5%) were the only species contributed to height class VII. Thus, height class VII was represented by upper canopy trees. *Juniperus procera* was the top emergent woody species that grows above the canopy of all species in the forest followed by *Podocarpus falcatus* and *Hygenia abyssinica.*

Height provides useful information regarding the age and stage of the forest succession; a higher proportion of stems in lower height classes demonstrated an early stage of succession with strong potential for regeneration [26]. In addition of showing the dominance of medium and small-sized individuals, the inverted J-shape patterns of individual distributions in DBH and height classes [44] also revealed

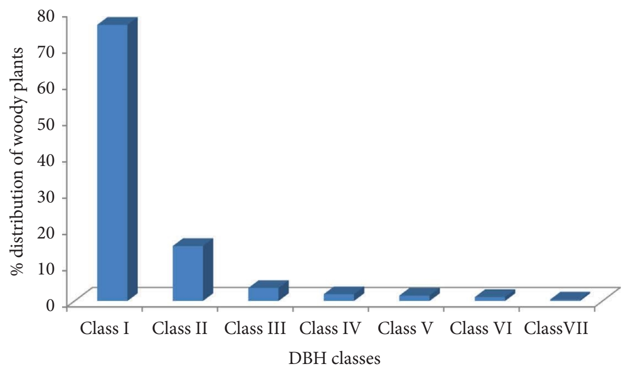

Figure 7: Distribution of individuals across DBH classes per ha.

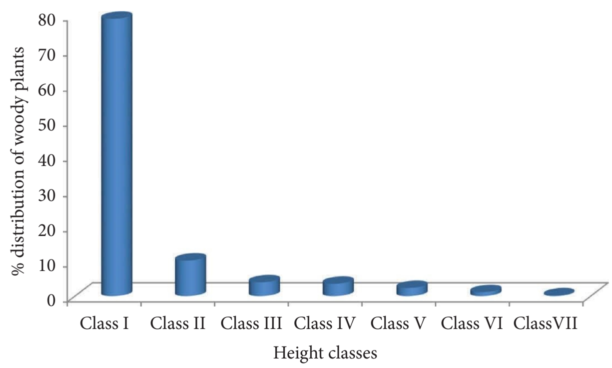

Figure 8: Distribution of individuals across height classes.

a continuous decline in adult tree individuals in the subsequent upper DBH and height classes, which may be the result of targeted logging of mature trees for various reasons.

3.3.5. Basal Area. The basal area of all woody species in Robe-Raya Natural Forest was 57.52 $m^2 \cdot ha^{-1}$. The basal area was significantly greater than the typical total basal area of tropical forests (23–37 $m^2 \cdot ha^{-1}$) [45]. Conversely, the study forest had much lower basal area than Dodola [23], Boda [46] and Menna-Angetu [25] but significantly higher than Gosh Beret [38] (Table 7). Basal area is a standard measurement (parameter) to evaluate the state of a forest's structure and conservation efforts; a higher basal area demonstrates that the forest is made up of large and old aged trees that have been conserved for long period of time. Conversely, lower basal area shows that the majority of the forest's species are young trees and shrub species. Thus, the basal area of a species is used to determine its relative importance [46]. The species with the largest contributions to the forest's overall basal area were *Juniperus procera* (14.4 $m^2 \cdot ha^{-1}$), *Hagenia abyssinica* (7.3 $m^2 \cdot ha^{-1}$), and *Podocarpus falcatus* (6.5 $m^2 \cdot ha^{-1}$). Together, these species contributed approximately half (28.2 $m^2 \cdot ha^{-1}$) of the overall basal area. On the other hand, *Vachellia tortolis, Dombeya torrida, Macaranga capensis, Euclea racemosa* subsp. *schimperi, Olea capensis,* and *Gymnosporia addat* with minimum contribution to the forest basal area (below 0.1 $m^2 \cdot ha^{-1}$) were the least important species (Appendix 1).

In addition, examining the basal area classes showed that a significant proportion of individuals with low DBH were concentrated in the lower basal area classes, and this proportion gradually decreased in the successive higher classes (Figure 9). This implies in the lower basal area classes, large proportion of small DBH stems contributed by several species has little effect to the total basal area while few large DBH individuals contributed by small number of species in the upper basal area classes has significant effect to the total basal area.

3.3.6. Importance Value Index (IVI). In accordance with their IVI value, the forest species were categorized into five IVI classes (Table 8). Twenty-three species in IVI class V and 49 species in class IV contributed 7.9% and 35.1%, respectively while four species in IVI class 1 contributed 30.6% to the total IVI value. The most significant indicator of a species' ecological relevance is its IVI value [41], which is derived from a combination of three metrics (RF, RD, and RDo) [14]. Thus, the dominant and ecologically most important species in IVI class I are those with higher IVI values [19]. It is believed that these species are victorious in regeneration, disease tolerant and coexist with other plants, least palatable, and capable of drawing pollinators and dispenser [17]. The top species in their IVI value (in class I and II) were *Podocarpus falcatus, Juniperus procera, Hagenia abyssinica, Myrsine melanophloeos* and *Olea europea* subsp. *cuspidata* (Appendix 1).

Table 7: BA comparisons of study forest with other forests in Ethiopia.

No	Forest	BA ($m^2 \cdot ha^{-1}$)	Sources
1	Dodola	129	[23]
2	Boda	114.64	[46]
3	Menna-angetu	94.22	[25]
4	Sese	88.62	[17]
5	Jibat	59.79	[24]
6	Robe-Raya	57.52	The present study
8	Woatgisho	45.14	[33]
9	Dindn	35.54	[47]
10	Gosh Beret	19.81	[38]

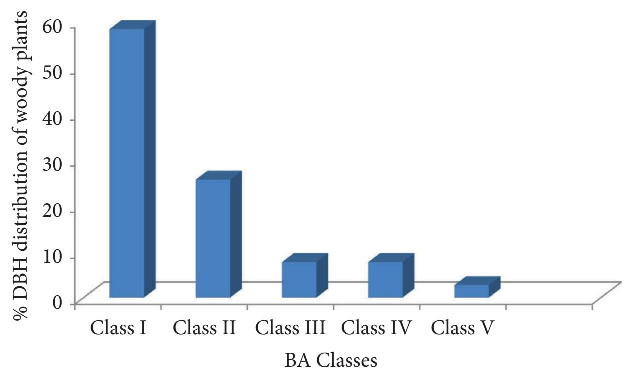

Figure 9: Basal area class of woody plant species.

Table 8: IVI classes, number of species in each class, IV values, and their percentage.

IVI classes and intervals	No of species	Sum of IVI	The total IV percentage
V (≤1)	32	23.1	7.9
IV (1–5)	49	102.5	35.1
III (5.1–10)	9	65.3	22.4
II (10.1–15)	1	11.6	4.0
I (>15)	4	89.3	30.6%

Conversely, species in IVI class IV and V, with lower IVI values, were not successful in their natural environment. *Vachellia abyssinica* (0.9), *Vachellia tortolis* (0.5), *Draceana steudneri* (0.6), *Erythrina brucei* (0.6) and *Macaranga capensis* (0.7) were some of the species with the least IVI value (Appendix 1). According to [46], species with a high IVI are better adapted to endure environmental stresses and disturbances than species with a lower IVI value. Therefore, a species' IVI value provides a clue which species should receive immediate conservation measure. Hence, species in IVI class V should receive conservation priority because they have the lowest IVI value, while species in IVI class I need regular follow up (monitoring) [17].

3.4. Regeneration Status. The density ratios of seedling to mature (772/1119), seedling to sapling (772/748), and sapling to mature (748/1119) were found to be 1.03 : 1, 0.69 : 1, and 0.67 : 1, respectively (Figure 10, Appendix 1). The result demonstrated that the density of seedlings was > the saplings < adults denoting fair regeneration of the forest species [21, 22].

Higher seedling densities were contributed by *Myrsine melanophloeos* ($91.3\,m^2 \cdot ha^{-1}$), *Podocarpus falcatus* ($50\,m^2 \cdot ha^{-1}$), *Hypericum revolutum* ($40\,m^2 \cdot ha^{-1}$), *Vernonia amygdalina* ($35.4\,m^2 \cdot ha^{-1}$), *Juniperus procera* ($33.3\,m^2 \cdot ha^{-1}$) and *Carissa spinarum* ($33.3\,m^2 \cdot ha^{-1}$). Species with lowest seedling density ($0.4\,m^2 \cdot ha^{-1}$ each) were *Boscia angustifolia, Crotalaria agatiflora* and *Gymnosporia addat* and species that totally lack seedlings were *Scutia myrtina, Solanum anguivi, Olea capensis, Maesa lanceolata,* and *Vachellia tortolis.* Seedlings and saplings density are correlated with the degree of disturbance and species tolerance to disturbance. Seedlings and saplings of certain species withstand higher trampling and grazing conditions, while others are rapidly destroyed. In addition, some species (rare species) by nature produce few juveniles [48].

Juniperus procera ($81.7\,m^2 \cdot ha^{-1}$), *Myrsine melanophloeos* ($54.2\,m^2 \cdot ha^{-1}$), *Podocarpus falcatus* ($53.3\,m^2 \cdot ha^{-1}$) and *Carissa spinarum* ($49.2\,m^2 \cdot ha^{-1}$) were the species with the highest sapling density. Conversely, the species that had the lowest sapling density were *Macaranga capensis, Acanthus sennii, Canthium oligocarpum, Crotalaria agatiflora, Vepris*

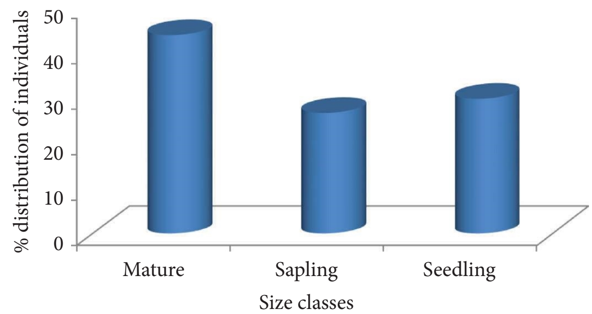

Figure 10: Regeneration status of woody plant species.

Table 9: Tree and selected shrub species categories for conservation priorities.

Category I	Category II		Category III	
Vachellia tortilis	*Vachellia abyssinica*	*Clematis hirsuta*	*Buddleja polystachya*	*Lippia abyssinica*
Olea capensis	*Albizia schimperana*	*Canthium oligocarpum*	*Calpurnia aurea*	
Maesa lanceolata	*Asparagus africanus*	*Carduus leptecathus*	*Carissa spinarum*	*Myrsine africana*
	Asparagus setaceus	*Carduus nyassanus*	*Coffee arabica*	*Myrsine melanophloeos*
	Bersama abyssinica	*Cissampelos pareira*	*Discopodium eremanthum*	*Gymnosporia arbutifolia*
	Boscia angustifolia	*Clutia abyssinica*	*Discopodium penninervium*	*Olea europea* subsp.*cuspidata*
	Buddleja davidii	*Conyza spinosa*	*Dodonaea viscose* subsp. *angustifolia*	*Podocarpus falcatus*
	Combretum adenogonium	*Crassula alba*	*Ekebergia capensis*	*Premna schimperi*
	Dombeya torrida	*Crotalaria agatiflora*	*Galineria saxifraga*	*Prunus africana*
	Dovyalis abyssinica	*Diospyros abyssinica*	*Hagenia abyssinica*	*Rhamnus staddo*
	Draceana afromontana	*Echinops ellenbeckii*	*Hypericum revolutum*	*Searsia pyroides*
	Dracaena steudneri	*Echinops longisetus*	*Juniperus procera*	*Rubus apetalus*
	Vepris nobilis	*Ehretia abyssinica*	*Rubus steudneri*	*Zizphus abyssinica*

nobilis, Diospyros abyssinica, Echinops ellenbeckii, Euphorbia schimperiana with 0.8 ha^{-1} each and *Gymnosporia addat* (0.4 ha^{-1}). Species that lacked saplings were *Olea capensis, Inula confertiflora, Erythrina brucei* and *Vachellia tortilis. Olea capensis* and *Vachellia tortolis* were the two species that were not regenerating at all since they were devoid of seedlings and saplings. Since they are more likely to become extinct locally, species lacking or with minimum density of juveniles require immediate conservation actions.

Priority-setting for conservation involved examining the seedling densities of woody species. Accordingly, species were grouped into three categories or priority classes as used by [19, 49]. Species that lacked seedlings or represented by one seedling only were grouped under category I; species with seedling number more than one, but less than 15 were grouped under category II and species with seedling number greater than or equal to 15 were grouped under category III. Three and 26 species were grouped in category I and II respectively and the remaining species were placed in category III (Table 9). Species under categories I should get first priority for conservation measures as they were found without or represented by one seedling only and species in category II needs to get priority next to species in category I. Conversely, species belonging to category III require consistent monitoring.

4. Conclusion and Recommendations

4.1. Conclusion. Robe-Raya Natural Forest is endowed with rich plant biodiversity. This demonstrated that the forest functions as an *in-situ* conservation area. Higher species diversity is a sign of favorable environmental conditions that support a complex and healthy community that permits regular interactions between species and increased ecological stability. Vegetation structure analyses demonstrated that a large number of species and their individuals are concentrated in the lower structural classes (i.e., lower density, DBH, height, and BA classes). This proved that the forest is made up of small tree and shrub species, which is a feature of secondary forests. In addition, the IVI value showed that a sizeable number species had low IVI values, suggesting that some species need conservation priority. Moreover, examination of the regeneration status of several species revealed that they either had few or no seedlings, demonstrating that they are vulnerable or need immediate management action [50].

4.2. Recommendations. Based on the result of the study the following recommendations are forwarded.

(i) Appropriate managerial intervention or a start of plantation program is required for those species with minimum IVI value (such as Acacia abyssinica, Draceana steudneri, Erythrina brucei, and Macaranga capensis), with few or without seedling (Acacia tortoli, Maesa lanceolata, and Olea capensis).

(ii) Participatory forest management system/strategy shall be put into practice for sustainable utilization of the forest.

(iii) Detailed ecological studies are vital concerning the association of plant community formation and species distribution patterns and the environmental factors such as terrain variables and soil properties, which were not the subject of this study. This would help in capitalizing on the current findings through generation of more quantitative data to clearly identify the environmental factors responsible for the observed patterns.

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

GMK, YAS, and AMB curated the data, analyzed the study, and wrote the study. GCW and AMB supervised, reviewed, and edited the study.

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Supplementary Materials

Appendix 1: Seedlings, Saplings, Density (D), Frequency (F), Relative Frequency (RF), Relative Density (RD), Relative Dominance (RDo = Relative Basal Area) and Impertinence Value Index (IVI). (*Supplementary Materials*)

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