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Research Article

Vegetation Structure and Regeneration Status of Woody Species in Gerba Dima Moist Afromontane Forest of Southwestern Ethiopia: Implications for Conservation

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This study assessed vegetation structure and regeneration status of woody species in Gerba Dima forest, southwestern Ethiopia. Ninety sample plots measuring 25 m × 25 m were laid through a stratified random sampling procedure. The studied forest was stratified into three forest strata based on its altitudinal variation. Stratum I was found at an altitudinal range of 1500–1800 m, while strata II and III were located at altitudinal ranges of 1801–2000 m and 2001–2300 m, respectively. All woody plant species with a diameter at breast height (dbh) equal to or larger than 2.5 cm and a height of at least 1.5 m were recorded. Analysis of the structure of the vegetation was conducted using frequency distribution of dbh, height, and importance value (IV). The regeneration pattern of the study species was assessed by employing the total count of seedlings and saplings. The density of woody species in the study area was 1829 individuals ha^{-1}. Basal area of the Gerba Dima forest was 65.05 m^2ha^{-1}. Total densities of seedlings, saplings, and trees/shrubs were 4558 ha^{-1}, 2149 ha^{-1}, and 1515 ha^{-1}, respectively. Structural analysis and assessment of the regeneration status of woody species in the Gerba Dima forest showed that the overall ecological condition of the forest was healthy as indicated by inverse J-curve dbh distribution, which showed a large number of individuals in lower dbh classes. Furthermore, a large number of seedlings and saplings were recorded for most species, in addition to the presence of a sufficient number of matured trees. However, some species exhibited abnormal population structure and abnormal patterns of regeneration characterized by fewer or no individuals in lower dbh, as well as in seedling and sapling stages. It was thus concluded that species with abnormal population structure and regeneration status (e.g., *Sapium ellipticum* and *Trichilia dregeana*) require urgent conservation attention.

1. Introduction

Several scholars have studied the vegetation resources of Ethiopia, including forests, woodlands, and bushlands [1–7]. Recently, a detailed vegetation map for Ethiopia was published, which classified the vegetation of Ethiopia into 12 types [8]. The vegetation type at Gerba Dima forest is part of the moist Afromontane forest type, which is found in areas at 1500 m to 2500 m elevation, with an all-round annual rainfall of 1500 mm to more than 2000 mm [8, 9].

Moist Afromontane forest type is characterized by one or more closed strata of evergreen trees that may reach a height of 30 to 40 m. Sometimes, only the lower stratum remains, owing to the logging of the tallest trees [8]. These forests mainly contain broad-leaved evergreen species in the multilayered canopy. In this vegetation type, *Pouteria adolfi-friederici* is the characteristic emergent species at 20–30 m high canopy. Other characteristic species include *Albizia gummifera*, *A. schimperiana*, *A. grandibracteata*, *Sapium ellipticum*, *Euphorbia ampliphylla*, *Ekebergia capensis*, *Ficus sur*, *Hallea rubrostipulata*, *Ocotea kenyensis*,

Olea welwitschii, *Polyscias fulva,* and *Schefflera abyssinica* [8, 9]. Another very characteristic feature of this vegetation type is the tree fern, *Cyathea manniana* (Cyatheaceae). Woody climbers include *Tiliacora troupinii* (an endemic). Epiphytes includinge ferns, lycopods, orchids, and *Peperomia* spp. are also encountered in moist Afromontane forests of Ethiopia [8, 9].

Vegetation structure refers to the organization in space of individuals that form a vegetation type [10]. Species size-class structure reveals whether regeneration is taking place or not. Where regeneration is occurring continuously, the species has a stable population distribution with an inverse J-curve, which is an indicator of good regeneration [11, 12]. Such population structure (inverse J-curve) is common in natural forests where external disturbances are limited. On the other hand, bell-shaped or variable size-class distribution is associated with a disturbed forest where regeneration is hampered [13]. Population structure (size-class distribution) provides a good indication of the impact of disturbance and the forest successional trends. Such information is vital in increasing our understanding of the conservation needs of tropical forest ecosystems [14, 15].

Environmental factors influencing seedling features differ at spatial scales; hence, they act at micro-site—depending on the way they alter the seedling survivorship [16]. The regeneration of existing tree populations in an area can be hampered by a lack of recruitment due to several factors, such as scarce production and dispersion of seeds, high mortality of seedlings, severity of droughts, anthropogenic activities, and herbivory [17]. In a forest ecosystem, regeneration success and stand dynamics are strongly correlated with seedling and juvenile performance [18].

Regeneration is a key ecological process and a vital component of forest ecosystem dynamics and restoration of degraded forestlands. The availability of sufficient information on the regeneration dynamics and factors affecting important canopy tree species is vital for sustainable forest management and utilization. If native long-lived trees are unable to survive and regenerate in a particular forest, then there is little hope to sustain normal forest functioning in the long term [19].

In Ethiopia, Reusing [20] estimated deforestation and degradation to be at 150,000–200,000 ha/year, and this was associated with loss of forest structure and diversity. Owing to anthropogenic impacts, the closed high forest cover of southwestern Ethiopia has declined from 38.4% in 1975 to 18.4% in 1996/97 [21]. In southwestern Ethiopia, new investment prospects are transforming these remnant forests into other land uses, such as tea and coffee plantations [22]. Resettlement programme in the early 1980s brought thousands of people from northern Ethiopia, leading to serious forest degradation [23, 24].

So far, apart from carbon stock assessment, no studies have been conducted in this forest, particularly in the area of vegetation structure and regeneration status [5]. Thus, this study aimed at obtaining sufficient information on density, frequency, frequency classes, vertical stratification, population structure based on diameter at breast height (dbh), and regeneration status of woody species in the Gerba Dima forest. Results of the present study will contribute to the planning, conservation, and management of forest resource programmes.

2. Materials and Methods

2.1. The Study Area. Gerba Dima forest is found in the Ilu Aba Bora zone of the Oromia regional state of Ethiopia, between 7°45′ to $8^0$10′ north latitude and 35°29′ to 35°50′ and at altitudinal ranges of 1582 m to 2285 m a.s.l (Figure 1). The soils of the area are characterized by red or brownish ferrisols derived from volcanic parent material [25].

The study area receives high annual rainfall characterized by unimodal rainfall pattern, which records low rainfall in December, January, and February, gradually increasing to a peak in August. Mean annual rainfall is 1854 mm, while monthly mean maximum and mean minimum temperatures of the area are 27.2°C and 13.3°C, respectively. The mean annual temperature is 19.2°C, with slight variation from year to year.

2.2. Sampling Technique and Measurements. A stratified random sampling technique was employed to collect vegetation data. The forest was stratified into three contour-based strata demarcated on the basis of altitudinal gradients recorded from ARC GIS version 10.3 (Figure 1). The forest area covers about 106,287.3 hectares. The three forest strata were distributed at altitudinal ranges of 1500–1800, 1801–2000, and 2001–2300 m having an area of 36,137.7, 54206.5, and 10628.7 ha, respectively. Ninety sample plots measuring 25 × 25 m (625 m^2) were randomly laid along contours by taking into account the size of each stratum, i.e., 31, 46, and 13 plots were assigned to strata I, II, and III, respectively. All woody plant species with a diameter at breast height (dbh) ≥2.5 cm and height ≥1.5 m were recorded in 25 m × 25 m plots. Within the major plots, five 3 m × 3 m subplots (9 m^2), four at the corners and one in the centre, were set up and used to collect data on saplings and shrubs with dbh <2.5 cm and >1.5 m height, as well as the seedlings of all trees and number of climbers. Height and diameter at breast height (dbh) were measured for all woody plant species with height ≥1.5 m and dbh ≥2.5 cm thick. Height and dbh measurements were made using a clinometer and tree calliper, respectively. The regeneration pattern of study species was assessed by employing the total count of seedlings (woody species of height ≤50 cm and dbh ≤2.5 cm) and saplings (woody species of height >50 cm and dbh ≤2.5 cm) within their respective subplots. All plant species encountered in each plot were recorded. Plant specimens were collected, pressed, dried, and brought to the National Herbarium (ETH), Addis Ababa University, for taxonomic identification. Specimen identities were determined by

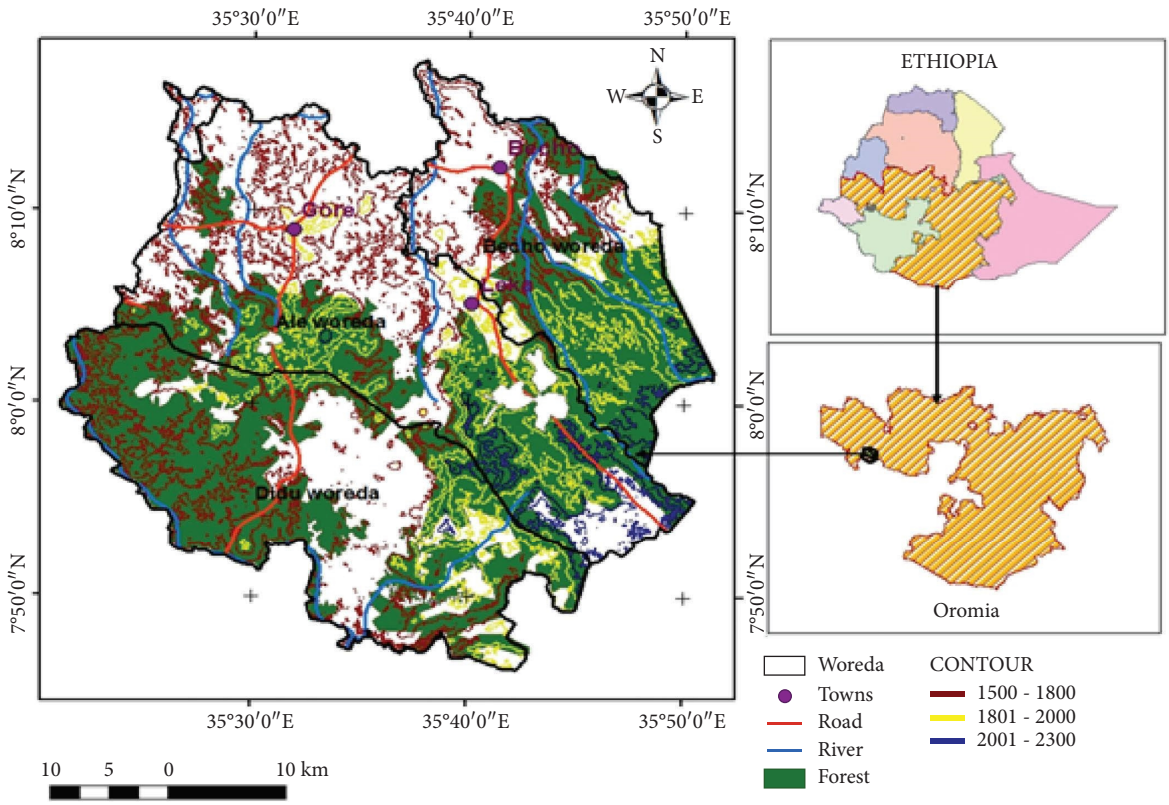

Figure 1: Map of the study area.

comparing them with authenticated specimens housed at ETH and by referring to published volumes of Flora of Ethiopia and Eritrea. Nomenclature followed that of flora of Ethiopia and Eritrea [26–34].

Physiographical variables, namely, altitude, geographic coordinates, and slope, were recorded for plot using GPS and clinometer. For each sample plot, disturbance was determined on the basis of a five-point scale following Anderson and Currier [35]. The five scales of disturbance scores were based on visible signs of tree cutting, grazing, and the presence of beehives. The points of scale were as follows: 0 = (No disturbance), 1 = (0–20% of the quadrat disturbed), 2 = (21–40% of the quadrat disturbed), 3 = (41–60% of the quadrat disturbed), 4 = (61–80% of the quadrat disturbed), and 5 = (81–100% of the quadrat disturbed). For analysis of soil variables, soil samples were collected with a soil core sampler from the top 40 cm within 1 m × 1 m subplots at the four corners and middle of the quadrat. Composite soil samples were brought to the soil laboratories of Addis Ababa University. The soil samples were air-dried, rolled, and passed through a 2 mm sieve for laboratory analyses. These soil samples were analysed for pH, potassium, organic matter, total nitrogen, and available phosphorus following standard procedures outlined in Allen [36].

2.3. Data Analysis. The structure of the vegetation was described using frequency distribution of dbh, height, and importance value (IV). Tree or shrub density and basal area values were computed on a hectare basis. Importance value indices were computed for all woody species based on their relative density, relative dominance, and relative frequency to determine their dominance as recommended by Kent [37].

$$\begin{aligned}
\text{IV} &= \text{relative density (abundance)} + \text{relative dominance (basal area)} + \text{relative frequency},\\
\text{relative density} &= \frac{\text{the number of all individuals of a species}}{\text{the number of all individuals of all species}} \times 100,\\
\text{relative basal area} &= \frac{\text{the basal area of a species}}{\text{total basal area}} \times 100,\\
\text{basal area} &= \frac{\pi D^2}{4}, \text{where } \pi = 3.14;\ \text{D} = \text{dbh (m)},\\
\text{relative frequency} &= \frac{\text{the number of plots where a species occur}}{\text{the total occurrence of all species in all of the plots}} \times 100,\\
\text{relative dominance (basal area)} &= \frac{\text{dominance (basal area) of a species}}{\text{dominance (basal area) of all species}}.
\end{aligned} \tag{1}$$

Following [38], the frequency and density of woody species were calculated as follows:

$$\begin{aligned}
\text{frequency}\,(F) &= \frac{\text{no. of quadrats in which a species occurs}}{\text{total no. of quadrats examined}} \times 100,\\
\text{density}\,(D) &= \frac{\text{total no. of individuals of a species found}}{\text{total area examined}}.
\end{aligned} \tag{2}$$

According to their total frequency expressed as a percentage, species were grouped in the following five Raunkiaer frequency classes: $A = 0$–20%; $B = 21$–40%; $C = 41$–60%; $D = 61$–80; and $E = 81$–100% [37].

The woody species were classified into six density classes, A–F as follows: $A \leq 1$; $B = 1.01$–10; $C = 10.1$–20; $D = 20.1$–35; $E = 35.01$–50; and $F = >50$ following Didita et al. [39].

The vertical structure of the woody species occurring in the Gerba Dima forest was analysed using the IUFRO classification scheme [40]. This scheme categorizes a vertical structure of vegetation into the upper, middle, and lower storey. The upper storey includes trees whose height exceeds 2/3 of the top height, while the middle storey includes species having a height between 1/3 and 2/3 of the top height and the lower storey is less than 1/3 of the top height.

The population structures of some selected species, which show various patterns, were also analysed based on dbh classes for the interpretation of the pattern of population dynamics in the forest. For population structure analysis, seven dbh classes were established arbitrarily (dbh classes: 1 = 2.5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–30 cm; 4 = >30.01–40 cm; 5 = 40.01–50 cm; 6 = 50.01–80 cm; and 7 = >80 cm).

The regeneration status of woody species was summarized based on the total count of seedlings and saplings of each species across all plots. Regeneration status was determined from the assessment of seedlings, saplings, and adults. A species is considered to have good regeneration if seedlings > saplings > adults; fair regeneration if seedlings > or ≤ saplings ≤ adults; and poor regeneration if the species survives only in the sapling stages. If a species is present only in the adult stage, it is considered as not regenerating [41]. Pearson product-moment correlation was conducted between densities of seedlings, saplings, mature trees/shrubs, and the environmental variables like altitude, slope, disturbance, organic matter, PH, N, P, K, and the number of species [42].

3. Results

3.1. Vegetation Structure. One hundred and one woody species with a density of 1829 individuals ha^{-1} were recorded in the study forest. Twenty-five species exhibited density class A, 40 species density class B, 11 species density class C, 9 species density class D, 5 species density class E, and 11 species exhibited density class F. The density of trees and shrubs with dbh 10–20 cm was 297.77 individuals ha^{-1}. The density of trees and shrubs with dbh greater than 20 cm was 207.48 individuals ha^{-1}. Accordingly, the ratio of individuals with dbh 10–20 cm (a) to dbh >20 cm (b) was 1.44.

In this study, 54, 17, 14, 10, and 6 species were recorded in frequency classes A, B, C, D, and E, respectively. *Vepris dainellii* (Pichi-Serm.) Kokwaro was the most frequent woody species in the Gerba Dima forest, occurring in 97.8% of the sample plots, followed by *Tiliacora troupinii* (96.7%), *Albizia gummifera* (91.1%), *Hippocratea pallens* (88.9%), *Landolphia buchananii* (88.9%), and *Millettia ferruginea* (85.6%). The least frequent woody species in the study forest,

each occurring only in 1.1% of the sampled plots, were *Ficus ovata*, *Clerodendrum myricoides*, *Alangium chinense*, *Solanaceo manni*, *Vangueria apiculata, Polyscias farinosa,* and *Vernonia rueppellii*.

The basal area of the Gerba Dima forest was 65.05 m^2ha^{-1}. The highest (20.55%) and lowest (0.001%) BA ha^{-1} was contributed by *Schefflera abyssinica* and *Vernonia rueppellii*, respectively. About 61.4% of the total basal area was covered by six large-sized tree species, i.e., *Schefflera abyssinica*, *Pouteria adolfi-friederici, Albizia gummifera*, *Ficus sur, Polyscias fulva*, and *Croton macrostachyus*. *Schefflera abyssinica* possesses low density but high BA due to its maximum average dbh value. Fifty-nine trees of this species contributed to 13.37 m^2h^{-1} (20.55%) (Additional file 1).

The first top ten species that contributed 47.29% of the IVI in decreasing order were *Schefflera abyssinica, Pouteria adolfi-friederici, Albizia gummifera, Vepris dainellii, Millettia ferruginea, Ficus sur, Croton macrostachyus, Syzygium guineense, Olea capensis, and Dracaena afromontana*. About 52.71% of the IVI was contributed by the remaining 91 species (Table 1).

The tallest species in Gerba Dima forest was *Pouteria adolfi-friederici,* with 45 m. Therefore, the upper storey is represented by a height >30 m, the middle storey ranges by 15–30 m, and lower storey ranges by <15 m (Table 2).

Trees and shrubs in the lower storey of the forest (2–15 m) contributed about 91.5% of the total individuals in the forest. The most dominant trees and shrubs in the lower storey (<15 m) of the forest were *Vepris dainellii* (13.93%), *Millettia ferruginea* (10.15%), *Albizia gummifera* (6.28%), *Olea capensis* (6.17%), *Dracaena afromontana* (5.88%), *Oxyanthus speciosus* (5.21%), *Deinbollia kilimandscharica* (4.91%), *Lepidotrichilia volkensii* (3.95%), *Maytenus gracilipes* (3.65%), *Pouteria adolfi-friederici* (3.53%), *Clausena anisata* (3.30%), *Syzygium guineense* (2.74%), *Ehretia cymosa* (2.53%), *Rothmannia urcelliformis* (2.30%), *Dracaena steudneri* (2.26%), and *Croton macrostachyus* (2.18%). The remaining species accounted for less than 2% each.

Trees in the middle storey of the forest (15–30 m) contributed about 8.28% of the total individuals in the forest. The tree species that occupied the middle storey in the Gerba Dima forest include the following: *Albizia gummifera* (20.14%), *Pouteria adolfi-friederici* (12.70%), *Croton macrostachyus* (9.32%), *Ilex mitis* (7.84%), *Ficus sur* (6.89%), *Syzygium guineense* (6.22%), *Schefflera abyssinica* (6.22%), *Polyscias fulva* (5.95%), *Sapium ellipticum* (3.51%), *Millettia ferruginea* (3.38%), *Macaranga capensis* (3.38%), *Olea welwitschii* (2.16%), and *Albizia schimperiana* (2.16%), and the remaining species contributed less than 2% each.

The upper storey also contained only seven emergent tree species (0.18%) out of the total individuals in the forest. The tree species that occupied the upper storey in Gerba Dima forest included *Pouteria adolfi-friederici* (50%), *Olea welwitschii* (12.5%), *Elaeodendron buchananii* (12.5%), *Millettia ferruginea* (6.25%), *Trilepisium madagascariense* (6.25%), *Bersama abyssinica* (6.25%), and *Ekebergia capensis* (6.25%).

3.2. Species Population Structure. Tree species of the study area were divided into seven dbh classes. The overall dbh class distribution of all individuals in different sizes showed an inverse J-curve distribution. In this study, six representative patterns of population distribution based on dbh were revealed for tree species (Figure 2). These include the following:

(a) Inverse J-curve showed a pattern where species frequency distribution had the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes, e.g., *Albizia gummifera*, *Cassipourea malosana*, *Dracaena afromontana*, *Ehretia cymosa*, *Macaranga capensis*, *Oxyanthus speciosus*, *Millettia ferruginea, Rothmannia urcelliformis*, and *Vepris dainellii*, among others.

(b) A pattern which shows an increase in number of individuals as we move from dbh class one to dbh class two and followed by a gradual decrease towards the higher dbh classes, e.g., *Allophyllus abyssinicus*, *Croton macrostachyus*, and *Syzygium guineense*.

(c) U-shape showed a type of frequency distribution in which there was a high number of lowest and highest diameter classes but a very low number in the intermediate classes, e.g., *Ficus sur*, *Pouteria adolfi-friederici*, *Olea welwitschii*, and *Prunus africana*.

(d) Irregular shape showed a pattern where frequency was high at lower dbh classes but became irregular towards higher classes. The species that showed such a pattern were *Albizia schimperiana*, *Polyscias fulva,* and *Trilepisium madagascariense*.

(e) Bell shape was a type of frequency distribution in which the number of individuals in the middle diameter classes was high and lower in lower and higher diameter classes, e.g., *Ilex mitis*.

(f) J-curve, e.g., *Sapium ellipticum*, showed a pattern where species frequency distribution had the highest frequency in the higher diameter classes and a gradual decrease towards the lower classes.

3.3. Regeneration Status of Gerba Dima Forest. In this study, the total density of seedlings, saplings, and trees/shrubs was 4558 ha^{-1}, 2149 ha^{-1}, and 1829 ha^{-1}, respectively (Table 3). Out of 101 woody species, 10 species were not represented in the seedling class and 9 species were not represented in the sapling class (Additional file 2). Twelve species contributed 65.54 and 65.51 per cent of the total seedling and sapling count, respectively. These are *Albizia gummifera*, *Vepris dainellii*, *Olea capensis*, *Oxyanthus speciosus*, *Millettia ferruginea*, *Clausena anisata*, *Maytenus gracilipes*, *Coffea arabica*, *Psychotria orophila*, *Lepidotrichilia volkensii*, *Deinbollia kilimandscharica*, and *Rothmannia urcelliformis*.

Five distribution patterns of regeneration status were observed from the 101 woody species investigated for regeneration and shown in Figure 3. These are as follows:

(1) Seedling > sapling > tree/shrub state. This pattern was exhibited by *Albizia gummifera*, *Bersama abyssinica*, *Canthium oligocarpum*, *Coffea arabica*,

Table 1: The top ten species with the highest IVI value in the Gerba Dima forest.

Scientific name	Relative frequency	Relative density	Relative dominance	IVI
Schefflera abyssinica	1.35	0.57	20.55	22.47
Pouteria adolfi-friederici	2.10	3.02	16.00	21.13
Albizia gummifera	3.25	6.44	8.62	18.32
Vepris dainellii	3.49	11.08	1.36	15.93
Millettia ferruginea	3.05	8.31	3.01	14.38
Ficus sur	1.90	1.45	6.79	10.14
Croton macrostachyus	2.58	2.10	4.28	8.95
Syzygium guineense	2.02	2.62	3.47	8.12
Olea capensis	2.26	4.91	0.66	7.82
Dracaena afromontana	1.55	4.67	1.18	7.40

Table 2: Density and number of woody species by storey in the Gerba Dima forest.

Storey	Height (m)	Density (no. of stems ha^{-1})	Percentage (%)	Species number	Percentage (%)
Lower	2–15	1454.4	91.5	66	95.65
Middle	15–30	131.56	8.28	26	37.68
Upper	>30	2.84	0.18	7	10.14

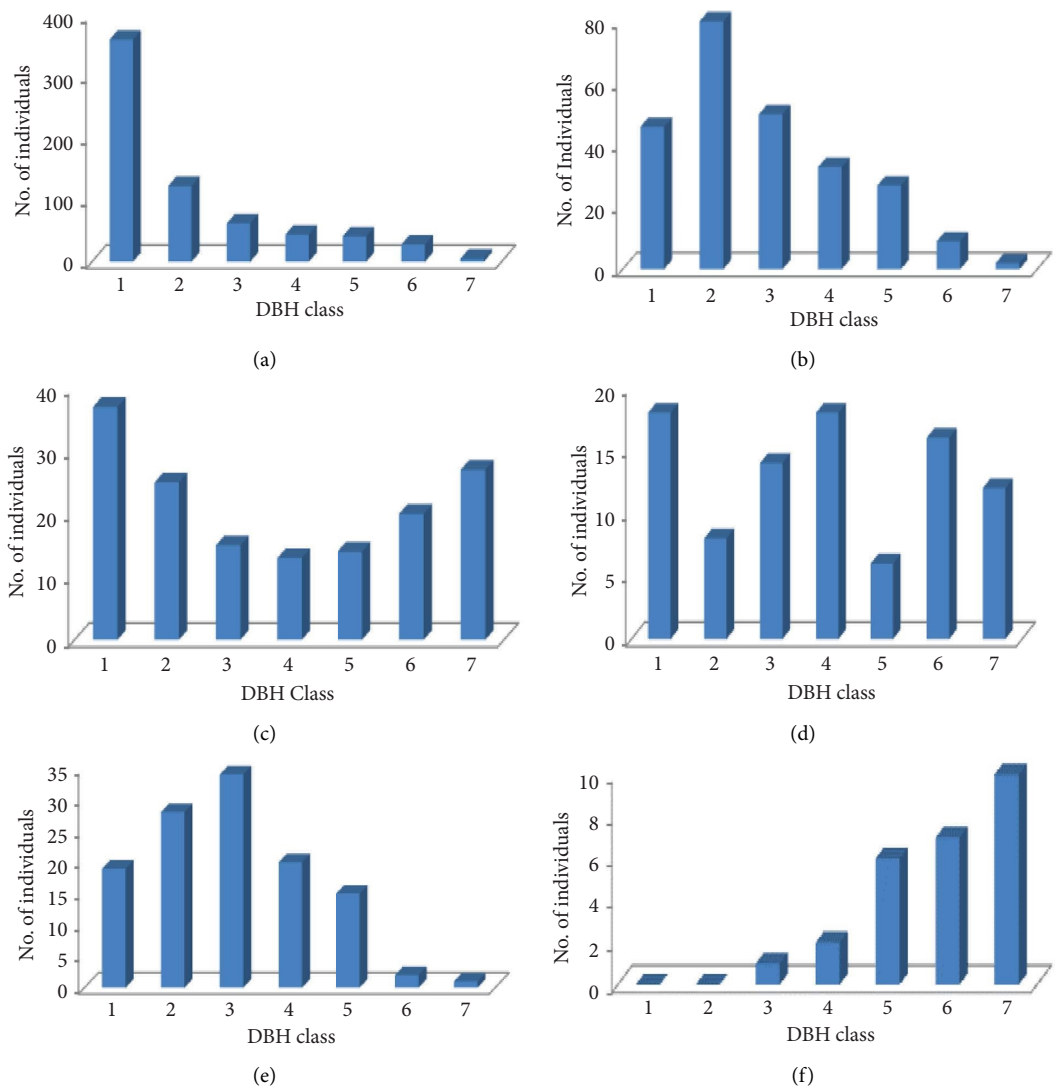

Figure 2: (a–f) Pattern of frequency distribution of selected tree species over dbh classes (dbh classes: 1 = 2.5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–30 cm; 4 = ≥30.01–40 cm; 5 = 40.01–50 cm; 6 = 50.01–80 cm; 7 = >80 cm). (a) *Albizia gummifera*. (b) *Croton macrostachyus*. (c) *Ficus sur*. (d) *Polyscias fulva*. (e) *Ilex mitis*. (f) *Sapium ellipticum*.

Table 3: List of top 12 species in the regeneration.

Name of species	Seedling ha^{-1}	Percentage (%)	Sapling ha^{-1}	Percentage (%)
Albizia gummifera	446.04	9.78	169.60	7.89
Vepris dainellii	356.62	7.82	200.00	9.31
Olea capensis	314.67	6.90	146.84	6.83
Oxyanthus speciosus	264.36	5.80	103.47	4.81
Millettia ferruginea	258.84	5.68	103.47	4.81
Clausena anisata	233.60	5.12	111.47	5.19
Maytenus gracilipes	228.27	5.01	110.04	5.12
Coffea arabica L.	214.93	4.71	96.53	4.49
Psychotria orophila	192.36	4.22	104.71	4.87
Lepidotrichilia volkensii	169.96	3.73	56.89	2.65
Deinbollia kilimandscharica	155.73	3.42	140.98	6.56
Rothmannia urcelliformis	152.71	3.35	63.82	2.97
Total		65.54		65.51

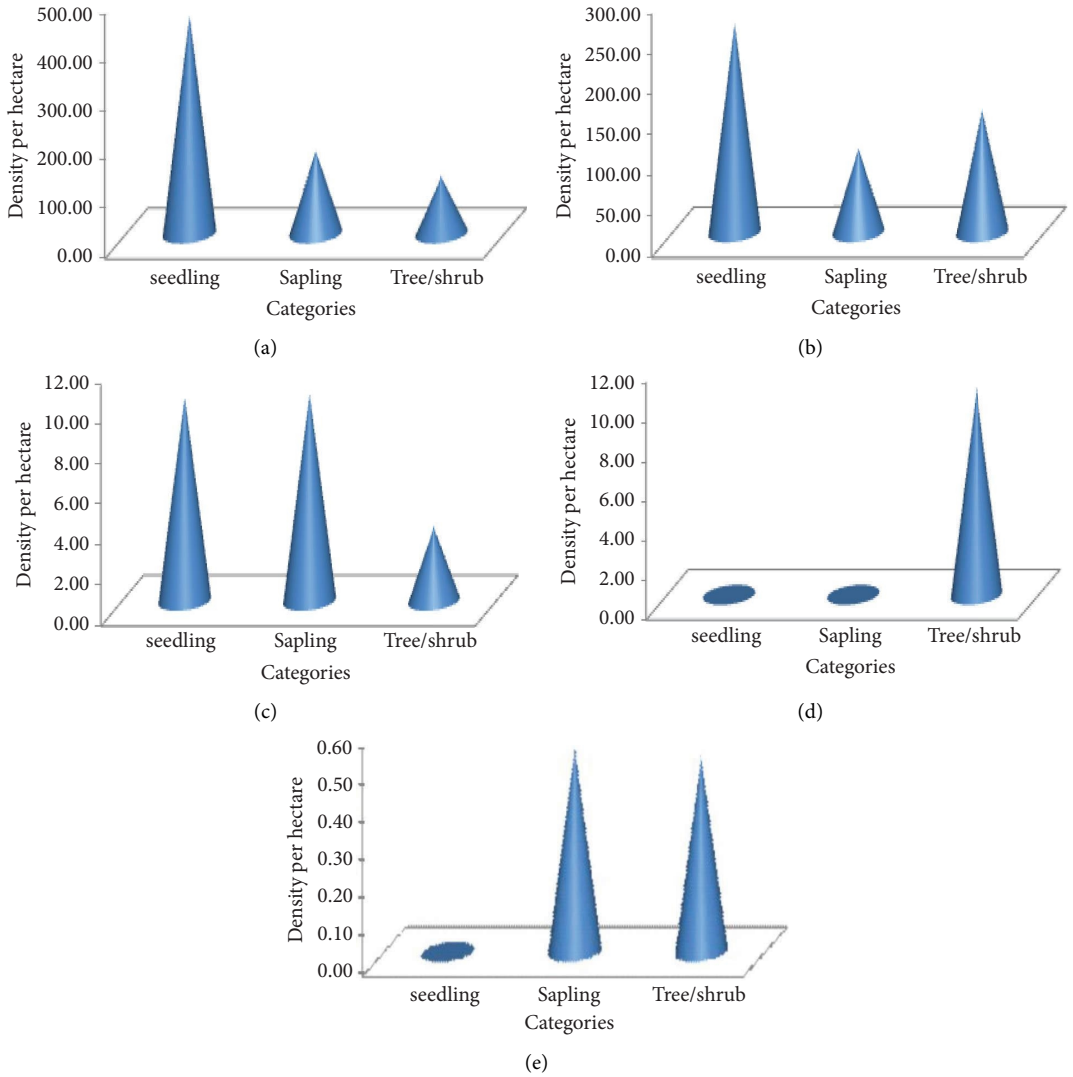

Figure 3: (a–e). Seedlings, saplings, and tree/shrub distribution of some selected species occurring in the Gerba Dima forest. (a) *Albizia gummifera*, (b) *Millettia ferruginea*, (c) *Trilepisium madagascariense*, (d) *Schefflera abyssinica*, (e) *Chionanthus mildbraedii*.

Cassipourea malosana, *Clausena anisata*, and *Deinbollia kilimandscharica* (Figure 3(a)).

(2) Seedling > sapling < tree/shrub state. *Cordia africana*, *Ficus sur*, *Hallea rubrostipulata*, *Ilex mitis*, *Lepidotrichilia volkensii*, *Macaranga capensis*, *Millettia ferruginea*, *Ritchiea albersii*, *Syzygium guineense*, *Trema orientalis,* and *Vernonia amygdalina* exhibited this pattern.

(3) Seedling < sapling > tree/shrub. A distribution pattern showed a small density value of seedling species and a higher value of sapling followed by the smaller value of seedling density. *Trilepisium madagascariense* was categorized under this distribution pattern.

(4) With no individual in the seedling and sapling stages, but relatively many individuals in the tree/shrub stage. This pattern was recognized by *Ficus ovata*, *Ficus thonningii*, *Lobelia giberroa, Polyscias farinosa*, *Schefflera abyssinica*, *Trichilia dregeana*, *Urera hypselodendron*, *Vangueria apiculata*, and *Vernonia rueppellii.*

(5) With smaller density values of the mature trees or shrubs, but higher density values at the sapling stage and a complete absence of seedling species. *Chionanthus mildbraedii* was recognized under this regeneration pattern.

3.4. Correlation between Densities of Seedlings, Saplings, Mature Trees, and Environmental Variables. Seedling density showed a significant positive correlation with altitude and K, but showed a significant negative correlation with disturbance. Sapling density showed a significant positive correlation ($P < 0.01$) with altitude, K, and PH, but showed a significant negative correlation with disturbance. The density of mature trees or shrubs exhibited a significant positive correlation with the number of species (species richness) but significantly negatively correlated with PH ($P < 0.05$) (Table 4).

4. Discussion

4.1. Vegetation Structure. The result of this study indicates that of 101 woody species, 65 (64.4%) species are found in the lower density classes (A and B). Thus, most of the species (64.4%) were less abundant and contributed little to the total density of tree and shrub species in the study forest. In this study, the ratio of dbh > 10 cm to dbh > 20 cm (a/b ratio) indicates the predominance of small-sized individuals of woody species in the forest. The predominance of small-sized individuals in the forest is largely attributed to the high density of *Albizia gummifera, Millettia ferruginea*, and *Vepris dainellii*. The ratio described as a/b is taken as the measure of size-class distribution [43]. The proportion of small plants (dbh < 10 cm) was much greater (68.34%). This indicates that the Gerba Dima forest is in the secondary stage of development.

The basal area value of the Gerba Dima forest is very high (65.05 m^2ha^{-1}). The normal basal area value for a virgin tropical forest in Africa is 23–37 m^2ha^{-1} [40]. *Schefflera abyssinica*, *Pouteria adolfi-friederici, Albizia gummifera*, *Ficus sur, Polyscias fulva*, and *Croton macrostachyus* covered 61.4% of the total basal area. The basal area provides a better measure of the relative importance of the species than simple stem count [44]. Thus, the species with the largest contribution in the basal area can be considered the most important woody species in the study area. Accordingly, the above six species were the most important species in the study area. *Schefflera abyssinica* possesses low density but high BA due to its maximum average dbh value.

In this study, 54 species (53.5%) were found in the lower frequency class (A). Hence, they are less frequent in the study forest. High values in higher frequency classes (D and E) and low values in lower frequency classes (A and B) indicate constant or similar species composition. On the other hand, high values in lower frequency classes and low values in higher frequency classes indicate a high degree of floristic heterogeneity [40]. In this study, high values were obtained in lower frequency classes. This indicates the existence of a high degree of floristic heterogeneity in the Gerba Dima forest. *Landolphia buchananii*, *Hippocratea pallens*, *Albizia gummifera, Millettia ferruginea, Tiliacora troupinii,* and *Vepris dainellii* are the six most frequent species each occurring in more than 85% of the study plots and belong to frequency class E in the Gerba Dima forest. The occurrence of the most frequent species in the study forest could be attributed to the usual occurrence of plant species at a wide range of altitudes, seed dispersal capacity, germination vigour, resistance to pests and pathogens, habitat preferences, adaptation, the degree of exploitation, and availability of suitable environmental conditions for regeneration [45].

In this study, *Schefflera abyssinica, Pouteria adolfi-friederici, Albizia gummifera, Vepris dainellii, Millettia ferruginea, Ficus sur, Croton macrostachyus, Syzygium guineense, Olea capensis*, and *Dracaena afromontana* were the top ten species with the highest IVI value in decreasing order. The importance value index (IVI) allows for comparison of species in a given forest type and depicts the sociological structure of a population in its totality in the community. It often reflects the extent of dominance, occurrence, and abundance of a given species in relation to other associated species in an area [37]. Curtis and McIntosh [46] pointed out that the importance value index gives a more realistic figure of dominance from the structural point of view. It is useful to compare the ecological significance of species [40]. In the present study, the above ten species with higher IVI values were abundant, frequent, and dominant in the Gerba Dima forest.

The result of the vertical structure of the Gerba Dima forest indicates that the lower storey contains the highest density of stems, but the lowest density of stems represents the upper storey. Similarly, more species were found in the lower and middle storey but fewer species in the upper storey. Hence, the result still confirms the dominance of small-sized individuals in the forest, indicating a secondary developmental stage of the forest. The ability of species in the lower storey to grow under the canopy layer is determined by the condition of the soil, component species, and solar

Table 4: Correlation between densities of seedling, sapling, mature trees, and environmental variables.

	Seedling	Sapling	Mature T/s	No. of species	Altitude	Slope	Disturbance	pH	OM	K	N	P
Seedling	1											
Sapling	0.880**	1										
Mature T/S	0.250*	0.264*	1									
No. of Species	−0.001	0.046	0.232*	1								
Altitude	0.405**	0.294**	−0.023	0.004	1							
Slope	0.117	0.063	−0.054	−0.033	0.145	1						
Disturbance	−0.231*	−0.337**	−0.156	−0.085	−0.098	0.294**	1					
pH	0.189	0.214*	−0.249*	0.006	0.169	0.147	−0.183	1				
OM	0.042	0.049	−0.066	0.029	0.237*	0.068	0.075	−0.176	1			
K	0.478**	0.412**	0.016	−0.046	0.479**	0.071	0.021	0.361**	−0.117	1		
N	−0.160	−0.102	−0.022	−0.068	−0.145	−0.225*	−0.112	0.103	−0.212*	−0.012	1	
P	−0.034	−0.032	0.050	−0.040	−0.027	−0.046	0.076	−0.029	0.046	0.025	0.044	1

**Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

radiation intensity at lower vegetation layer associated with opening and closing rate of the crown [47].

The overall dbh class distribution of all individuals of different sizes showed an inverse J-curve distribution. This general pattern demonstrates that the majority of species had the highest number of individuals at relatively low dbh and height classes with a gradual decrease towards both high dbh and height classes. This pattern is an indicator of healthy regeneration of the forest and species and shows a good reproduction and recruitment capacity [48]. A significant proportion of individuals in the Gerba Dima forest (i.e., >52.61%) were found in height class 2–5 m. Only a few individuals (<0.18%) attain heights of greater than 30 m. The dbh distribution of woody species in the study forest also revealed that most of the individuals, i.e., about 87%, were in the dbh class ≤20 cm and a very small proportion (i.e., 1.47%) reached dbh greater than 80 cm.

Investigation of population structure based on dbh classes for individual tree species in the Gerba Dima forest revealed six different distribution patterns. The difference in the patterns of species population structure can be interpreted as an indication of variation in population dynamics and regeneration status in the forest. The first pattern that showed an inverse J-curve distribution was represented by *Albizia gummifera*. Species in this distribution pattern had a high number of individuals in the lower dbh class and with gradual decreases towards higher dbh classes. This pattern is an indicator of stable population status or healthy regeneration of the species and indicates a good reproduction and recruitment capacity [11, 12]. Plants in small size class easily replace dead adult plants. Hence, plant population with this distribution pattern seems to be self-sustaining.

The second pattern represented by *Croton macrostachyus* showed an increase from dbh class one to dbh class two, followed by a gradual decrease towards the higher dbh classes. The relatively fewer individuals in dbh class one than in dbh class two is attributed to selective logging of individuals in dbh class 1. The third pattern is a U-shaped distribution pattern represented by *Ficus sur*. A U-shaped pattern indicates selective logging and removal of medium-sized trees most likely for house and beehive construction or farm tools making. The fourth pattern is an irregular shape with a high number of individuals at lower dbh classes, becoming irregular towards higher classes. This pattern indicates good reproduction, but with discontinuous recruitment. The fifth pattern is bell-shaped and represented by *Ilex mitis*. In this distribution pattern, the number of individuals in the middle diameter classes is high and lower in lower and higher diameter classes. This pattern indicates a poor reproduction and recruitment of species, and is attributed to overharvesting of seed-bearing individuals. Selective cutting of large-sized individuals for various purposes, mainly timber for construction, could also be the reason for a decline in the number of large-sized trees. The sixth pattern represented by *Sapium ellipticum* represents abnormal population dynamics and show poor reproduction and hampered regeneration because either most trees are not producing seeds due to age or there are losses due to predators after reproduction.

4.2. Regeneration Status. Based on the density of seedlings, saplings, and mature trees, five distribution patterns of regeneration status were observed in the Gerba Dima forest. The first distribution pattern of regeneration status showed good regeneration and recruitment potential. The presence of good regeneration potential confirms the stability of the species in the environment. Higher seedling density values are reduced to sapling due to biotic disturbances and competition for space and nutrients [41]. This regeneration status pattern also indicates the possibility of replacement of mature plants in the future and indicates a relatively better regeneration status. The second pattern of regeneration represents fair regeneration and recruitment of the species. The third distribution pattern of regeneration status, which shows a small density value of seedling species, and a higher value of sapling, followed by a smaller value of seedling density, indicates poor regeneration attributed to poor stocking, adverse conditions in the forest, continuous and selective logging, and general human disturbance in the form of livestock grazing and trampling [49]. Prevention of livestock grazing and overexploitation could improve the regeneration status of woody species under this regeneration status. Species in the fourth pattern of regeneration status are

not recruiting as they survive only at the adult or mature tree level [41]. Thus, this situation calls for conservation and management action to sustain their life by giving them time to rejuvenate themselves from seeds deposited in the soil. However, even though species like *Schefflera abyssinica*, *Ficus thonningii*, and *Urera hypselodendron* exhibits this pattern of regeneration, it is difficult to conclude that these species were not recruiting. The main reason is these plants start life as epiphytes and finally overwhelm the host tree to become an independent tree. Thus, seedling and sapling stages are not observable on the ground [50]. The fifth regeneration status pattern represented by the low density of matured trees and high density of saplings, but with a complete absence of seedlings, also indicates poor regeneration capacity and requires conservation and management schemes to extend the life of those species.

A statistically significant positive correlation between seedling and sapling density with altitude is explained by increasing temperatures and drought stress towards lower altitudes that lead to low survival of seedlings and saplings [51, 52]. Seedlings are more sensitive to drought since they are shallow rooted with restricted access to lower soil layers characterized by high water potential. On the contrary, the higher altitude in the study forest is optimal for their survival. The significant negative correlation of seedling and sapling density with disturbance is attributed to the removal of plants, which may have deleterious effects on germination and seedling establishment [53, 54]. Disturbance in the form of trampling by cattle can be a cause for the mortality of seedlings by their hooves. Browsing at high stocking rates also reduces the survival of seedlings and saplings [55]. Browsing and trampling can cause leaf loss that can lower growth rates and increase mortality of seedlings and saplings [56]. The significant positive correlation between seedlings and potassium is explained by the fact that potassium is part of the NPK essential macronutrients. A previous study found that adding K has limited but significant effect on *in situ* seedling growth of understorey species [57].

5. Conclusion

Structural analysis and assessment of the regeneration status of woody species in the Gerba Dima forest showed that the overall ecological condition of the forest was healthy. However, structural analysis and assessment of regeneration of some species revealed that there are species, which exhibit abnormal population structure and abnormal pattern of regeneration. This abnormal pattern could be attributed to poor stocking, adverse conditions in the forest, continuous and selective logging, and other anthropogenic factors in the form of livestock grazing and trampling. The occurrence of abnormal population structure and abnormal patterns of regeneration in some plant species calls for the conservation and management of these species. Thus, establishing nursery sites to grow threatened species in the area and reafforestation with threatened indigenous trees should be encouraged to save this species from extinction at the local level. Furthermore, the existence of high species diversity and a number of endemic plant species in the study forest show the potential of the area for biodiversity conservation. Thus, all stakeholders including Oromia Forest and Wildlife Enterprise (OFWE) and the regional government should work to designate the forest as a biosphere reserve and being registered under UNESCO.

Data Availability

We have also included part of the data used in this research and attached as Additional files 1 and 2 under supplementary material. Thus, the data used for this manuscript are available.

Disclosure

This work is part of the PhD dissertation submitted to Addis Ababa University [58]. The funders had no role in study design, data collection and interpretation, or the decision to submit the work for publication.

Conflicts of Interest

The authors declare that they have no known conflicts of financial interest or personal relationships that could have appeared to influence the work reported in this study.

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Supplementary Materials

Additional file 1: Frequency, density, basal area, and importance value index of woody species of the Gerba Dima forest. Additional file 2: Seedlings and trees/shrubs per hectare of woody species in the Gerba Dima forest. (*Supplementary Materials*)

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