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Research Article

Woody Species Diversity, Vegetation Structure, and Regeneration Status of the Moist Afromontane Forest of Agama in Southwestern Ethiopia

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This study was conducted in Agama Forest in Kafa Zone, Southwestern Ethiopia, to assess species diversity, vegetation structure, and regeneration status of woody species. A systematic sampling technique was employed to collect vegetation data. Sixty (60) sample plots of 25 m × 25 m were laid at 300 m intervals all along ten grids interspaced 800 m apart. Sample plots of 25 m × 25 m were used to record DBH and *H* of all woody plant species reaching a DBH >2.5 cm and height >2 m. For the inventory of seedling and sapling, two subplots of 2 m × 5 m were used at the beginning and the end of the baseline on opposite sides of the main quadrat. Vegetation data such as DBH, height, seedling, and sapling density of woody species were recorded in each plot. Altogether, 72 woody plant species of 65 genera and 35 families were identified. Analysis of selected tree species showed diverse population structures. This study showed that small trees and shrubs dominated the Agama Forest, which revealed its status under a secondary regeneration stage. Study on the structure and regeneration of some woody species indicated that there are species that require urgent conservation measures. Sound management and monitoring, as well as maintenance of biodiversity and cultural and economic values of the forest, require conservation activities that encourage sustainable uses of the forest and its products.

1. Introduction

Ethiopia's highly variable ecology, topography, and climate make it an internationally recognized centre of biodiversity [1]. The country has around 6000 higher plant species of which about 10% are endemic [2, 3]. The vegetation of Ethiopia has been classified into 12 types [4]. The vegetation type at Agama Forest in Southwestern Ethiopia, the subject of this paper, is part of the moist evergreen Afromontane forest that is characterized by one or more closed strata of evergreen trees that may reach heights of 30 to 40 m.

Southwestern Ethiopia best represents remnant natural forests but those are being destroyed at an alarming rate [5]. Human-induced loss of forest cover, structure, and biodiversity is of global concern; in Ethiopia, [6] estimated rates of deforestation and forest degradation at between 150,000 and 200,000 ha/year and this was associated with loss of forest structure, diversity, dynamics, and evolution. New investment opportunities in Southwestern Ethiopia are converting these remnant forests into other land uses such as tea and coffee plantations [7]. New settlers migrating from the northern and central parts of Ethiopia have also contributed to land use changes and forest degradation [8, 9].

The Shannon–Wiener index, *H*, is the most popular measure of species diversity because it scores for both species richness and evenness and is not affected by sample size [10, 11]. In the analysis of vegetation structure, the growth stages of trees as seedlings, saplings, and mature trees as well as the distribution of size classes within a population can be essential elements of diversity that permit or deny the likelihood of quick recovery after disturbances [12]. The status and dynamics of woody-tree populations can be examined by conducting a size class distribution and seedling and sapling counts [13, 14]. Healthy natural populations with continuous regeneration exhibit an exponentially decaying size class distribution, whereby trees in smaller size classes are represented in greater numbers than in larger classes. The absence or rarity of seedlings can be considered an indication of a declining population. The population structure of a tree species is indicative of its history of past disturbance and can be used to predict its future status in the forest [13]. This study investigated the woody species diversity, structure, and regeneration status of the Agama Forest in Southwestern Ethiopia. The results will be used to set conservation and management strategies for this forest.

2. Materials and Methods

2.1. Study Area. This study was conducted in Gimbo district of the Kafa Zone in the Southern Nations' Nationalities and Peoples' Regional State (SNNPRS), which is located 500 km from Addis Ababa and 30 km from Bonga (Figure 1). The area is centered at 7.16°N, 36.11°E, the altitudinal range is from 1800 m to 2370 m, and the topography is undulating, with valleys and rolling plateaus [15]. The size of the study forest covers about 1872 hectares (Figure 1).

The climate data between the years 2005 and 2018 recorded by the meteorological station at Bonga that is located 20 km south of the study area was used to describe the climatic condition of the study area. There is a unimodal rainfall pattern with eight months between March and October with rainfall >100 mm/month [16]. The mean annual rainfall is 1830 mm, and the monthly mean maximum and mean minimum temperatures are 29.6°C and 9.5°C, respectively. The mean annual temperature is 19.7°C.

The major soil groups of the study area, according to the FAO/UNESCO legend of soil classification, are Nitisols, Acrisols, and Vertisols [17]. The Nitisols are agriculturally the most important and dominant type of soils in the Kafa Zone. The Nitisols are clay-red in color and have moderate CEC and relatively high organic matter content and total nitrogen.

2.2. Vegetation Sampling. A preliminary survey was made from 30 April 2017 to 15 May 2017 to obtain an impression on the general physiognomy of the vegetation and identify sampling sites in the study area. The actual field study was conducted from 10 December 2017 to 30 April 2018. The systematic sampling design was used to collect vegetation and environmental data [10, 18, 19]. Sixty (60) sample quadrats of 25 × 25 m were laid at 300 m intervals along ten grids interspaced 800 m apart. Seedling and sapling inventories of all woody-tree and shrub species were recorded in two 2 × 5 m subquadrats located on opposite sides of each quadrat. For all woody species of height (H) ≥ 2 m and diameter at breast height (DBH) ≥ 2.5 cm, H and DBH were measured using a clinometer and diameter tape, respectively. Regeneration patterns were assessed using the total count of seedlings ($H \leq 50$ cm and DBH ≤ 2.5 cm) and saplings ($H > 50$ cm and DBH ≤ 2.5 cm) within the subquadrats. Geographical coordinates and altitudes were recorded for each quadrat using GPS. Plant specimens were collected, pressed, dried, and brought to the National Herbarium (ETH), Addis Ababa University, for taxonomic identification and nomenclature. These were determined by comparison with authenticated specimens housed at ETH and by referring to published volumes of the Flora of Ethiopia and Eritrea [20–25].

2.3. Data Analysis. Species diversity was calculated using the Shannon–Wiener diversity index, H, as

$$H = -\sum_{i=1}^{s} p_i \ln p_i, \tag{1}$$

where s is the number of woody species and p_i is the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of the total.

Shannon's evenness, J, was calculated as the ratio of observed diversity, H, to the maximum diversity, $H_{\max}$, using the following equation:

$$J = \frac{H}{\ln(s)} = \frac{H}{H_{\max}}, \tag{2}$$

where $\ln(s) = H_{\max}$

The structure of the vegetation was described using a frequency distribution of H, DBH, and Importance Value Index (IVI). Tree or shrub density and basal area values were calculated on a per-hectare basis. For all species, IVIs were calculated as the sum of their relative density (RD), relative frequency (RF), and relative dominance (RDO) [10] where

$$\text{RD} = \frac{\text{the number of all individuals of a species}}{\text{the total number of all individuals}} \times 100,$$

$$\text{RF} = \frac{\text{the number of plots where a species occurs}}{\text{the total occurrence of all species in all plots}} \times 100,$$

$$\text{RDO} = \frac{\text{the basal area of a species}}{\text{total basal area}} \times 100, \tag{3}$$

where the basal area of an individual was$\pi d^2/4$ ($\pi = 3.14$; d = DBH).

Five IVI classes were established: I < 1; II = 1–10; III ≥ 10–20; IV ≥ 20–30; V > 30.

Frequency (F) and density (D) were calculated as [26]

$$F = \frac{\text{no. of quadrats in which a species occurs}}{\text{total no. of quadrats examined}} \times 100. \tag{4}$$

Species were grouped into five frequency classes: A = 0–20%; B = 21–40%; C = 41–60%; D = 61–80%; E = 81–100%:

$$D = \frac{\text{total no. of individuals of a species found}}{\text{total area examined}}. \tag{5}$$

Species were classified into six density classes: $A \leq 1$; $B \geq 1$–10; $C \geq 10$–20; $D \geq 20$–35; $E \geq 35$–50; $F \geq 50$ individuals per hectare.

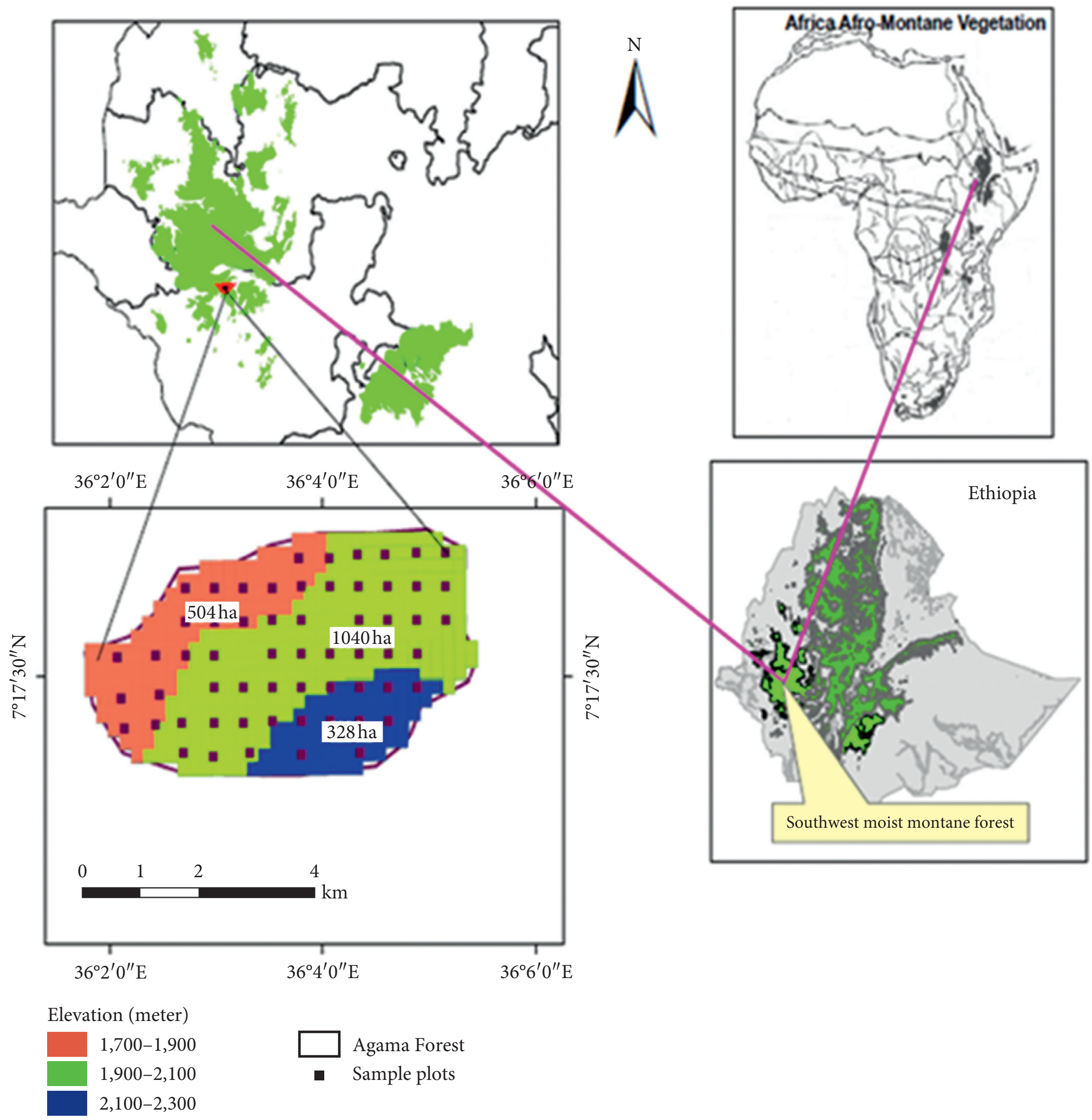

Figure 1: Map and sample plots of the study area.

The vertical stratification of trees in Agama Forest was examined following the IUFRO classification scheme [27] where three simplified vertical structures are distinguished: the upper (individuals > 2/3 top height), middle (individuals between 1/3 and 2/3 top height), and lower (individuals < 1/3 top height) storey.

To interpret the dynamics of woody species in the forest, the population structures of selected species were expressed as a frequency of individuals against established DBH classes. The emerging patterns of diameter class distribution were also used to interpret the recruitment processes of a given species. Species were divided into seven *H* and DBH classes. To use the regeneration analysis for priority setting, the species considered in the study area were classified into three groups based on the density of the total regeneration.

3. Results

3.1. Woody Species Diversity. Seventy-two woody plant species belonging to 35 families and 65 genera were recorded (Table 1). Of these, 43 species were trees, 18 were shrubs, and 12 were lianas. Rubiaceae was the most common family with 8 (11.0% contribution) species in 8 (12.3%) genera. Acanthaceae and Euphorbiaceae were the second most common, each with 5 (6.9%) species in 5 (7.7%) genera. The Rutaceae had 4 species in 4 genera and the Fabaceae 4 species in 3 genera. The Araliaceae, Celastraceae, Dracenaceae, Oleaceae, and Rosaceae contributed 3 species each and the remaining 25 families <3 species each. The Shannon–Wiener diversity index and Shannon's evenness values were 3.25 and 0.78, respectively.

Table 1: List of woody species in Agama moist Afromontane forest.

No.	Species name	Family	*Local name	Habit
1	*Acanthopale ethio-germanica* Ensermu	Acanthaceae	Huxxo	Shrub
2	*Acanthus eminens* C.B.Clarke	Acanthaceae	Pheecco	Shrub
3	*Alangium chinense* (Lour.) Harms	Alangiaceae	Shotto	Tree
4	*Albizia gummifera* (J.F.Gmel.) C.A. Sm.	Fabaceae	Caatto	Tree
5	*Albizia Schimperiana* Oliv.	Fabaceae	Caatto	Tree
6	*Allophylus abyssinicus* (Hochst.) Radlk.	Sapindaceae	Sheeo	Tree
7	*Apodytes dimidiata* E. Mey. ex Arn.	Icacinaceae	Wundifo	Tree
8	*Bersama abyssinica* Fresen.	Melianthaceae	Booqqoo	Tree
9	*Brillantaisia madagascariensis* T. Anders. ex Lindau	Acanthaceae	Huxxo	Shrub
10	*Buddleja polystachya* Fresen.	Loganiaceae	Ataaro	Tree
11	*Canthium oligocarpum* Hiern	Rubiaceae	Xixiribbo	Tree
12	*Cassipourea malosana* (Baker) Alston	Rhizophoraceae	Woraalo	Tree
13	*Celtis africana* Burm.f.	Ulmaceae	Uffo	Tree
14	*Clausena anisata* (Willd.) Benth.	Rutaceae	Immico	Shrub
15	*Clematis longicauda* Steud. ex A. Rich	Ranunculaceae	Shaggee qombo	Liana
16	*Clematis simensis* Fresen.	Ranunculaceae	Phi'o Qombo	Liana
17	*Coffea arabica* L.	Rubiaceae	Bunoo	Tree
18	*Combretum paniculatum* Vent.	Combretaceae	Baggo	Liana
19	*Cordia africana* Lam.	Boraginaceae	Di'o	Tree
20	*Croton macrostachyus* Del.	Euphorbiaceae	Waagoo	Tree
21	*Cyathea manniana* Hook.	Cyatheaceae	Sheshino	Tree
22	*Dalbergia lactea* Vatke	Fabaceae	Gimiro	Liana
23	*Dombeya torrida* (J.F.Gmel.) P. Bamps	Sterculiaceae	Shawakko	Tree
24	*Dracaena afromontana* Mildbr.	Dracaenaceae	Coqimato	Tree
25	*Dracaena fragrans* (L.) Ker Gawl.	Dracaenaceae	Emoo	Shrub
26	*Dracaena steudneri* Engler	Dracaenaceae	Yuddo	Tree
27	*Ehretia cymosa* Thonn.	Boraginaceae	Wagaamo	Tree
28	*Ekebergia capensis* Sparrm	Meliaceae	Ororo	Tree
29	*Elaeodendron buchananii* (Loes.) Loes.	Celastraceae	Washo	Tree
30	*Erythrococca trichogyne* (Muell Arg.) Prain	Euphorbiaceae	Biccre kucco	Shrub
31	*Euphorbia ampliphylla* Pax	Euphorbiaceae	Gachoo	Tree
32	*Fagaropsis angolensis* (Engl.) Dale	Rutaceae	Yaayyo	Tree
33	*Ficus sur* Forssk.	Moraceae	Caaro	Tree
34	*Flacourtia indica* (Burm.f.) Merrill	Flacourtiaceae	Anam shiko	Tree
35	*Galiniera saxifraga* (Hochst.) Bridson	Rubiaceae	Diidoo	Tree
36	*Hippocratea pallens* Planch. ex Oliv.	Celastraceae	Qawe qombo	Liana
37	*Ilex mitis* (L.) Radlk.	Aquifoliaceae	Qetoo	Tree
38	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	Hawute qombo	Liana
39	*Justicia schimperiana* (Hochst. ex Nees)T. Anders	Acanthaceae	Sharsharo	Shrub
40	*Landolphia buchananii* (Hall.f.) Stapf.	Apocynaceae	Yame qombo	Liana
41	*Lepidotrichilia volkensii* (Gurke) Leroy	Meliaceae	Shahiyo	Tree
42	*Macaranga capensis* (Baill.) Sim	Euphorbiaceae	Shakkaro	Tree
43	*Maesa lanceolata* Forssk.	Myrsinaceae	Caggo	Shrub
44	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	Celastraceae	Shikko	Shrub
45	*Millettia ferruginea* (Hochst.) Baker	Fabaceae	Bibero	Tree
46	*Ocotea kenyensis* (Chiov.) Robyns & Wilczek	Lauraceae	Najjo	Tree
47	*Olea capensis* L.	Oleaceae	Shigiyo	Tree
48	*Olea welwitschii* (Knobl.) Gilg & Schellenb.	Oleaceae	Yaahoo	Tree
49	*Oxyanthus speciosus* DC.	Rubiaceae	Opharo	Shrub
50	*Pavetta abyssinica* Fresen.	Rubiaceae	—	Shrub
51	*Phoenix reclinata* Jacq.	Araliaceae	Yabbo	Tree
52	*Pittosporum viridiflorum* Sims	Pittosporaceae	Sholloo	Shrub
53	*Polyscias fulva* (Hiern) Harms	Araliaceae	Karasho	Tree
54	*Pouteria adolfi-friederici* (Engl.) Baehni	Sapotaceae	Qararo	Tree
55	*Premna schimperi* Engl.	Verbenaceae	Xumo	Shrub
56	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae	Omo	Tree
57	*Psychotria orophila* Petit	Rubiaceae	Aa'imaato	Shrub
58	*Rhamnus prinoides* L'Herit.	Rhamnaceae	Geeshoo	Shrub
59	*Rothmannia urcelliformis* (Hiern) Robyns	Rubiaceae	Dibo	Tree
60	*Rubus apetalus* Poir.	Rosaceae	Garoo	Liana

Table 1: Continued.

No.	Species name	Family	*Local name	Habit
61	*Rubus steudneri* Schweinf.	Rosaceae	Garoo	Liana
62	*Rytigynia neglecta* (Hirn) Robyns	Rubiaceae	Naxaacho	Shrub
63	*Sapium ellipticum* (Krauss) Pax	Euphorbiaceae	Shaddo	Tree
64	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	Buto	Tree
65	*Sericostachys Scandens* Gilg &Lopr.	Amaranthaceae	Shuddii	Liana
66	*Syzygium guineense* (Willd.) DC.	Myrtaceae	Yinoo	Tree
67	*Teclea nobilis* Del.	Rutaceae	Shangaro	Tree
68	*Tiliacora troupinii* Cuf.	Menispermaceae	Caamee qombo	Liana
69	*Trema orientalis* (L.) Bl.	Ulmaceae	Ufo	Tree
70	*Vepris dainellii* (Pic. Serm.) Kokwaro	Rutaceae	Mangirexxo	Tree
71	*Vernonia amygdalina* Del.	Asteraceae	Giraawwoo	Tree
72	*Vernonia auriculifera* Hiern	Asteraceae	Dangaretto	Shrub

*Local name = Kafinono

3.2. Density of Woody Species. The density, D, of trees and shrubs with $H > 2$ m and DBH > 2.5 cm was 1446 individuals per hectare. Twelve species were in density class A and 20, 10, 10, 3, and 7 species in classes B, C, D, E, and F, respectively. The seven most abundant species in the density class F ($D > 50\,\text{ha}^{-1}$) were *Coffea arabica*, *Elaeodendron buchananii*, *Millettia ferruginea*, *Olea capensis*, *Oxyanthus speciosus*, *Syzygium guineense*, and *Vepris dainellii*.

The D of trees and shrubs with DBH 10–20 cm and DBH > 20 cm were, respectively, 556 and 281 individuals per hectare. Accordingly, the ratio of individuals with DBH 10–20 cm (a) to DBH > 20 cm (b) was 2.0.

Comparison of trees and shrub densities with DBH 10–20 cm (a), DBH > 20 cm (b), and the ratio (a/b) for Agama Forest with 5 other forests in Ethiopia is given in Table 2.

Table 2: Comparisons of tree and shrub densities with DBH 10–20 cm (a) and tree density with DBH > 20 cm (b) from Agama Forest with 5 other moist Afromontane forests in Ethiopia.

Forests	Density (a)	Density (b)	Ratio a/b	Sources
Belete	305.1	149.0	2.04	[28]
Gelesha	315.4	244.6	1.29	[29]
Komto	330.0	215.0	1.53	[30]
Masha	633.0	286.0	2.21	[31]
Menna Angetu	292.0	139.0	2.10	[32]
Agama	556.3	280.9	1.98	Present study

3.3. Frequency. Twenty-seven, 17, 8, 4, and 6 species were recorded in frequency classes A, B, C, D, and E, respectively. The six most frequently occurring species in class E were *Elaeodendron buchananii*, *Olea capensis*, *Olea welwitschii*, *Oxyanthus speciosus*, *Syzygium guineense*, and *Vepris dainellii*.

3.4. Basal Area. The total basal area was 80.8 m^2/ha. The highest (33.3%) and the lowest (0.001%) BA ha^{-1} were contributed by *Olea welwitschii and Pavetta abyssinica*, respectively. *Elaeodendron buchananii*, *Olea welwitschii*, *Sapium ellipticum*, *Schefflera abyssinica*, and *Syzygium guineense* covered 71.4% of the total basal area.

3.5. Important Value Index (IVI). Ten species contributed 59.9% of the IVI. These were in decreasing order: *Olea welwitschii*, *Elaeodendron buchananii*, *Olea capensis*, *Syzygium guineense*, *Schefflera abyssinica*, *Vepris dainellii*, *Oxyanthus speciosus*, *Millettia ferruginea*, *Sapium ellipticum*, and *Coffea arabica*. About 39% of the IVI was contributed by the remaining 52 species. Percentage values in the five IVI classes, I to V, were 2.5%, 43%, 18.9%, 21.9%, and 13.7%, respectively. Most species were in classes I and II.

3.6. Vertical Stratification. The tallest tree was an individual of *Olea welwitschii* with $H = 46$ m. The lower storey contained the highest number of species, 60, and stem density, 1309/ha, and the upper the lowest, 7 and 17/ha, respectively; the middle storey was intermediate, 26 and 11/ha, respectively (Table 3).

The seven tree species that occupied the upper storey were *Apodytes dimidiata*, *Olea welwitschii*, *Pouteria adolfi-friederici*, Prunus africana, *Sapium ellipticum*, *Schefflera abyssinica*, and *Syzygium guineense*, and the 11 in the middle storey were *Albizia gummifera*, *Croton macrostachyus*, *Elaeodendron buchananii*, *Fagaropsis angolensis*, *Ficus sur*, *Ilex mitis*, *Macaranga capensis*, *Millettia ferruginea*, *Ocotea kenyensis*, *Phoenix reclinata*, and *Polyscias fulva*. The main species in the lower storey, shrubs and small trees, were *Allophylus abyssinica*, *Coffea arabica*, *Cyathea manniana*, *Clausena anisata*, *Dombeya torrida*, *Dracaena afromontana*, *Ehretia cymosa*, *Erythrococca trichogyne*, *Maesa lanceolata*, *Maytenus gracilipes*, *Olea capensis*, *Oxyanthus speciosus*, *Rothmannia urcelliformis*, *Rytigynia neglecta*, *Teclea nobilis*, and *Vepris dainellii*.

3.7. Height and DBH Class Distribution. The H and DBH class distributions of all individuals in the different size classes were an inverted J shape. Thus the majority of species had the greatest number of individuals with relatively low H and DBH with a gradual decrease in numbers of both with increasing H and DBH. About 63% of individuals were found in the first height class (2.5–5 m); only a few individuals, about 1%, attained heights > 30 m. DBH distribution showed that about 81% of individuals were in the DBH class <20 cm, and a very small proportion (1.2%) reached DBH > 110 cm.

Table 3: Density and number of woody species by storey in Agama Forest.

Storey	Height (m)	Density (no. of stems/ha)	Percentage	Species number
Lower	2–15	1309.3	87.88	60
Middle	15–30	163.74	10.99	26
Upper	>30	16.8	1.33	7

3.8. Population Structure of Agama Forest. There were four main patterns of population structure (Figures 2(a)–2(d)). The first was a bell-shaped distribution, in which the number of individuals in the middle diameter classes is highest, e.g., *Olea welwitschii* and *Syzygium guineense*. The second was a J-shaped distribution, in which the number of individuals increases with diameter class, e.g., *Schefflera abyssinica*, *Cyathea manniana*, and *Rytigynia neglecta*. The third was formed with species showing an inverted J shape, a pattern where the highest frequency is in the lower diameter classes and it decreases towards the higher diameter classes, e.g., *Elaeodendron Buchananii*, *Olea capensis*, *Vepris dainellii*, *Oxyanthus speciosus*, and *Teclea nobilis*. The fourth pattern had no individual in DBH class one, an abrupt increase from DBH class two to the middle classes, and an abrupt decrease from the middle to the higher classes, e.g., *Sapium ellipticum*, *Croton macrostachyus*, and *Poliscas fulva* (Figure 2(d)).

3.9. Regeneration Status of Agama Forest. Total density of seedling, sapling, and tree/shrubs was 3378 ha^{-1}, 1888 ha^{-1}, and 1486 ha^{-1}, respectively. Out of 54 trees and shrubs of DBH > 2.5 cm, 6 were not represented as seedlings and 11 not represented as saplings. Nine species, *Coffea arabica*, *Elaeodendron buchananii*, *Galiniera saxifraga*, *Maytenus gracilipes*, *Millettia ferruginea*, *Olea capensis*, *Oxyanthus speciosus*, *Phoenix reclinata*, and *Vepris dainellii*, contributed 54.3% and 55.2% of the total seedling and sapling count, respectively.

Regeneration status was represented by five distribution patterns (Figure 3): (I) seedling > sapling > tree/shrub, a pattern exhibited by *Albizia gummifera*, *Bersama abyssinica*, *Canthium oligocarpum*, *Coffea arabica*, and *Millettia ferruginea* (Figure 3(a)); (II) seedling > sapling < tree/shrub by *Elaeodendron buchananii*, *Oxyanthus speciosus*, *Erythrococca trichogyne*, and *Vepris dainellii* (Figure 3(b)); (III) seedling < sapling < tree/shrub by *Dracaena afromontana*, *Ficus sur*, *Ocotea kenyensis*, *Olea welwitschii*, and *Sapium ellipticum* (Figure 3(c)); (IV) no individual in either seedling or sapling stages but many trees/shrubs by *Buddleja polystachya*, *Euphorbia ampliphylla*, *Fagaropsis angolensis*, *Flacourtia indica*, *Premna schimperi*, *Rhamnus prinoides*, and *Trema orientalis* (Figures 3(d) and 3(e)); (V) with no individual in seedling and sapling stages but relatively many individuals in tree/shrub stage, e.g., *Alangium chinense*, *Cordia africana*, *Cyathea manniana*, *Ekebergia capensis*, and *Schefflera abyssinica* (Figure 3(f)).

Three priority classes based on the total density of seedlings and saplings were established for conservation: class 1 with no seedling or sapling, class 2 with density of seedlings and saplings >0 but <50 individuals ha^{-1}, and class 3 with density of seedlings and saplings >50 individuals ha^{-1} (Table 4).

4. Discussion

4.1. Floristic Diversity. Seventy-two (72) species of shrubs, lianas, or trees were recorded. Among the tree species, two, *Vepris dainellii* and *Millettia ferruginea*, are endemic to Ethiopia. The Shannon–Weiner diversity and evenness indexes were 3.25 and 0.78, respectively. Thus, the species mix at Agama is representative of a forest with high species diversity [10] and the species are well represented across the extent of the forest.

4.2. Vegetation Structure. The ratio of DBH > 10 cm to DBH > 20 cm (a/b ratio) was 2.0 and indicative of the predominance of small-sized individuals in the forest. This was largely due to the high density of *Olea capensis* and *Vepris dainellii*. This ratio can also be used as a measure of size class distribution [33] and shows that, in Ethiopia, Agama Forest is comparable to moist Afromontane forests at Belete, Masha, and Menna Angetu, but with a greater predominance of small-sized individuals than those at Gelesha and Komto. That the proportion of individuals of DBH between 2.5 and ≤10 cm was 42.1% suggests that Agama Forest is in a secondary stage of development.

Frequency provides an approximate indication of the homogeneity of a stand [10]. 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 [27]. In this study, high values were obtained in lower frequency classes, which showed the existence of high degree of floristic heterogeneity in Agama Forest.

Elaeodendron buchananii, *Olea welwitschii*, *Sapium ellipticum*, *Schefflera abyssinica*, and *Syzygium guineense* occupied >70% of the total basal area and can be considered the most important species in Agama Forest. A basal area provides a better measure of the relative importance of the species than simple stem count [34]. Thus, species with the largest contribution in a basal area can be considered the most important woody species in the study area.

Important Value Index (IVI) permits a 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 [10]. It is also important to compare the ecological significance of a given species. Therefore, it is a good index for summarizing vegetation characteristics and ranking species for management and conservation practices. Important Value Index combines data for three parameters

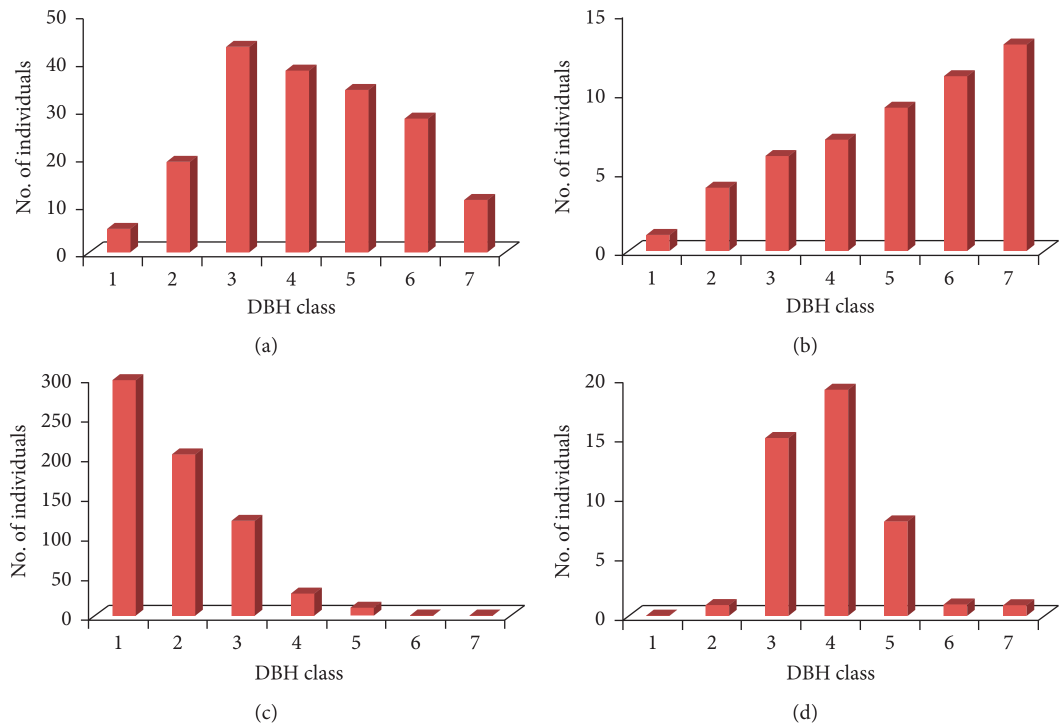

Figure 2: (a–d) Pattern of frequency distribution of selected tree species over DBH classes (DBH classes: 1 = 2.5–10 cm; 2 = 10.01–20 cm; 3 = 20.01–50 cm; 4 = 50.01–80 cm; 5 = 80.01–110 cm; 6 = 110.01–140 cm; 7 ≥ 140 cm). (a) *Olea welwitschii*. (b) *Schefflera abyssinica*. (c) *Elaeodendron Buchananii*. (d) *Sapium ellipticum*.

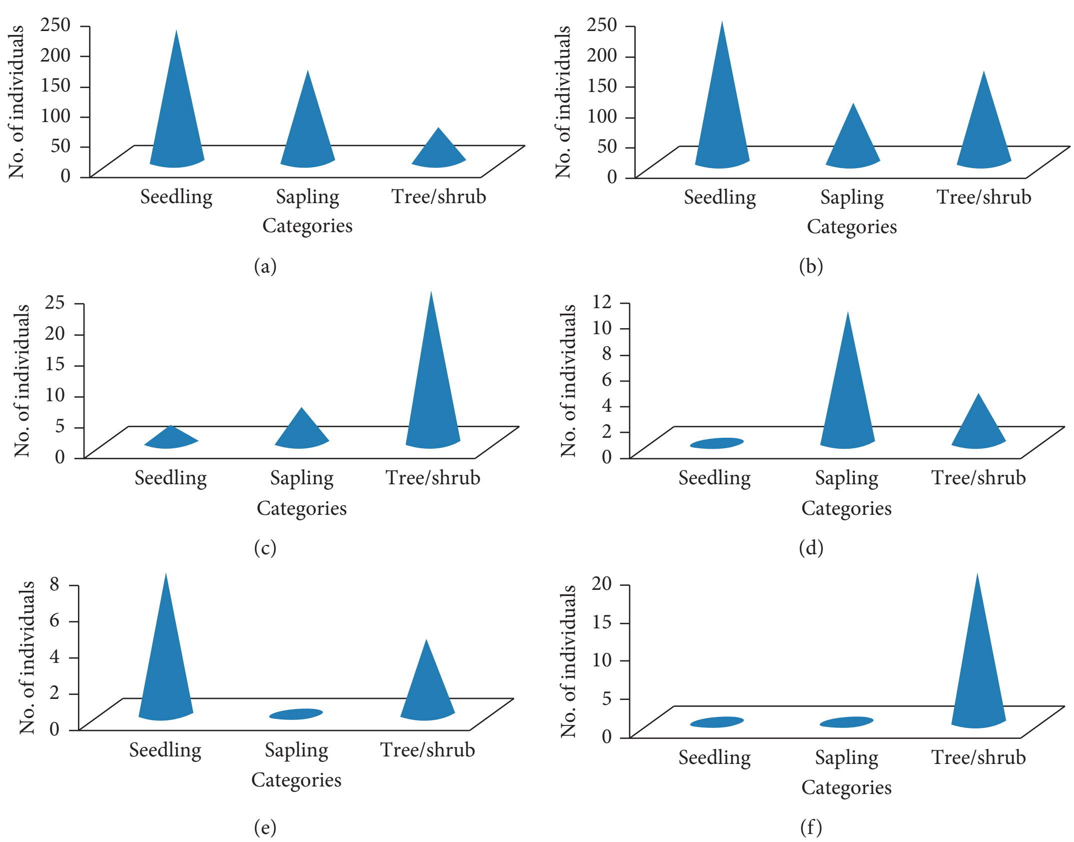

Figure 3: (a–f) Seedlings, saplings, and tree/shrub distribution of some selected species occurring in Agama Forest. (a) *Coffea arabica*. (b) *Vepris dainellii*. (c) *Ficus sur*. (d) *Flacourtia indica*. (e) *Buddleja polystachya*. (f) *Schefflera abyssinica*.

Table 4: Species conservation priority classes.

Priority class 1	Priority class 2	Priority class 3	
Alangium chinense	*Cassipourea malosana*	*Albizia gummifera*	*Maesa lanceolata*
Buddleja polystachya	*Celtis africana*	*Allophylus abyssinica*	*Maytenus gracilipes*
Cordia africana	*Dombeya torrida*	*Apodytes dimidiata*	*Millettia ferruginea*
Cyathea manniana	*Ehretia cymosa*	*Bersama abyssinica*	*Olea capensis*
Ekebergia capensis	*Erythrococca trichogyne*	*Canthium oligocarpum*	*Oxyanthus speciosus*
Euphorbia ampliphylla	*Ficus sur*	*Clausena anisata*	*Phoenix reclinata*
Fagaropsis angolensis	*Ocotea kenyensis*	*Coffea arabica*	*Psychotria orophila*
Flacourtia indica	*Olea welwitschii*	*Croton macrostachyus*	*Rothmannia urcelliformis*
Premna schimperi	*Pittosporum viridiflorum*	*Dracaena steudneri*	*Rytigynia neglecta*
Rhamnus prinoides	*Polyscias fulva*	*Dracaena afromontana*	*Syzygium guineense*
Schefflera abyssinica	*Pouteria adolfi-friederici*	*Elaeodendron buchananii*	*Teclea nobilis*
Trema orientalis	*Prunus africana*	*Galiniera saxifraga*	*Vepris dainellii*
	Sapium ellipticum	*Ilex mitis*	
	Vernonia amygdalina	*Lepidotrichilia volkensii*	
	Vernonia auriculifera	*Macaranga capensis*	

(relative frequency, relative density, and relative abundance) [35]. We pointed out that Important 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 [27]. In the present study, 59.92% of the IVI was contributed by *Olea welwitschii*, *Elaeodendron buchananii*, *Olea capensis*, *Syzygium guineense*, *Schefflera abyssinica*, *Vepris dainellii*, *Oxyanthus speciosus*, *Millettia ferruginea*, *Sapium ellipticum*, and *Coffea arabica*. These species were abundant, frequent, and dominant in Agama Forest.

In Agama Forest, distribution of all individuals in different height and DBH classes indicated an inverted J-shaped curve, which shows a normal population structure with a high number of individuals in the lower size classes and only a few individuals in the higher size classes. This pattern is an indicator of healthy regeneration of the forest and species and shows a good reproduction and recruitment capacity. Even though the overall height and DBH distribution revealed inverse J shape, different population dynamics for different species were in this study.

Information on the population structure of a tree species indicates the history of the past disturbance to that species and the environment and, hence, is used to forecast the future trend of the population of that particular species [13]. Population structure is an extremely useful tool for orienting management activities and perhaps most important for assessing both the potential of a given resource and the impacts of resource extraction [13]. In this study, four patterns population distributions based on DBH were revealed for selected woody species. These are J-shaped, bell-shaped, inverted J-shaped, and irregular shaped. The J-shaped patterns show poor reproduction and hampered regeneration due to the fact that either most trees are not producing seeds due to age or there are losses due to predators after reproduction (e.g., *Schefflera abyssinica*). A bell shape follows a Gauss distribution pattern. This pattern indicates a poor reproduction and recruitment of species, which may be associated with the overharvesting of seed bearing individuals (e.g., *Olea welwitschii*). Bell-shaped or variable size class distribution has been attributed to a disturbed forest where regeneration is hampered [36]. An inverted J-shaped distribution pattern of species is considered as an indication of stable population status or good regeneration status [37]. An irregular shaped pattern characterized by no individual in DBH class one, with an abrupt increase from DBH class two to the middle classes and with an abrupt decrease from the middle to the higher classes (e.g., *Sapium ellipticum*), might reflect limited regeneration, possibly due to human disturbance, livestock trampling or browsing, and other biotic and abiotic factors.

4.3. Regeneration Status. Regeneration refers to the process of silvigenesis by which trees and forests survive over time [38]. The population structure along different developmental stage of a species in a forest can express its regeneration behavior [39]. The population structure, described by the existence of sufficient population of seedlings, saplings, and adults, shows successful regeneration of forest species [39].

In this study, five distribution patterns of regeneration status were observed from the 54 woody species investigated for regeneration. (1) Seedling > sapling > tree/shrub state (e.g., *Millettia ferruginea*): this pattern indicates good regeneration. (2) Seedling > sapling < tree/shrub state (e.g., *Elaeodendron buchananii*): this pattern represents fair regeneration and recruitment of the species. (3) Seedling < sapling < tree/shrub state (e.g., *Ficus sur*): this pattern shows poor reproduction and hampered regeneration either due to the fact that most trees are not producing seeds as a result of their old age or there has been a loss of seeds by predators after reproduction. For instance, the fruits of *Ficus sur* were usually eaten as food by many animals including humans, which might be a reason for this pattern. (4) With no individual either in seedling or sapling stages but relatively many individuals in tree/shrub stage (e.g., *Fagaropsis angolensis* and *Flacourtia indica*): this pattern also shows poor reproduction and hampered regeneration. (5) With no individual in seedling and sapling stages but relatively many individuals in tree/shrub stage (e.g., *Ekebergia capensis* and *Schefflera abyssinica*): species exhibiting this pattern were not regenerating. Even though *Schefflera abyssinica* exhibits this pattern of regeneration, it is difficult to conclude the species was not regenerating. The main reason is that it grows as an epiphyte mainly on other tree species and finally overtakes it to become an independent tree; as a result, the seedling and sapling stages are not visible on the ground [40].

From the three classes established for priority setting based on their regeneration status for the sake of conservation activities, those species under class 1 and class 2 are recommended to be given the highest priority. Thus, all stakeholders at both national and regional level should participate in the conservation endeavor of these species which can encompass both in situ and ex situ conservation.

5. Conclusion

Description of floristic diversity of woody species in Agama Forest revealed the presence of high species diversity. Of the species recorded in this forest, two tree species, *Vepris dainellii* and *Millettia ferruginea*, are endemic to Ethiopia. Structural analysis and assessment of regeneration status of woody species in this 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 which in turn necessitates conservation and management of these species. The in situ conservation strategy, which has been implemented by FARM Africa, an NGO that has been engaged in conservation endeavor of the study forest, in the form of participatory forest management (PFM), should be strengthened via collaboration of all potential stakeholders to reverse the unhealthy population structure and regeneration status of woody species.

Data Availability

Part of the data used in this research are included and attached as Additional Files 1, 2, and 3. Thus, the data used for this manuscript are available.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Additional File 1: data were used to calculate density, frequency, basal area, and relative density, relative frequency, and relative basal area. Additional File 2: data were used to calculate Importance Value Index (IVI). Additional file 3: data were used to determine regeneration status and priority class for conservation. (*Supplementary Materials*)

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