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Research Article

Investigation of Woody Species Structure and Regeneration Status in the Central Rift Valley, Sidama Regional State, Ethiopia

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Protected areas are the most commonly used tool for in situ conservation of biodiversity. Selective removal of species proposed by the local communities living surrounding the national park and grazing pressure negatively affect the composition, structure, and regeneration of woody species. Assessment of vegetation structure and regeneration status of woody species is essential for orienting management activities. The purpose of this study was to investigate the floristic composition, population structure, and regeneration status of woody species in the Loka Abaya National Park, to design conservation strategies. A total of 99, 20 m × 20 m quadrats were systematically laid along an established line transect to collect a list of woody species, abundance, height, and diameter at breast height (DBH), while five 3 m × 3 m subquadrats within the main quadrats were established to assess the regeneration status of woody species. In each quadrat, all woody species were identified, counted, and recorded. In each quadrat, all tree and shrub species higher than ≥2 m in height and ≥2 cm in diameter at breast height were measured by a calibrated wooden stick and by a caliper, respectively. Density, frequency, basal area, importance value index (IVI), height, and diameter at breast height (DBH) were used for description of vegetation structure, while the density of mature trees, saplings, and seedlings was used for assessment of regeneration status of woody species. A total of 101 woody plant species representing 40 families in 69 genera were collected, identified, and documented. Fabaceae was the most diverse family representing 16 (15.84%) species, followed by Euphorbiaceae 9 species (8.91%) and Anacardiaceae with 6 species (5.94%). Four families including Combretaceae, Moraceae, Olacaceae, and Tiliaceae were represented by 4 species each. 4 families were also represented by 3 species each, 12 families were represented by two species each, and 18 families were represented by one species. The density of trees was 831.31 individuals ha^{-1}, while the total basal area was 73.18 $m^2 \cdot ha^{-1}$. *D. angustifolia*, *C. molle*, *E. schimperi*, *R. natalensis*, *O. europaea L. subsp. cuspidata D. cinerea, A. brevispica*, *I. mitis,* and *E. tirucalli* were ecologically important woody species. The majority (75%) of woody plant species had a less than 5% importance value index (IVI). The diameter class distribution of selected tree species demonstrated various patterns of population structure, implying the existence of different population dynamics among ecologically important tree species. The regeneration assessment results demonstrate that 32.35% had poor regeneration, 19.12% had good regeneration, 16.17% had fair regeneration, 8.82% lacked regeneration, and 14.08% appeared as newly regenerated species in the national park. The majority of woody species had a small population size, and some of them were found in specific habitats which need attention for conservation, and those woody species lack regeneration study soil seed bank and propagation methods for sustainable conservation.

1. Introduction

Ethiopia has a wide range of altitudes, varying between 125 m below sea level at Danakil depression (Afar) and 4533 m.a.s.l at Ras Dashen (Gondar) that have resulted in a wider range of climatic conditions and a multitude of agroecological zones. This varied ecological setting has enhanced the evolution of various life forms including about 6027 species of vascular plants out of which about 10% are believed to be endemic [1]. The total number of woody plants is estimated to be about 1000, about 300 of which are estimated to be trees [2, 3]. According to Kent and Coker [4], vegetations are a crucial part of the earth and an integral part of an ecosystem that provides essential services to human society. The high floristic and ecological diversity of Ethiopian vegetation is a source of wild and domesticated plants. It is also a source for at least 197 species of crops including grains, pulses, vegetables, tubers, fruits, spices, stimulants, fibers, dye, and medicine [5].

Records on conservation efforts in Ethiopia dated to the days of Emperor Zera Yakob (1434–1468) who brought juniper seedlings from Wof washa of North Shewa and planted them in the Managesha Suba area [6]. Modern conservation was started by Emperor Menelik II in 1895 by introducing exotic species mainly Australia Eucalyptus in 1895 to solve the shortage of fuel wood and construction materials and for conservation of indigenous tree species. This conservation initiative eventually evolved into the formulation of protected areas in the 1960s [6]. Today, the country has established several protected areas which include 21 national parks and 58 national forest priority areas [7]. These areas are critical habitats for the most endangered wildlife forests and biodiversity in the country and the foundation for national conservation strategies. Millennium Ecosystem Assessment [8] reports indicated that significant amounts of forests have come under protected status over the past several decades.

The vegetation of Ethiopia has been modified by anthropogenic activities for long periods. This strong and prolonged human interference is believed to have degraded a range of vegetation types to a badly eroded landscape with very little differentiation of the vegetation left [9]. In Ethiopia, environmental degradation and deforestation have been taking place for hundreds of years; trees have been used and still are cleared for agriculture and fuel wood [10]. The forest cover of Ethiopia was about 16% of the land area in the early 1950s and rapidly declined to 3.6% in the early 1980s and 2.7% in 1989 [11]. According to the FAO, 2007, [12] reported deforestation in Ethiopia as 1410000 ha per year, that is, 0.93% between 1900 and 2000 which had an increase to 1.04% between 2000 and 2005. A study on forest cover change and socioeconomic drivers of southwest Ethiopia estimated a forest decline of 2.1% per year in four districts between 1973 and 2005 [13], and Getaneh [14] reported deforestation rate of 1.35% per year for the Yayu forest in southeast Ethiopia. This is higher than the deforestation rate of tropical forests in Asia, at a range of 0.4–0.9% per year. Thus, in our world, extensive biodiversity loss, including loss of genetic, species, and habitat diversity, has been one result of the shrinking of the world's forests [15].

In Ethiopia, the increasing population and demand for more agricultural land and forest products resulted in the destruction of natural vegetation. In addition, Ethiopia also ranks first in Africa with a livestock population that exerts heavy grazing pressure and degradation of natural vegetation. This horizontal expansion of cultivated land at the expense of forest and other natural vegetation is as old as crop culture [16]. According to the IBC report [7], most of the national parks in Ethiopia are found in the *Acacia–Commiphora* woodland ecosystem, which is currently under strong environmental stress, such as extraction of fuel wood and charcoal, and major towns in the country have increased the rate of deforestation and natural resource depletion. The settlement, charcoal production, and grazing are common in all Ethiopian national parks. The destruction of vegetation in protected areas, national forest priority areas, and elsewhere has continued alarmingly. Even though no concrete evidence is available, species unknown to science and/or those species restricted to areas where anthropogenic impacts are hostile may have gone extinct [2].

Loka Abaya is one of the national parks of Ethiopia found in the Loka Abaya district, Sidama Regional State, in the central rift valley of Ethiopia. The park was formally established in 2009, in an area of 500 km^2. Before delineation as a park, the land served as a community-free grazing area. The park accommodates a mosaic forest, woodland, bushland, riverine vegetation, and Lake Abaya-associated wetland vegetation. Additionally, the park shares some portion of the water body from Lake Abaya. Twenty-seven large mammal species were found, including the IUCN Red listed African wild dog which is endangered [17]. Seasonal settlement within the national park, grazing, selective removal of species for firewood, charcoal production, and construction are currently the prevailing problems of the national park. The selective removal of species may have different effects on the establishment of seedlings and saplings [18]. It could create favorable conditions for the regeneration of some species and disfavor others by reducing the abundance of mother trees. Selective removal of such important species leads to higher dominance of low-quality species [3]. Knowing the abundance, relative density, frequency, and even regeneration of woody species would provide the essential foundations for the formulation of strategies for in situ and ex situ conservation of the species [19]. Tesfaye et al. [20] added natural regeneration is important to identify plant species for conservation priority. The national park has a recent establishment history, so its floristic composition, vegetation structure, and regeneration status of woody species were not investigated. For effective management and conservation of this area, there is a need to develop management plans, and this, in turn, requires detailed information on the floristic composition, vegetation structure, and regeneration status of woody species. Therefore, this study aimed to assess the floristic composition, population structure, and regeneration status of woody species in the vegetation of Loka Abaya National Park.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Loka Abaya National Park which is one of the national parks found in the Sidama Regional State of Ethiopia (Figure 1). It is located about 345 km away from Addis Ababa and 72 km from the regional capital, Hawassa, and is managed by the regional government. The altitude ranges from 1178 m.a.s.l Shall–Oda at the bottom of Lake Abaya to 1650 m.a.s.l. at Gedano hill.

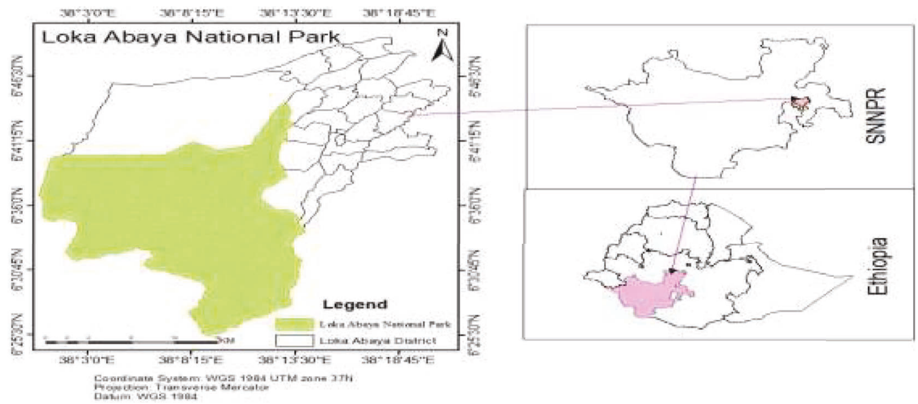

Figure 1: Map of the study area.

2.1.1. Vegetation and Wild Life. The vegetation of the study area is dominantly woodland, wooded grassland, forestland, and vegetation along the seasonal and permanent riversides, Lake Abaya, and associated wetland vegetation. The local community practices traditional home garden agroforestry. The dominant plant species in the traditional agroforestry practice are *E. ventricosum*, *Z. mays*, *C. arabica*, *C. edulis*, *S. officinarum*, *P. vulgaris*, *S. bicolor*, and *C. cajan* which are some of the cultivated crops in the system mainly for home consumption. *C. macrostachyus*, *C. africana*, *A. schimperiana*, and *B. aegyptiaca* are the dominant woody species in the surrounding land use system. Additionally, the national park shares some portion of the water body from Lake Abaya. The national park also harbors a significant variety of large and medium-sized mammals in different habitats. According to the survey report [17]), the conspicuous and observed mammals in the park include savanna, baboon (*Papio cynocephalus*), buhshbuck (Tragelaphus scriptus), lion (*Panthera leo*), and common duiker (*Sylvicapra grimmia*). The park also contains different bird species such as Helimmeted gunieafowl (*Numida meleagris*), bee-eater (*Merops nubicus*), long-crested eagle (*Lophaetus occipitalis*), and white-headed vulture (*Aegypius occipitalis*) which are some of commonly found bird species.

2.1.2. Climate. The meteorological data collected from Billate Meteorological Station, which is found at an altitude of 1361 m.a.s.l and a distance of 2 km away from Loka Abaya National Park, indicate that the area receives bimodal rainfall; the first peak starts from mid-March to the end of April and the second peak from July to mid-October. The mean annual rainfall of the range of the study area is 857.86 mm, with a mean monthly maximum rainfall of 125.38 mm in April and a mean monthly minimum rainfall of 13.36 mm recorded in December (National Meteorological Service Agency Hawassa Branch). The mean annual minimum temperature of the area is 14.1°C in November, while the mean annual maximum temperature recorded in February is 33.8°C (Figure 2).

2.1.3. Geology and Soil. The geology of the Sidama regional state is one of the parts of the basement complex and the younger formations that were deposited in the basement which contains the oldest rock in the country [21]. The Precambrian rocks with ages of over 600 million years form the foundation of all rocks. It is exposed in areas where the younger cover rocks have been eroded. The physical and chemical compositions of soils are very important in determining the occurrence, growth, diversity, and distribution of plant species [16]. The soil type of the study area is dominantly Eutric Fluvisols [21]. This soil is derived from materials transported from the draining area of the river, including topsoil from high land.

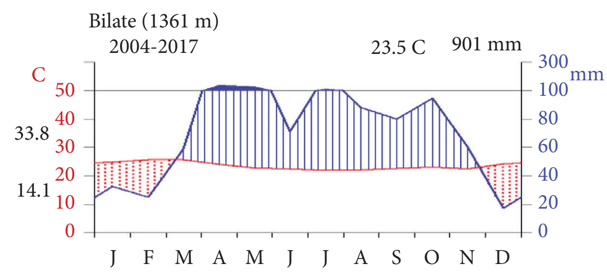

Figure 2: Climate diagram of the study area showing monthly rainfall distribution and temperature variation from 2004 to 2017 at Billate station at an altitude of 1361 m.a.i.s.l. Data source: Ethiopian National Meteorological Service Agency, Hawassa branch.

2.2. Reconnaissance Survey and Delineation of the Study Site. Before starting the sample collection, a reconnaissance survey was carried out to identify the study site. The reconnaissance survey was made across the Loka Abaya National Park in the 3rd and 4th weeks of February 2017 to obtain an impression of the conditions of the vegetation, collect information on accessibility, identify sampling sites, and calculate the sample size. Then, the transect directions of the vegetation data collection were determined.

2.3. Sampling Design. The systematic sampling design was used to locate the sample quadrats to assess woody species composition in the Loka Abaya National Park following the [22] method. Quadrats were laid systematically at every 200 m along transect lines and 800 m apart between the consecutive transect lines. To eliminate any influence of the road effects on the species of the use of vegetation national park, all quadrats were laid at least 50 m away from the nearest roads.

2.4. Sampling Techniques. Sampling quadrats of 20 m × 20 m were established systematically at every 200 m interval along the transect lines which are 800 m apart. The systematic sampling method was used to take vegetation samples. Vegetation composition and related data were collected from the Loka Abaya National Park by using transect lines laid parallel to each other. Accordingly, a total of 99 quadrats in the 17 transect lines were used for vegetation data collection.

2.5. Methods of Data Collection

2.5.1. Structural Data Collection. In all plots, all mature trees ≥2 m in height and ≥2 cm diameter at breast height were recorded, and diameter at breast height (DBH) was measured at a height of 1.3 m using a diameter caliper, and the height of individual trees was measured by a 6 meter calibrated wooden stick and above it was visually estimated. In cases where a tree or shrub bole branched at breast height or below, the diameters were measured separately for the branches, and each diameter was squared and put under square root; the square root of the sum of all squared stems averaged as one DBH [23]:

$$\mathrm{DBH} = \left[(b1)^2 + (b2)^2 + (b3)^2 + (b4)^2 \right]^{1/2}, \quad (1)$$

where $b1$ represents the branch one and $b2$ represents the branch two. Maximums of up to four branches were measured. Finally, woody species near a 10-meter radius but absent in the sample quadrats were noted for floristic completion.

2.5.2. Natural Regeneration Status Data Collection. Regeneration of woody plants was assessed with five 3 m × 3 m subplots at four corners and one at the center of main plots (totally 45 m^2) was used to count saplings (individuals height > 0.5 m and dbh < 2 cm) and seedlings (with two normal leaves above the cotyledons and with height less than 0.5 m). The regeneration status of the species was based on the population size of seedlings and saplings [25]. Good regeneration, if seedlings > saplings > adults; fair regeneration, if seedlings > or ≤ saplings ≤ adults; poor regeneration, if the species survives only in the sapling stage, but not seedlings (saplings may be or = adults). If a species is present only in an adult form, it is considered as not regenerating.

2.6. Plant Identification. Finally, plant specimens were collected during the interview and brought to the National Herbarium (ETH) of Addis Ababa University for identification. The specimens were properly dried and identified based on the published volumes of flora of Ethiopia and Eritrea [26–32]. The specimens identified were compared with the properly identified specimens. Botanical names and authorities were verified using the species and family lists in Volume 8 of the Flora of Ethiopia and Eritrea [26]. All plant specimens were properly labeled and deposited at the National Herbarium (ETH) of Addis Ababa University.

2.7. Data Analysis

2.7.1. Structural Analysis. The diameter at breast height (DBH), basal area, tree density, height, frequency, and important value index were used for the description of vegetation structure [22] as follows:

Frequency (%): this term refers to the degree of dispersion of individual species in an area and is usually expressed in terms of percentage occurrence. It is calculated by the following equation.

$$\text{Percent frequency of a species} = \frac{\text{the number of plots in which that species occurred}}{\text{Total number of plots}}. \quad (2)$$

Relative frequency (RF): the degree of dispersion of individual species in an area in relation to the number of all species that occurred.

$$\text{Relative frequency} = \frac{\text{Frequency of a species in the sample}}{\text{Total frequency of all species in the sample}}. \quad (3)$$

Density: it is an expression of the numerical strength of a species where the total number of individuals of each species in all quadrats is divided by the total number of quadrats studied. Density is calculated by the following equation.

$$\text{Density of a species} = \frac{\text{the number of individuals of that species}}{\text{area sampled}} \times 100. \quad (4)$$

Relative density: it is the study of the numerical strength of a species in relation to the total number of individuals of all species and can be calculated as

$$\text{Relative density} = \frac{\text{density of a species}}{\text{total density of all species}} \times 100. \quad (5)$$

The density of individuals with DBH 10–20 cm and DBH > 20 cm was computed, and the ratio of these two was taken as a measure of the proportion of small and large-sized individuals following [33].

Basal area ($\mathrm{m}^2 \cdot \mathrm{ha}^{-1}$): it is measured as the cross-section area of a tree at breast height, computed from the measurement of DBH as follows.

$$\text{Basal area}\left(\mathrm{m}^2\right) = \left(\frac{\pi d^2}{4}\right), \quad (6)$$

where d represents the diameter at breast height (m), and $\pi = 3.14$. However, since DBH was measured in centimeters, the formula was modified in such a way that the basal area was in square meters. Thus, $\mathrm{Ba} = \pi d2/40{,}000$ or $0.0000785d2$, where d is the DBH in centimeters. The mean basal area of all investigated plots was converted to the mean basal area per hectare. The basal area provides a better measure of the relative importance of tree species than simple stem counts [34].

$$\text{Dominancy} = \frac{\text{total basal area}}{\text{area sampled}}. \tag{7}$$

Relative dominance: relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

$$\begin{aligned} \text{Relative dominance} &= \frac{\text{total basal area}}{\text{total area sampled}} \times 100, \\ \text{Importance value index (IVI)} &= \text{relative frequency} \\ &\quad + \text{relative density} \\ &\quad + \text{relative dominance}. \end{aligned} \tag{8}$$

2.7.2. Population Structure of Woody Species. Analyses of the population structure of woody species in the study area were performed by categorizing trees and shrubs into nine height and twelve DBH classes following [35, 36]. Diameter at breast height (DBH) was classified into twelve classes: C_1 = <2 cm, C_2 = 2 cm–5 cm, C_3 = 5.1 cm–8 cm, C_4 = 8.1 cm–11 cm, C_5 = 11.1 cm–14 cm, C_6 = 14.1 cm–17 cm, C_7 = 17.1 cm–20 cm, C_8 = 20.1 cm–23 cm C_9 = 23.1 cm–26 cm C_{10} 26.1–29 cm, C_{11} 29.1 cm–32 cm, and C_{12} = >32 cm. Height was classified into nine classes: C_1 = <2 m, C_2 = 2 m–5 m, C_3 = 5.1 m–8 m, C_4 = 8.1 m–11 m, C_5 = 11.1–14 m, C_6 = 14.1 m–17 m, C_7 = 17.1 m–20 m, C_8 = 20.1 m–23 m, and C_9>23 m. Histograms were constructed by using the density of individuals of each species (Y-axis) and categorized by diameter and height class (X-axis); then, based on the profile depicted in the population structures, the regeneration status of each woody species was determined. The patterns of species population structure were established based on the relative density of species in different DBH classes and interpreted as an indication of variation in population dynamics following [33, 37].

2.7.3. Regeneration Status Analysis. Regeneration status was estimated based on the composition and density of seedlings and saplings of all woody species recorded in each plot [25]. The density of seedlings and saplings was calculated per hectare. The regeneration status of the forest was examined by computing and comparing the present tree populations (large trees) with the regenerating populations (seedlings and saplings) of tree species according to [38, 39].

3. Results and Discussion

3.1. Floristic Composition of Woody Species. A total of 101 woody plant species that belong to 40 families in 69 genera were collected, identified, and documented from the study of national park (Table 1). Among these, 79 (86.29%) were recorded from 99 sample plots laid in the national park, while 22 (13.71%) species were recorded outside the quadrats but inside the national park for floristic compilation. Trees were the dominant growth forms in the study site representing 39.74% followed by shrubs (21.79%). *E. camaldulensis*, *J. acerifolia,* and *M. azedarach* were the only three exotic tree species recorded in the natural vegetation. The recorded woody plant species in the current study area were higher than 70 species of Kafta Sheraro National Park [40], while less than 118 trees and shrubs were recorded from Nechisar National Park [41]. The highest number of woody species in this study was partly explained by the entire vegetation of the national park which is dominated by woodland and forestland. Whitmore [42] noted that species richness in tropical forests varies greatly from site to site due to variations in habitat, level of ecological disturbance, and total area sampled. The floristic composition plays a crucial role in assessing the health of forests [43] and helps to design conservation and management plans. Of all families investigated in the study area, Fabaceae was the most diverse family representing 16 (15.84%) species, followed by Euphorbiaceae, 9 species (8.91%), and Anacardiaceae with 6 species (5.94%). Four families including Combretaceae, Moraceae, Olacaceae, and Tiliaceae were represented by 4 species each. Four families were also represented by 3 species, 12 families were represented by two species, and 18 families were represented by one species. The dominancy of Fabaceae was reported in several studies conducted in Ethiopia [1, 40, 41]. Fabaceae is also known to have the highest number of species, more than any other plant family in the world [44]. Woldearegay et al. [45] noted that the dominancy of the family Fabaceae could also be attributed to its efficient and successful dispersal strategies as well as better adaptation to a wide range of ecological conditions. In addition, in the tropics, N-fixation occurs primarily in Fabaceae.

3.2. Structure of Woody Species in the Loka Abaya National Park

3.2.1. Density and Frequency of Woody Species. Stem density is the result of recruitment, growth, and mortality that is potentially influenced by a wide variety of factors operating at a range of spatial and temporal scales with varying effects on different size classes [46]. In the current study, a total of 3292 individuals of woody plants (831 individuals per hectare) were recorded in the study site (Table 2). The stem density of the current study area was low compared to other studies in different forest vegetation of Ethiopia, Adelle (898 individuals ha^{-1}) [47] and Nechisar National Park, 867 stem

Table 1: List of woody species in the Loka Abaya National Park.

Species	Family	Local name	Growth	Vo. number
Acacia albida Del.	Fabaceae	Odoricho	Tree	AA184
Acacia asak (Forssk.) Willd.	Fabaceae	Xurura	Tree	AA121
Acacia brevispica Harms	Fabaceae	Hambressa	Tree	AA17
Acacia drepanolobium Harms ex Sjostedt.	Fabaceae	Wacho	Shrub	AA180
Acacia lahai Steud. & Hochst. ex Benth	Fabaceae	Odoricho	Tree	AA56
Acacia polyacantha subsp. *polycantha* Willd.	Fabaceae	Latee	Tree	AA148
Acacia seyal Delile	Fabaceae	Wacho	Tree	AA147
Acacia sieberiana DC	Fabaceae	Wacho	Tree	AA72
Acacia tortilis subsp. spirocarpa (Hochst. ex A. Rich.)	Fabaceae	Xadacha	Tree	AA53
Acokanthera schimperi (A. DC.) Schweinf.	Apocynaceae	Qararicho	Tree	AA62
Albizia schimperiana Oliv	Fabaceae	Maticho	Tree	AA150
Asparagus aspergillus Jessop	Asparagaceae	Chee 2	Shrub	AA23
Asparagus flagellaris (Kunth)	Asparagaceae	Butticho	Shrub	AA45
Asparagus racemosus Willd	Asparagaceae	Butticho	Climber	AA26
Balanites aegyptiaca (L.) Del.	Balanitaceae	Meuu Bedino	Tree	AA52
Balanites rotundifolia (van Tilghem) Blatter	Balanitaceae	Manu Bedino	Tree	AA06
Boscia minimifolia Chiov	Capparidaceae	Qaliqaliha	Tree	AA196
Boscia subtussulcata Chiov	Capparidaceae	Qaliqalicha	Tree	AA21
Buddleja polystachya Fresen	Scrophulariaceae	Bulancho	Tree	AA41
Calpurnia aurea (Ait.) Benth.	Fabaceae	Chakata	Tree	AA69
Carissa spinarum L.	Apocynaceae	Otlicho	Shrub	AA94
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Kincho	Tree	AA132
Celtis africana Burm.	Ulmaceae	Shisho	Tree	AA181
Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Madhessa	Shrub	AA185
Combretum rochetianum A. Rich. ex A. Juss.	Combretaceae	Lonna	Tree	AA07
Combretum collinum Fresen	Combretaceae	Xaxalicho	Tree	AA54
Combretum molle R.Br ex. G. Don	Combretaceae	Rukessa	Tree	AA08
Cordia sinensis Lam.	Boraginaceae	Grgeduwdew	Tree	AA178
Cordia africana Lam.	Boraginaceae	Wadicho	Tree	AA105
Croton macrostachyus Del	Euphorbiaceae	Masincho	Tree	AA119
Dichrostachys cinerea (L.) Wight and Arn	Fabaceae	Jermancho	Tree	AA09
Diospyros abyssinica (Hiern) F. White	Ebenaceae	Lokko	Tree	AA133
Diospyros mespiliformis Hochst. ex A. DC.	Ebenaceae	Babe	Tree	AA28
Dodonaea angustifolia L.f.	Sapindaceae	Itancha	Shrub	AA05
Dovyalis abyssinica (A. Rich.)	Flacourtiaceae	Shillo	Shrub	AA181
Duranta erecta L	Verbenaceae	Komolicho	Shrub	AA011
Ehretia cymosa Thonn.	Boraginaceae	Gidincho	Tree	AA73
Ekebergia capensis Sparrm	Meliaceae	Oloncho	Tree	AA106
Entada abyssinica Steud. ex A.Rich	Mimosaceae	Xankqdhicho	Climber	AA96
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Bherzafe	Tree	AA115
Euclea schimperi (A. DC.) Dandy	Ebenaceae	Meessa	Shrub	AA04
Euphorbia abyssinica Gmel	Euphorbiaceae	Caricho	Tree	AA34
Euphorbia adjurana Bally & Carter	Euphorbiaceae	Charicho	Tree	AA020
Euphorbia nubica N. E. Br	Euphorbiaceae	—	Creeping	AA022
Euphorbia septantnolis Bally & Carter	Euphorbiaceae	Lako Caricho	Shrub	AA023
Euphorbia tirucalli L.	Euphorbiaceae	Annaotte	Tree	AA48
Faurea rochetiana (A. Rich) Chinov. ex Pichi.serm	Protaceae	Dawaka	Tree	AA82
Faurea speciosa Welw	Proteaceae	Danshicho	Tree	AA007
Ficus sur Forssk.	Moraceae	Odacko	Tree	AA99
Ficus sycomorus L.	Moraceae	—	Tree	AA153
Ficus thonningii Blume	Moraceae	Dimbicho	Tree	AA144
Ficus vasta Forssk.	Moraceae	Qilitto	Tree	AA143
Flacourtia indica (Burm. f) Merr.	Flacourtiaceae	Hagalicho	Tree	AA173
Gardenia volkensii K. Schum	Rubiaceae	Gambella	Tree	AA174
Gnidia lamprantha Gig	Thymelaeaceae	Mrede	Shrub	AA026
Grewia bicolor Juss.	Tiliaceae	Hororessa	Shrub	AA02
Grewia ferruginea Hochst. ex A. Rich	Tiliaceae	Somacko	Shrub	AA027
Grewia tenax (Forssk.) Fiori	Tiliaceae	Shilicho	Shrub	AA78
Grewia villosa Will	Tiliaceae	Chabicha	Tree	AA028
Ilex mitis Radlk.	Aquifoliaceae	Miqqicho	Tree	AA03

Table 1: Continued.

Species	Family	Local name	Growth	Vo. number
Jasminum grandiflorum L. subsp. *Floribundum* (R.Br. ex Fresen.) P.S. Green	Oleaceae	Toreshicho	Shrub	AA074
Jatropha acerifolia Pax	Euphorbiaceae	Jatrofa	Shrub	AA117
Kirkia burgeri Stannard	Simaroubacfae	Shomboo	Tree	AA079
Kleinia squerosa Cufod	Asteraceae	Bokessa	Shrub	AA080
Lannea schimperi (Hochst. ex A. Rich.)	Anacardiaceae	Galicha	Shrub	AA37
Lannea triphylla (A. Rich.) Engl.	Anacardiaceae	Handracko	Tree	AA61
Lantana camara Linn.	Verbenaceae	Lembol-shisha	Shrub	AA64
Maerua crassifolia forssk	Capparidaceae	Kalkalcha	Shrub	AA030
Maytenus arbutifolia (A. Rich.) Wilczek	Celasteraceae	Cucho	Shrub	AA175
Melia azedarach Blanco	Meliaceae	Meme	Tree	AA116
Mimusops kummel Bruce ex DC	Sapotaceae	Olatee	Tree	AA138
Ochna inermis (Forssk.) Schweinf	Ochnaceae	Bula-Cucho	Shrub	AA032
Ocimum lamiifolium Hochst. ex. Benth.	Lamiaceae	Chbicha	Shrub	AA125
Olea europaea L. subsp. *cuspidata* (Wall. ex G. Don) Cif	Oleaceae	Egerssa	Tree	AA39
Osyris quadripartite Decn.	Santalaceae	Karcho	Shrub	AA31
Ozoroa insignis Del.	Anacardiaceae	Garee	Tree	AA18
Phyllanthus amarus Schum. & Thonn	Euphorbiaceae	Sooke	Shrub	AA176
Phytolacca dodecandra L'Her	Phytolaccaceae	Mee sahna	Shrub	AA038
Piliostigma thonningii (Schum.) Milne-Redh.	Fabaceae	Korra	Tree	AA191
Pittosporum viridiflorum Sims	Pittosporaceae	Boncho	Tree	AA77
Rhus natalensis Krauss	Anacardiaceae	Dawessa	Shrub	AA137
Rhus vulgaris Meikle	Anacardiaceae	Shisha	Shrub	AA074
Ricinus communis L	Euphorbiaceae	Qombo	Shrub	AA120
Salvadora persica L	Salvadoraceae	Ukka	Shrub	AA110
Sambucus canadensis (*Burchana*)	Caprifoliaceae	Burchana	Shrub	AA043
Schrebera alata (Hochst.) Welw.	Oleaceae	Tsemayee	Tree	AA89
Sclerocarya birrea (A. Rich.) Hochst	Anacardiaceae	Woshalicha	Tree	AA186
Senna didymobotrya (Fresen.) Irwin & Barneby	Fabaceae	Xoxamo	Shrub	AA87
Senna septemtrionalis (Viv.) Irwin & Barneby	Fabaceae	Woshicho	Shrub	AA122
Solanum incanum L	Solanaceae	Borbodhicho	Shrub	AA85
Solanum somalense Franchet	Solanaceae	Borbodhicho	Shrub	AA046
Syzygium guineese (Willd.)DC	Mytaceae	Duwancho	Tree	AA114
Tagetes minuta L	Asteraceae	Bowanhamo	Shrub	AA187
Tamarindus indica L.	Fabaceae	Rokko	Tree	AA016
Teclea nobilis Del.	Rutaceae	Hadhessa	Shrub	AA12
Terminalia brownii	Combretaceae	Rukessa	Tree	AA016
Tribulus terrestris. L	Zygophyllaceae	Hoqono	Tree	AA049
Vangueria apiculata K. Schum	Rubiaceae	Burure	Shrub	AA015
Withania somnifera (L.) Dunal	Solanaceae	Bulancho	Shrub	AA053
Ximenia americana L	Olacaceae	Huroo	Shrub	AA001
Zanthoxylum chalybeum Eng	Rutaceae	Gada	Shrub	AA054

ha^{-1} [41]. While its density is higher than Boditi (498 individuals ha^{-1}) [47] and woodlands (376.86 individuals ha^{-1}) [47] in Ethiopia. The variation in stem density directly correlates with topographic factors such as elevation, slope, aspect, and richness [48] and habitat quality linked to ecological requirements of component tree and shrub species in the respective forests [41] and age structure [49]. According to Richards [50], tree abundance can likewise be affected by natural and anthropogenic disturbances or soil conditions. In the vegetation of Loka Abaya National Park, 54.46% of the density of woody species was contributed by 8 abundant species. *D. angustifolia* had 108.33 individual ha^{-1}, *C. molle* 27.5 (69.44 individual ha^{-1}), *E. schimperi* 243 (61.36 individual ha^{-1}), *R. natalensis* 217 (54.75 individual ha^{-1}), *O. europaea* L. subsp. *cuspidata* 216 (54.54 individual ha^{-1}), *D. cinerea* 193 (48.23 individual ha^{-1}), *A. brevispica* 152 (38.38 individual ha^{-1}), *I. mitis* 148 (37.37 individual ha^{-1}), and *E. tirucalli* 138 (34.84% individual ha^{-1}) were the most abundant woody species. The majority of woody species in the study area including *M. kummel*, *S. birrea*, *F. rochetiana*, *E. cymosa*, *C. sinensis*, *C. africana, A. polyacantha*, *Z. chalybeum*, *D. abyssinica*, *V. apiculata*, *C. malosana*, and *C. africana* were found rare. Thus, those rare species might be important components of the ecological system, even more than the species having higher relative abundance. In highly diverse ecosystems such as tropical forests, rare species are an important component of biological diversity, generally comprising the majority of species, and they are also particularly vulnerable to extinction [51, 52], so they need attention for conservation.

Table 2: Structural analysis of trees and shrubs in the study area (99 plots of $20\,m \times 20\,m$ ($400\,m^2$) = (3.96 ha).

Species	Ab	Density (ha)	Relative density (ha)	BA (m^2)	FEQ	R.F	R.De	R.Do	IVI
Acacia albida	31	7.82	0.94	0.06	3.03	0.45	0.94	0.08	1.47
Acacia asak	6	1.51	0.18	0.00	1.01	0.15	0.18	0.00	0.33
Acacia brevispica	152	38.38	4.61	0.02	32.32	4.82	4.61	0.03	9.46
Acacia drepanolobium	38	9.59	1.15	0.12	3.03	0.46	1.15	0.16	1.77
Acacia lahai	21	5.30	0.63	0.82	4.04	0.61	0.63	1.12	2.36
Acacia polyacentha	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Acacia seyal	33	8.33	1.00	2.83	9.09	1.34	1.00	3.87	6.21
Acacia sieberiana	13	3.28	0.39	0.00	1.01	0.15	0.39	0.00	0.54
Acacia tortilis	6	1.51	0.18	0.00	9.09	1.38	0.18	0.00	1.56
Acokanthera schimperi	58	14.64	1.76	0.61	22.22	3.37	1.86	0.83	6.06
Balanites aegyptiaca	53	13.38	1.60	3.08	27.27	4.14	1.60	4.21	9.95
Balanites rotundifolia	6	1.51	0.18	0.00	1.01	0.15	0.39	0.00	0.54
Boscia minimifolia	60	15.15	1.82	0.52	17.17	2.61	1.82	0.71	5.14
Boscia subtussulcata	42	10.61	1.27	0.00	12.12	1.84	1.27	0.00	3.11
Buddleja polystachya	16	4.04	0.48	0.02	5.05	0.76	0.48	0.03	1.27
Calpurnia aurea	28	7.07	0.84	0.00	12.12	1.84	0.84	0.00	2.68
Carissa spinarum	10	2.52	0.30	0.00	3.03	0.46	0.3	0.00	0.76
Cassipourea malosana	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Celtis africana	4	1.01	0.12	0.00	2.02	0.29	0.12	0.00	0.41
Combretum rochetianum	57	14.39	1.72	1.72	11.11	1.61	1.72	2.35	5.68
Combretum collinum	89	22.47	2.69	0.79	15.15	2.3	2.69	1.08	6.07
Combretum molle	275	69.44	8.33	12.31	38.38	5.82	8.33	16.82	30.97
Cordia africana	3	0.75	0.09	0.00	2.02	0.29	0.09	0.00	0.38
Cordia sinensis	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Dichrostachys cinerea	193	48.23	5.78	1.23	36.36	5.29	5.78	1.68	12.75
Diospyros abyssinica	1	0.25	0.03	0.00	1.01	0.14	0.03	0.00	0.17
Diospyros mespiliformis	3	0.25	0.03	0.00	4.04	0.61	0.03	0.00	0.64
Dodonaea angustifolia	429	108.33	13.03	0.00	38.38	5.83	13.07	0.00	18.9
Dovyalis abyssinica	6	1.51	0.18	0.00	1.01	0.15	0.18	0.00	0.33
Ehretia cymosa	8	1.26	0.15	0.00	2.02	0.31	0.15	0.00	0.46
Euclea schimperi	243	61.36	7.36	6.29	33.33	5.06	7.38	8.62	21.06
Euphorbia tirucalli	138	34.84	4.18	5.93	9.09	1.38	4.18	8.27	13.83
Faurea rochetiana	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Ficus sur	43	10.83	1.3	0.03	3.03	0.46	1.37	0.05	1.88
Ficus vasta	29	7.37	0.88	0.56	4.04	0.30	0.98	0.77	2.05
Flacourtia indica	1	0.25	0.03	0.00	5.05	0.76	0.03	0.00	0.79
Grewia bicolor	104	26.26	3.15	0.18	24.24	3.68	3.15	0.28	7.11
Grewia ferruginea	18	4.54	0.54	0.00	9.09	1.38	0.54	0.00	1.92
Grewia tenax	29	7.32	0.87	0.00	7.07	1.07	0.87	0.00	1.94
Grewia villosa	12	3.03	0.36	0.00	3.03	0.46	0.36	0.00	0.82
Ilex mitis	148	37.37	4.48	23.93	37.37	5.68	4.48	32.08	42.24
Kleinia squerosa	7	1.76	0.21	0.00	1.01	0.15	0.21	0.00	0.36
Lannea schimperi	47	11.86	1.43	0.09	11.11	1.68	1.43	0.12	3.23
Lannea triphylla	19	4.79	0.56	0.58	5.05	0.76	0.56	0.79	2.11
Maytenus arbutifolia	14	3.53	0.42	0.00	3.03	0.46	0.42	0.00	0.88
Mimusops kummel	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Olea europaea L. subsp. *cuspidata*	216	54.54	6.56	9.00	35.35	5.37	6.56	12.36	24.29
Ozoroa insignis	55	13.89	1.66	1.13	19.19	2.92	1.66	1.55	6.13
Piliostigma thonningii	32	8.08	0.01	0.22	2.02	0.09	0.44	0.30	0.93
Pittosporum viridiflorum	6	1.51	0.18	0.00	2.02	0.31	0.18	0.00	0.49
Rhus natalensis	217	54.79	6.58	0.00	57.57	8.76	6.98	0.00	15.74
Rhus vulgaris	43	10.85	1.30	0.23	5.05	0.41	1.33	0.31	2.05
Salvadora persica	24	6.06	0.72	0.00	2.02	0.30	0.92	0.00	1.22
Schrebera alata	23	5.80	0.69	0.27	6.06	0.92	0.99	0.37	2.28
Sclerocarya birrea	5	1.26	0.15	0.03	5.05	0.76	0.15	0.37	1.28
Teclea nobilis	68	17.17	2.06	0.53	22.22	3.07	2.06	0.72	5.85
Vangueria apiculata	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Ximenia americana	103	26.01	3.12	0.05	37.37	5.64	3.12	0.07	8.83
Zanthoxylum chalybeum	1	0.25	0.03	0.00	1.01	0.15	0.03	0.00	0.18
Total	3292	831.31		73.18		100	100	100	300

Ab, abundances; FEQ, frequency, RF, relative frequency; R.De, relative density; R.Do, relative dominancy; IVI, important value index. "0" value indicates several decimal places, i.e., close to 0.

A comparison of tree density with DBH between 10 and 20 cm (a) and tree density with DBH >20 cm (b) and their ratios was present (Supplementary file 1). The ratio of density >10 cm to density >20 cm is taken as a measure of the distribution of the size classes as described by [33]. The density of woody species with DBH >2 cm was 466.48 individuals ha^{-1} and the density of woody species with DBH >10 cm was 239.69 individuals per ha, whereas species with DBH >20 cm was 93.64 individual ha^{-1}. About 58.32% of the total density of woody species was contributed by species with DBH >2 cm, whereas those woody species with DBH >10 cm and DBH >20 cm contributed 29.96% and 11.71%, respectively, to the total density (Additional File 1). The two species *I. mitis* and *C. molle* had the highest contribution for both DBH above 10 cm and 20 cm, while *D. cinerea*, *O. europaea* L. subsp. *cuspidata*, *D. angustifolia,* and *E. schimperi* had a higher contribution at lower DBH classes. The analysis of the ratio of the density of trees and shrubs of DBH greater than 10 cm to DBH greater than 20 cm for trees and shrubs was found to be 2.55 indicating that there is a predominance of small-sized trees and shrubs in the study site. This value was found to be higher than (1.85) Donkoro forest [53], (1.67) Nechisar National Park [41], and (2.09) Mena-Angut [54]. The dominance of small individuals in the vegetation of the current study area could be related to the recent establishment of the national park, before which the site was an open-access and unprotected area from communities that extracted wood and other products, which lead to the reduction of big trees and shrubs. Tamrat Bekele [35] concluded that if the forest has developed under natural conditions and without major disturbances, no differences were observed between the two size classes.

Frequency is the number of sample plots in which a given species occurred in the study area, expressed in percentage of the total number of sample plots. The most frequently found woody species in the vegetation of the national park were *R. natalensis* (57.57%), *C. molle* (38.38%), *D. angustifolia* (38.38%), *I. mitis* (37.77%), *X. americana* (37.37%), *D. cinerea* (36.36%), *O. europaea* L. subsp. *cuspidata* (35.35%), and *A. brevispica* (32.32%). In general, only nine species occurred in above 30% of all quadrats sampled, which means a higher percentage of woody species was found at lower frequency classes. 63.93% of species had a frequency value of less than 10%, indicating a relatively good floristic heterogeneity in the study area (Table 2). According to Rey et al. [55], variation in the frequency of species might be attributed to habitat preferences among species, species characteristics for adaptation, degree of disturbance, and availability of suitable conditions for regeneration. In the current study area, the pattern of floristic heterogeneity may be influenced by *D. cinerea*, the species encroached into different habitats. A similar observation was reported from Nechisar National Park [41]. According to Bekele [56], the species produces many pods, and each coiled pod contains four seeds, and the pods fall on the ground and rot to set free seeds that are prolifically and germinate easily. This may be the reason for the aggressive encroachment of the species in the national park. Some species including *A. polyacantha*, *Cassipourea malosana*, *S. persica*, *E. cymosa*, *Z. chalybeum,* and *M. kummel* were not only frequent but also habitat-specific as well as low population size in the national park. According to Tetetla-Rangel et al. [57], species having a small population size, high habitat specificity, and small geographic range were termed as the highest level of rarity. In the current study, those species qualified for at least a small population size and high habitat specificity are termed as an intermediate level of rarity that demands conservation attention.

3.2.2. Basal Area and Importance Value Index (IVI) of Woody Species. The total basal area of woody species in Loka Abaya National Park was 73.18 $m^2 \cdot ha^{-1}$ (Table 2). The trees belonging to higher DBH classes are few, but their contribution to the total basal area is high. The result shows that three species *I. mitis* (23.92%), *C. molle* (12.31%), and *Olea europaea* L. subsp. *cuspidata* (9.02%) contribute about 45.25% of the total basal area which shows their dominancy in the vegetation of the national park. The relative importance of tree species in a forest can better be depicted from measurements of the basal area than stem counts [58]. The basal area of Loka Abaya National Park is less than that reported from different study areas in Ethiopia; the basal area of Belete Forest (103.5 $m^2 \cdot ha^{-1}$) [59], Mana-Angetu (94 $m^2 \cdot ha^{-1}$) [54], Berbere Forest (87.49 $m^2 \cdot ha^{-1}$) [60], Kafta Sheraro National Park (79.3 $m^2 \cdot ha^{-1}$) [41], and Alemsaga Forest (75.37 $m^2 \cdot ha^{-1}$) [61] was higher than the basal area of woodlands of Metema (42.54 $m^2 \cdot ha^{-1}$) [62] and Munessa–Shashmene degraded secondary forest of (9.5 $m^2 \cdot ha^{-1}$) [62].

In terms of individual species, the highest basal area in the study was recorded by *Ilex mitis* (23.93 m^2) followed by *C. molle* (12.31 m^2), *O. europaea* L. subsp. *cuspidata* (9 m^2), *E. schimperi* (6.29 m^2), and *E. tirucalli* (5.93 m^2). Those five species contributed 78.51% of the total basal area of the woody vegetation in the national park. Analysis of the relationship between basal area, stem density, and mean stem DBH indicated that stem DBH had a stronger influence on standing basal area than stem density; *D. angustifolia*, *D. cinerea*, and *X. americana* had relatively high stem density, but their contribution to basal area was small due to smaller DBH [35]. Bekele noted that species with the highest basal area/ha do not always have the highest density, indicating size differences between the species. In other cases, differences in growth forms could be important; shrubby tree species such as *D. angustifolia*, *X. americana*, and *S. persica* and their contribution to the basal area were minimum. Basal area provides a measure of the relative importance of the species rather than a simple stem count [63]. In this study, basal area analysis across individual species revealed that there was high domination by very few or small woody species. According to Cain and Castro [58], basal area measurements are used to indicate the relative ecological significance and/or dominance of woody species in a forest ecosystem. In the current study, *I. mitis*, *C. molle*, *O. europaea* L. subsp. *cuspidata*, *E. schimperi*, and *E. tirucalli* were some of the most important species in terms of their basal area, and thus, they were the most ecologically important species in the national park.

(1) Importance Value Index of Woody Plants. The relative ecological significance and/or dominance of tree species in a forest ecosystem could best be unraveled from the analysis of IVI values [64]. Cain and Castro [58] and Uhl and Murphy [65] noted that few species have been reported to have high IVI in tropical and subtropical forests. In the study area, eight species had more than 10 values of IVI, and these include *I. mitis*, *C. molle*, *O. europaea* L. subsp. *cuspidata*, *D. cinerea*, *D. angustifolia*, *E. schimperi*, *E. tirucalli,* and *R. natalensis* had high IVI values (Table 2). These top eight woody species contributed about 59.66% of the total IVI of woody species. These species are dominant and more frequent in the national park and they have higher IVI values. On the other side, 22 woody species had less than one IVI value; the species include *A. asak*, *A. polyacantha*, *A. sieberiana*, *B. rotundifolia*, *C. spinarum*, *C. malosana*, *C. africana*, *C. sinensis*, *D. abyssinica*, *E. cymosa*, *D. mespiliformis*, *G. villosa*, *K. squerosa*, *F. rochetiana*, *F. indica*, *M. arbutifolia*, *M. kummel*, *V. apiculata*, *P. viridiflorum*, *P. thonningii,* and *Z. chalybeum* (Table 2). According to Kent and Coker [4], the important value index (IVI) is a good index for summarizing vegetation characteristics and ranking species for conservation practices. The species with the highest IVI are the most ecologically important species because those species have high relative dominance in the vegetation, which needs attention for monitoring and management. Those species that had low IVI values in the vegetation of the national park are rare and warrant high conservation efforts.

3.3. Overall Population Structure

3.3.1. Vertical Height (H) and Horizontal (Diameter at Breast Height) Distribution. Vertical structure (height) of the trees and shrubs indicated that the majority of individual species' height below 8 m indicated the vegetation was dominated by small size trees and shrubs. Few individuals were recorded above the height of 25 meters, and those individual species including *A. albida*, *F. sur,* and *I. mitis* were associated with along Billate riverside vegetation. This larger growth in terms of height may be associated with the high underground water table and soil nutrient inputs from the upper portion of the water shade especially in a dry land. The overall population patterns of the trees and shrubs in terms of height class revealed that the populations were in healthy status (inverted J-shaped) (Figure 3).

Similarly, the horizontal structure of the overall population pattern of trees and shrubs in terms of DBH class distribution also has shown an inverted *J* shape structure (Figure 4). Most of the individuals in the vegetation stand were found in the lowest DBH classes, which are reflected by the highest density of individuals in the lower height classes. According to Neelo et al. [36], an inverted *J* shape population structure is attributed to the prevalence of shrubs, pioneers, and other woody species naturally with small diameters rather than the normal regeneration of climax

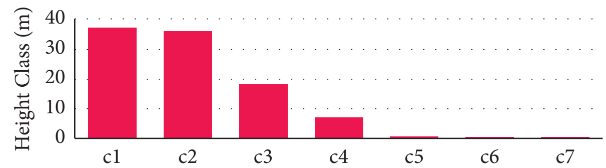

Figure 3: Frequency distribution of trees and shrubs in height classes: C_1 = <2 m, C_2 = 2 m–5 m, C_3 = 5.1 m–8 m, C_4 = 8.1 m–11 m, C_5 = 11.1–14 m, C_6 = 14.1 m–17 m, C_7 = 17.1 m–20 m, C_8 = 20.1 m–23 m, and C_9 > 23 m.

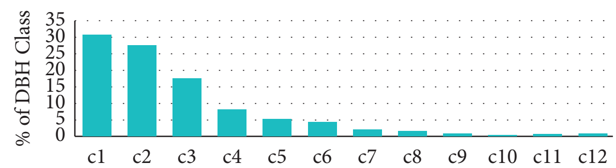

Figure 4: Frequency distribution of trees and shrubs in DBH class: C_1 = <2 cm, C_2 = 2 cm–5 cm, C_3 = 5.1 cm–8 cm, C_4 = 8.1 cm–11 cm, C_5 = 11.1 cm–14 cm, C_6 = 14.1 cm–17 cm, C_7 = 17.1 cm–20 cm, C_8 = 20.1 cm–23 cm, C_9 = 23.1 cm–26 cm, C_{10} 26.1–29 cm, C_{11} 29.1 cm–32 cm, and C_{12} = >32 cm.

species. In current, the overall population structure in terms of DBH and height classes revealed stable regeneration and recruitment; however, an inverted *J* shape population structure is commonly attributed to the prevalence of shrub species naturally small in terms of growth height including *X. americana*, *T. nobilis*, *M. arbutifolia, S. persica,* and *C. aurea*, and pioneers such as *D. angustifolia* and *E. schimperi* had a large contribution to an inverted *J* shape population structure in terms of height and DBH rather than health population structure of the vegetation in the national park.

3.3.2. Species Population Structure. Examination of patterns of species-level population structures could provide valuable information about their regeneration and/or recruitment status as well as the viability status of individual tree species, which could further be employed for devising evidence-based conservation and management strategies [36]. Various patterns of species-level population structures have been reported for different species in forests of the country and outside the country [35, 36, 54]. In this study, twenty-five woody species were investigated for population structure in national parks. The results indicated five different species-level population structure were identified. The first group was composed of species that exhibited a higher number of individuals at the lowest diameter class and progressively declining numbers with increasing diameter classes. An inverted J-shaped distribution was represented by *D. cinerea* (Figure 5(a)). This group includes *E. schimperi*, *O. europaea* L. subsp. *cuspidata*, *C. collinum,* and *S. alata*; tropical forests show inverted *J* curve structure [65] and regeneration was successful for those species. The second pattern is represented by *B. aegyptiaca* (Figure 5(b)) in this category species including *B. rotundifolia* and *O. insignis*; this pattern indicates good reproduction but discontinuous recruitment. The lack of a middle class in the population indicates that there

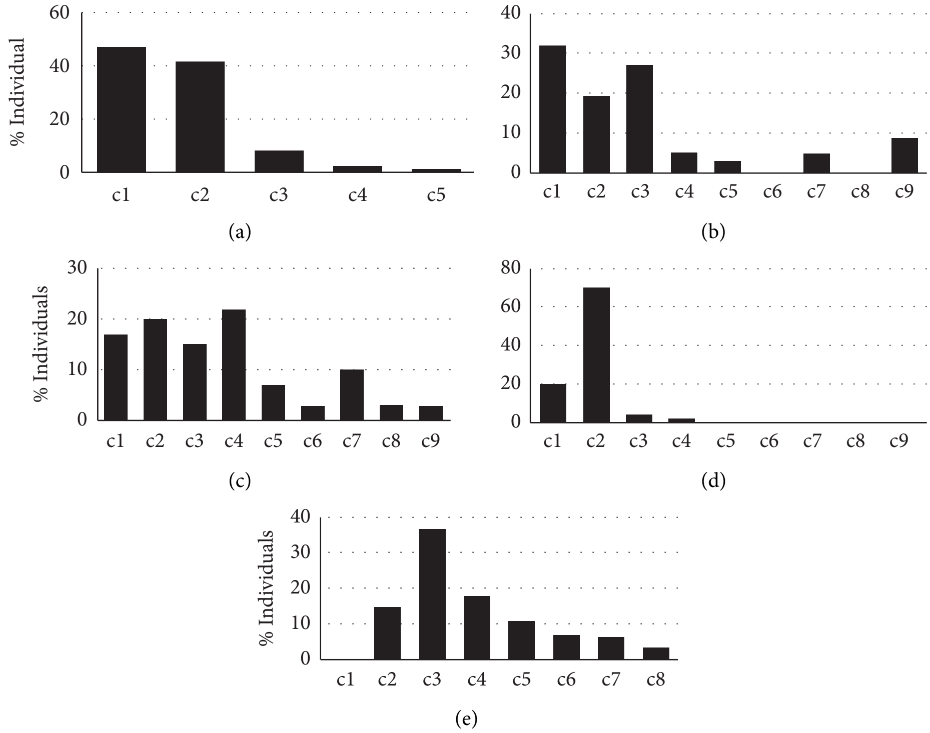

Figure 5: Population patterns of representative individual tree species: C_1 = <2 cm, C_2 = 2 cm–5 cm, C_3 = 5.1 cm–8 cm, C_4 = 8.1 cm–11 cm, C_5 = 11.1 cm–14 cm, C_6 = 14.1 cm–17 cm, C_7 = 17.1 cm–20 cm, C_8 = 20.1 cm–23 cm, C_9 = 23.1 cm–26 cm, C_{10} = 26.1–29 cm, C_{11} = 29.1 cm–32 cm, and C_{12} = >32 cm. (a) *Dichrostachys cinerea.* (b) *Balanites aegyptiaca.* (c) *Combretum molle.* (d) *Acacia brevispica.* (e) *Acacia seyal.*

was a selective removal of individuals of preferred size for a particular use by the local communities living surrounding the national park.

Third type of species shows the pattern where the frequency is high at lower DBH classes but becomes irregulartowards higher classes. This pattern indicates good reproduction but discontinuous recruitment. These species that showed such population patterns were represented by C. molle (Figure 5(c). Other species including I. mitis, A. schimperi, and A. tortilissubsp. spirocarpa had such a pattern because the species were used by the local community for more than four use categories, so different size class individuals were used for different use categories. The Fourth group is represented by A. brevispica figure 5(d); this group consisted of species that showed higher individuals at the first class and second class and no individuals at the higher diameter class. The absence of those species at the higher DBH classes was due to the growth nature of the species. This group was represented by species A. brevispica, X. americana, G. bicolor, M. arbutifolia, R. natalensis, and C. aurea. It suggests good reproduction. According to [5], the forest and woodlands of Ethiopia are generally characterized by poor regeneration and recruitment due to heavy and continued anthropogenic factors. The fifth group was represented by species that have no seedlings and saplings represented by *A. seyal* (Figure 5(e)); in this group, *A. lahai*, *A. sieberiana*, *L. triphylla*, *D. abyssinica,* and *A. polyacantha* were some of the species that showed such regeneration pattern.

3.4. Regeneration Status of Woody Species in the Loka Abaya National Park. The composition, distribution, and density of seedlings and saplings indicate the future appearance of a particular forest [66]. Thus, the regeneration or recruitment potential of plants is one of the major factors that are useful to see their conservation status. In the current study, the regeneration status of 70 woody species was investigated based on the total count of seedlings and saplings of each species across all quadrats. A total of 1792.72 seedlings ha^{-1}, 817.10 saplings ha^{-1}, and 831.31 ha^{-1} matured tree and shrub species were recorded, identified, and documented (Supplementary file 2). The ratio of seedlings and saplings to the matured woody plants was 2.19, 2.15, and 0.98, respectively. The ratio between the seedlings, saplings and mature trees can provide information regarding the distribution of mature trees, saplings, and seedlings in the national park. The large number of seedlings ha^{-1} as compared to the matured trees has shown that the vegetation seems under normal regeneration status, but this higher number of seedlings was contributed by a few individual species.

According to Dhaulkhandi et al. [38], the density values of seedlings and saplings are considered the regeneration potential of the species. Concerning the individual species, the highest seedling density in the study national park was recorded by *D. angustifolia* 446.69 seedling ha^{-1} followed by *D. cinerea* 222.22 seedling ha^{-1} and *E. schimperi* 172.84 seedling ha^{-1}. The sapling layers were also dominated by *D. angustifolia* 253.64 sapling ha^{-1} followed by *A. brevispica*

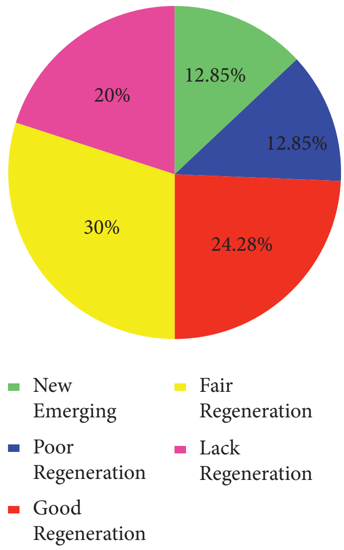

Figure 6: Regeneration status of tree and shrub species in the national park.

120.20 sapling ha^{-1} and *E. schimperi* 80.81 sapling ha^{-1} (Supplementary file 2). The regeneration pattern of the species varies depending on environmental variables including altitude, slope, aspect, canopy light, edaphic conditions, and the intrinsic and adaptation behavior of the species [5]. The regeneration status of the individual tree species categories as good, bad, poor, fair, and newly emerging species following [38, 39]. Out of 70 wood species, 17 (24.28%) tree species achieved good regeneration, and 21 species (30%) had fair regeneration (Figure 6). 9 species (20%) had no seedlings and only saplings and adults. Some disturbances influence seedling survival more than seedling emergences; the effect is also species-specific [5], for example, grazing and herbivores impose species-specific effects on seedling emergence, so grazing pressure can create a severe threat to plant biodiversity and species composition.

14 species (20%) including *A. asak*, *C. malosana*, *C. sinensis*, *D. abyssinica*, *E. cymosa*, *F. speciosa*, *F. indica*, *G. tenax*, *G. villosa*, *B. rotundifolia*, *M. kummel*, *V. apiculata*, *S. birrea,* and *L. schimperi* recorded only in an adult form which are not regenerating. All of them are multipurpose species and economically important species, for example, *C. sinensis*, *D. abyssinica*, *E. cymosa*, *F. indica*, *G. tenax*, *G. villosa*, *B. rotundifolia*, *M. kummel*, *V. apiculata*, *S. birrea,* and *L. schimperi* are edible fruit-bearing species as reported from ethnobotanical research conducted in Ethiopian and other parts of the worlds [68–70]; for those species, it is important to investigate soil seed bank analysis and study propagation methods for conservation of those valuable species. Seven species (10.29%) of new emerging species including *S. guineese*, *S. septemtrionalis*, *M. azedarach*, *J. acerifolia*, *F. thonningii*, *E. camaldulensis*, and *E. capensis* only found at sapling and seedling stage along Billate riverside vegetation were appearing as new species regenerating in the natural vegetation (Figure 4). This revealed that water is an important road for the introduction of invasive alien species to native natural vegetation and one of the great rift valley lakes Abaya, so it needs monitoring.

4. Conclusions

In this study, 101 woody species were recorded which are an essential component of forest vegetation. Those species play a crucial role in the national carbon stock of the country, so it is essential to investigate the carbon-storing potential of the national park. The study also confirms that the majority of woody species had a small population size, and some of them were found in a specific habitat. Therefore, those rare species need high conservation priority. In addition, our results indicated that the majority of woody species have low-frequency values indicating a relatively good floristic heterogeneity in the study of national park, but species like *D. cinerea* have encroached into different habitats which may significantly influence the pattern of species heterogeneity, diversity, structure, and soil nutrient dynamics, such change in vegetation may also associate with a change in carbon stocks, so the species needs monitoring to overcome further expansion and homogenization of the vegetation of the park. Furthermore, among a major plant invader species, *A. drepanolobium* was also confined to specific habitats in the national park which is a potential threat to the biodiversity in the area, so the vegetation needs monitoring. The diameter class distribution of selected tree species demonstrated various patterns of population structure, implying the existence of different population dynamics among ecologically important tree species. Morphological differences in species, pioneer nature of some species, selective removal of woody species as evidenced by the existence of stubs and illegal charcoal production sites/pits in the national park for livelihood diversification by local communities, grazing, and removal of preferred size for particular uses partly contributed to the existence of different population dynamics. Regeneration assessment result also confirms that some woody species occurred only in an adult form which was not regenerating and may become extinct. Thus, there is selective removal of species, although logging or grazing leads to higher dominancy of unpalatable and low-quality species. This negatively affects the structure, diversity, and regeneration of woody species and potential threats to the conservation of biodiversity at the local level. Therefore, based on our findings, the following recommendations were drowned for conservation of woody species in the study area. For those species with low population size and habitat-specific species, produce seedlings in the nursery for enrichment planting in the national park. Those species that lack regeneration ability study the soil seed banks to identify specific problems that make them unable to regenerate under the natural environment and investigate the coppicing ability of selectively removed species to design conservation strategies.

Data Availability

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

Ethical Approval

This study was approved by Addis Ababa University, Department of Plant Biology and Biodiversity Management, and Southern Agricultural Research Institute. The research was conducted inside the national park with the permission of the National Park Management Bureau under the Regional Bureau of Culture and Tourism.

Consent

Not applicable.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors played a vital role to accomplish this manuscript. Assegid Assefa developed the idea of the research, designed the research method, identified the plant, performed statistical analysis, and wrote the manuscript. Professor Tamrat Bekele, Professor Sebsebe Demissew, and Professor Tesfaye Abebe contributed significant input to the successful completion of the manuscript by supervising the study, consistent and inspiring guidance, valuable suggestions, constructive comments, and reviews on the manuscript preparation.

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Supplementary Materials

Supplementary File 1. The density of trees and shrubs with DBH greater than 2 cm, 10 cm, and 20 cm in Loka Abaya National Park. Supplementary file 2. The regeneration status of woody species in the Loka Abaya National Park: density of matured trees and shrubs and density of saplings and seedlings in the national park. (*Supplementary Materials*)

References

[1] E. Kelbessa and S. Demissew, "Diversity of vascular plant taxa of the flora of Ethiopia and Eritera Ethio," *The Journal of Biological Sciences*, vol. 13, pp. 37–45, 2014.

[2] E. Kelbessa, S. Demissew, Z. Woldu, and S. Edwards, "Some threatened endemic plants of Ethiopia," in *The Status of Some Plant Resources in Parts of Tropical Africa. Botany 2000: East and Central Africa. NAPRECA Monograph Series No.2.Published by NAPRECA*, S. Edwards and Z. Asfaw, Eds., Addis Ababa University, Addis Ababa, Ethiopia, 1992.

[3] G. Dalle, "Forest biodiversity: opportunities and challenges in Ethiopia," in *Proceedings of the Commemoration, 3rd National Mother Earth Day. International Year of Forest*, Addis Ababa Ethiopia, 2011.

[4] M. Kent and P. Coker, *Vegetation Description and Analysis. A Practical Approach*, p. 363, Wiley, New York, NY, USA, 1992.

[5] D. Teketay, M. Lemennih, Y. Ymshaw et al., "Forest resources and challenges of sustainable forest management and conservation in ethiopia book," in *Degraded Forests in Eastern Africa: Management and Restoration*Earthscan, London, UK, 2010.

[6] J. A. Huxley, T. Gille, M. L. Swift, and E. B. Worthington, *The Conservation of Nature and Natural Resources in Ethiopia*, p. 46, United Nation Educational, Scientific and Cultural Organization, London, UK, 1963.

[7] IBC (Institute of Biodiversity Conservation), *Ethiopia's Fifth National Report to the Convention on Biological Diversity*, p. 86, IBC (Institute of Biodiversity Conservation), Addis Ababa, Ethiopia, 2014.

[8] Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Scenarios*, S. R. Carpenter, P. Pingali, E. M. Bennet, and M. B. Zurek, Eds., Island Press, Washington, DC, USA, 2005.

[9] S. Demissew and Nordal, *Aloes and Lilies of Ethiopia and Eritrea*, Addis Ababa University Press, Addis Ababa, Ethiopia, p. 358, 2010.

[10] J. L. E. Vivero and S. Demissew, *The Red List Endemic Trees and Shrubs of Ethiopia and Eritrea Fauna and Flora International United Kingdom*, 2005.

[11] EFAP (Ethiopian Forestry Action Program), *The Challenge for Development, Volume II*, Ethiopian Forestry Action Program, Addis Ababa, Ethiopia, 1994.

[12] FAO, *State of World Forest*, Food and Agriculture Organization of United Nations, Romce, Italy, 2007.

[13] D. Tadesse, "Forest cover change and socio economic drivers of Southwest Ethiopia," M. Sc. thesis, Center of Land Management and Land Tenure Technische Universitaer, Munich, Germany, 2007.

[14] T. Getaneh, "remote sensing and Gis assisted participatory biosphere reserve zoning for wild coffee conservation: case of yayu forest," M. Sc. thesis, Addid Ababa University, Addis Ababa, Ethiopia, 2008.

[15] N. Myers, "The world's forests: problems and potentials," *Environmental Conservation*, vol. 23, no. 2, pp. 156–168, 1996.

[16] W. Tadesse, M. Sintayehu, S. Alem, A. Worku, G. Desalegn, and W. Zewdie, "Adverse economic, social, and ecological consequences and major driver of deforestation in Ethiopia," in *Proceedings of the Commemoration, 3rd National Mother Earth Day International Year of Forest*, Addis Ababa Ethiopia, 2011.

[17] LANP (Loka Abaya National Park), *Boundary Demarcation and Biological Survey of Loka- Abaya National Park Sidama Zone SNNPRS-Ethiopia*, Loka Abaya National Park, Ts'enga, Ethiopia, 2009.

[18] S. Numata, M. Yusada, T. Okuda, N. Kachi, and M. N. Nur Supardi, "Canopy gap dynamics of two different forest stands in a Malaysian lowland rain fores," *Journal of Tropical Forest Science*, vol. 18, no. 2, pp. 109–116, 2006.

[19] P. W. Ondachi, "Nutritional studies of indigenous fruit trees in support of conservation," *Annual Research Report*, African Academy of Sciences, Nairobi, Kenya, 1999.

[20] G. Tesfaye, D. Teketay, M. Fetene, and E. Beck, "Regeneration of seven indigenous tree species in a dry Afromontane forest,

Southern Ethiopia," *Flora-Morphology, Distribution, Functional Ecology of Plants*, vol. 205, no. 2, pp. 135–143, 2010.

[21] SZPEDD (Sidama Zone Planning and Economic Development Department), *Atlas of Sidama Administrative Zone*, SZPEDD (Sidama Zone Planning and Economic Development Department), Yirgalem, Ethiopia, 2001.

[22] D. Mueller-Dombois and H. Ellenberg, *Aims and Methods of Vegetation Ecology*, John Wiley & Sons, New York, NY, USA, 1974.

[23] K. Awang, P. Venkateswarlu, A. Nor Aini et al., "Three year performance of international provenance trials of *Acacia auriculiformis*," *Forest Ecology and Management*, vol. 70, no. 1–3, pp. 147–158, 1994.

[24] Y. A. Magarik, L. A. Roman, and J. G. Henning, "How should we measure the DBH of multi-stemmed urban trees?" *Urban Forestry and Urban Greening*, vol. 47, no. 1, Article ID 126481, 2020.

[25] M. L. Khan, J. P. N. Rai, and R. S. Tripathi, "Population structure of some tree species in disturbed and protected subtropical forests of north-east India," *Acta Oecologica Oecologia Applicata*, vol. 8, pp. 247–255, 1987.

[26] S. Edwards, S. Demissew, and I. Hedberg, *Flora of Ethiopia and Eritrea Hydrocharitaceae to Arecaceae Volume 6*, The National Herbarium, Addis Ababa, Ethiopia, 1997.

[27] S. Edwards, M. Tadesse, S. Demissew, and I. Hedberg, *Flora of Ethiopia and Eritrea. Magnoliaceae to Flacourtiaceae Volume 2*, The National Herbarium, Addis Ababa, Ethiopia, 2000.

[28] S. Edwards, M. Tadesse, and I. Hedberg, "Flora of Ethiopia and Eritrea," *Canellaceae to Euphorbiaceae Volume 2*, Department of Systematic Botany. the National Herbarium, Addis Ababa, Ethiopia, 1995.

[29] I. Hedberg and S. Edwards, "Addis Ababa, Ethiopia," *Flora of Ethiopia and Eritrea Pittosporaceae to Araliaceae Volume 3*, The National Herbarium, 1989.

[30] I. Hedberg, I. Friis, and S. Edwards, "Addis Ababa, Ethiopia," *Flora of Ethiopia and Eritrea. Asteraceae Volume 4 Part 2*, The National Herbarium, 2004.

[31] I. Hedberg, E. Kelbessa, S. Edwards, S. Demissew, and E. Persson, "Flora of Ethiopia and Eritrea," *Gentianaceae to Cyclochelicaceae Volume 5*, The National Herbarium, Addis Ababa, Ethiopia, 2006.

[32] M. Tadesse, "Flora of Ethiopia and Eritrea part two," *Asteraceae (Compositae) Volume 4. Addis Ababa, Ethiopia: The National Herbarium*, Addis Ababa University, 2004.

[33] P. J. Grubb, J. R. Lloyd, T. D. Pennington, and T. C. Whitmore, "A comparison of montane and lowland rain forest in Ecuador I. The forest structure, physiognomy, and floristics," *Journal of Ecology*, vol. 51, no. 3, pp. 567–601, 1963.

[34] A. Berhanu, "Vegetation ecology and conservation status of evergreen afromontane forest patches," Ph. D. dissertation, Addis Ababa University, Addis Ababa, Ethiopia, 2017.

[35] T. Bekele, "Vegetation ecology of remnant afromontane forests on the central plateau of Shewa, Ethiopia," *Acta Phytogeographica Suecica*, vol. 79, pp. 1–59, 1993.

[36] J. Neelo, D. Teketay, W. Masamba, and K. Kashe, "Diversity, population structure and regeneration status of woody species in dry woodlands adjacent to <>molapo<i> farms in northern Botswana," *Open Journal of Forestry*, vol. 3, no. 4, pp. 138–151, 2013.

[37] J. Popma, F. Bongers, and J. Meave del Castillo, "Patterns in the vertical structure of the tropical lowland rain forest of Los Tuxtlas, Mexico," *Vegetatio*, vol. 74, no. 1, pp. 81–91, 1988.

[38] M. Dhaulkhandi, A. Dobhal, S. Bhatt, and M. Kumar, "Community structure and regeneration potential of natural forest site in Gangotri, India," *Journal of Basic & Applied Sciences*, vol. 4, no. 1, pp. 49–52, 2008.

[39] G. P. K. Tiwari, K. Tadele, F. Aramde, and S. C. Tiwari, "Community structure and regeneration potential of shore arobusta forest in subtropical sub montane zone of Garhwal Himalaya, India," *Nature and Science*, vol. 8, pp. 70–74, 2010.

[40] F. Temesgen and B. Warkineh, "Woody species structure and regeneration status in kafta sheraro national park dry forest, tigray region, Ethiopia," *International Journal of Financial Research*, vol. 2020, pp. 1–22, 2020.

[41] S. Shimelse, T. Bekele, and A. Mengistu, "Floristic diversity and structure of nechisar national park, Ethiopia," *Journal of the Drylands*, vol. 3, no. 1, pp. 165–180, 2010.

[42] T. C. Whitemore, "Tropical forest disturbance, disappearance and species loss," in *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities*, W. F. Laurance and R. O. Bierregaard, Eds., p. 616, The University of Chicago Press, Chicago, IL, USA, 1997.

[43] P. W. Richards, *The Tropical Rain Forest*, Cambridge University Press, Cambridge, UK, Second edition, 1996.

[44] R. Marles and N. Farnsworth, "Antidiabetic plants and their active constituents," *Phytomedicine*, vol. 2, pp. 137–189, 1995.

[45] M. Woldearegay, Z. Woldu, and E. Lulekal, "Species diversity, population structure and regeneration status of woody plants in yegof dry afromontane forest, north eastern Ethiopia European," *Journal of Advanced Research in Biological and Life Sciences*, vol. 6, p. 4, 2018.

[46] M. Breugel, "Dynamics of secondary forests," Ph. D. thesis, Wageningen University, Wageningen, The Netherlands, 2007.

[47] H. Yineger, E. Kelbessa, T. Bekele, and E. Lulekal, "Floristic composition and structure of the dry afromontane forest at Bale Mountains National Park, Ethiopia," *Sinet: Ethiopian Journal of Science*, vol. 31, no. 2, pp. 103–120, 2011.

[48] M. Kebede, M. E. Y. Kanninen, E. Yirdaw, and M. Lemenih, "Vegetation structural characteristics and topographic factors in the remnant moist afromontane FOREST of wondo Genet, south central Ethiopia," *Journal of Forestry Research*, vol. 24, no. 3, pp. 419–430, 2013.

[49] F. O. Ademoh, J. I. Muoghalu, and B. Onwumere, "Temporal pattern of tree community dynamics in a secondary forest in southwestern Nigeria, 29 years after a ground fire," *Global Ecology and Conservation*, vol. 9, pp. 148–170, 2017.

[50] P. W. Richards, *The Tropical Rain Forests*, Cambridge University Press, Cambridge, UK, 1952.

[51] K. J. Gaston and W. E. Kunin, "Concluding comments," in *The Biology of Rarity: Causes and Consequences of Rare-Common Differences*, W. E. Kunin and K. J. Gaston, Eds., pp. 262–272, Chapman & Hall, London, UK, 1997.

[52] D. Rabinowitz, "Seven forms of rarity," in *In the Biological Aspects of Rare Plant Conservation*, H. Syngeg, Ed., pp. 205–217, Wiley, New York, NY, USA, 1981.

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

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

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

[56] A. Bekele, *Useful Trees of Ethiopia: Identification, Propagation and Management In 17 Agroecological Zones*, p. 552pp, RELMA in ICRAF Project, Nairobi, Kenya, 2007.

[57] E. Tetetla-Rangel, J. L. Hernandez-Stefanoni, and J. M. Dupuy, "Patterns of rare woody species richness: the influence of environment, landscape attributes and spatial structure across different spatial scales," *Biodiversity & Conservation*, vol. 22, no. 6-7, pp. 1435–1450, 2013.

[58] S. A. Cain and G. M. O. Castro, *Manual of Vegetation Analyses*, Harper and Brothers, New York, NY, USA, 1959.

[59] K. Gebrehiwot and K. Hundera, "Species composition, plant community structure and natural regeneration status of belete moist evergreen montane forest, oromia regional state, southwestern Ethiopia," *Momona Ethiopian Journal of Science*, vol. 6, no. 1, pp. 97–101, 2014.

[60] T. Bogale, D. Datiko, and S Belachew, "Structure and natural regeneration status of woody plants of berbere afromontane moist forest, bale zone, south east Ethiopia; implication to biodiversity conservation," *Open Journal of Forestry*, vol. 7, no. 3, pp. 352–371, 2017.

[61] G. Masresha, T. Soromessa, and E. Kelbessa, "Status and species diversity of Alemsaga forest, northwestern Ethiopia," *Advances in Life Science and Technology*, vol. 34, 2015.

[62] H. A. Wale, T. Bekele, and G. Dalle, "Plant community and ecological analysis of woodland vegetation in Metema area, amhara national regional state, northwestern Ethiopia," *Journal of Forestry Research*, vol. 23, no. 4, pp. 599–607, 2012.

[63] Girma and Mosandl, "Structure and potential regeneration of degraded secondary stands in munessa-shashemene forest, Ethiopia," *Journal of Tropical Forest Science*, vol. 24, no. 1, pp. 46–53, 2012.

[64] H. Lamprey, *Challenges Facing Protected Area Management in Sub-saharan Africa*, pp. 9–17, Narobi, Kenya, UNESCO, 1992.

[65] C. Uhl and P. W. Murphy, "Composition, structure, and regeneration of aTierra firme forest in amazon basin of Venezuela," *Tropical Ecology*, vol. 22, pp. 219–231, 1981.

[66] V. T. Nguyen, R. Mitlöhner, and N. van Bich, "Comparison of floristic composition in four sites of a tropical lowlandforest on the North-Central Coast of Vietnam," *Journal of Nature and Science*, vol. 1, no. 8, p. e144, 2015.

[67] M. Ashagre, Z. Asfaw, and E. Kelbessa, "Ethnobotanical study of wild edible plants in burji district, segan area zone of southern nations, nationalities and peoples region (SNNPR), Ethiopia," *Journal of Ethnobiology and Ethnomedicine*, vol. 12, no. 1, p. 32, 2016.

[68] G. Addis, Z. Asfaw, and Z. Woldu, "Ethnobotany of wild and semi-wild edible plants of konso ethnic community, south Ethiopia," *Ethnobotany Research and Applications*, vol. 11, pp. 121–141, 2013.

[69] T. Teklehaymanot and M. Giday, "Ethnobotanical study of wild edible plants of kara and kwego semi-pastoralist people in lower omo river valley, debub omo zone, SNNPR, Ethiopia," *Journal of Ethnobiology and Ethnomedicine*, vol. 6, no. 1, p. 23, 2010.