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# Abundance and Density Distribution of Trees in Intact and Disturbed Parts of Agoro-Agu Central Forest Reserve, Lamwo District, Northern Uganda

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## ABSTRACT

Knowledge of the abundance and density distribution of trees is critical for sustainable land management and biodiversity conservation. The study aimed to assess the abundance and density distribution of trees in the intact and disturbed portions of Agoro-Agu Central Forest Reserve (AACFR), Lamwo District, Northern Uganda. Fifteen 2-km-long transects were laid: nine in the intact part and six in the disturbed part of AACFR. Nested quadrats of $25 \times 25$ m, $10 \times 10$ m, and $5 \times 5$ m were laid out systematically at 100-m intervals for the enumeration of mature trees (dbh $\geq 10$ cm), saplings (dbh 3–9.9 cm), and seedlings (rcd = 1–2.9 cm). Soil samples were collected from each plot at 10-cm depth and mixed thoroughly to form a composite sample for laboratory analysis, and the basal area was calculated for each tree species encountered. The results indicated a reverse J–shaped decline in the number of trees with increasing size classes for the intact part and a lack of a smooth reverse J–shaped curve for the disturbed part. The basal area was high (96 $m^2$/ha) in the intact part of the reserve, with size classes 10–19.9 cm and 20–29.9 cm contributing more on the midslope. The average stand density was 370–603 trees $ha^{-1}$, with *Combretum molle*, *Vachellia hockii*, and *Albizia grandibracteata* being the most abundant in both parts of the reserve. The population stability and natural regeneration were promising enough for future conservation planning of AACFR, indicating that the observed differences in species and their abundance were largely due to the anthropogenic disturbances. There is a need for constant monitoring of the population dynamics of tree species that either appear to have low regeneration potential or are not represented in the disturbed part of the reserve as a way of maintaining the natural stability of tree species in AACFR.

## 1 | Introduction

Protected natural reserve forests such as Agoro-Agu Central Forest Reserve (AACFR) are biodiversity-rich habitats on the globe because they host diverse flora and fauna species that provide both tangible and intangible products/services to society and the environment [1]. Despite being important to both rural/urban populations and forest-based communities, these forest

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resources in most African countries and other developing countries are threatened by natural and anthropogenic disturbances [2]. According to Hishe et al. [3], anthropogenic disturbances are increasingly affecting the vitality of dry afromontane forests.

In Uganda, AACFR is one of the dry afromontane forests at the border of Uganda and South Sudan [4], with the adjoining high elevations in South Sudan–Northern Uganda border harboring a mixture of various kinds of forests, including afromontane forests, shrub lands, woody grasslands, and bamboo—*Sinarundinaria alpina* [5]. According Gorsevski et al. [6], for many years since the mid-1980s, the reserve and surrounding areas suffered from the persistent presence of the Lord's Resistance Army (LRA) and the Sudanese People's Liberation Army (SPLA). This situation got exacerbated by the high level of encroachment from the resettling population as people return from captivity [7]. Thus, assembling information on the abundance and density distribution of tree species in AACFR was needed to enable a full understanding of where returnees settled and how their use of land had affected forest cover in the reserve. Such information is not only the key to understanding important aspects of tropical forest ecosystems but also helps determine the population structure of tropical forest ecosystems more effectively than any other living component of the system [8].

Apart from providing the necessary context for planning and interpreting long-term ecological research [9], data from such a study would be equally relevant to AACFR, with a lot of the pressure from resettling war returnees and the need to make choices and decisions for biodiversity conservation in this forest landscape. In addition, ascertaining tree density and basal area (BA) parameters would also be useful for managing natural forest resources and facilitating proper planning and management of biodiversity and ecosystem services provided in such a reserve [10]. Specifically, the study (i) determined the abundance and density of tree species by size classes and (ii) assessed factors influencing the abundance and density distribution of trees in the AACFR. This study hypothesized that the abundance, BA, and densities of different tree sizes in the disturbed parts of AACFR show patterns traceable to those of the intact parts of the forest.

## 2 | Materials and Methods

### 2.1 | Location and Size of the Study Area

The Agoro-Agu forest landscape is within the Agoro-Agu Sector in Uganda. It consists of 17 central forest reserves in the Aswa River range [11]. The reserve covers a total area of 236 $km^2$/ 26,508 ha [12]. It is among patches of diverse Eastern Afromontane landscape at the border between Uganda and South Sudan, located in Lamwo District, Northern Uganda, between 3° 40′–3°53′ N and 32°42′–33°04′ E (Figure 1 [13]).

The vegetation of AACFR has been broadly classified as dry *Combretum* savannah, forest-savannah mosaic, and dry montane forest [13]. The climate of AACFR is tropical afromontane, and its rainfall is fairly constant throughout the season with warm daytime temperatures up to 35°C that cool to 15°C at night (at Katire, 800 m A.S.L.). Rainfall across the study region is seasonal, with the rainy season beginning in late March and lasting until the end of October [6]. AACFR is one of the important plant areas (IPAs) of Uganda, the most important sites for conservation of plants owing to the presence of rare and threatened plant species, including *Cordyla richardii* (VU), *Ocotea kenyensis* (VU), *Aloe macleaya* (EN), and *Pentas purseglovei* [14].

### 2.2 | Data Collection

The study followed a design by Delgado-Aguilar et al. [15] in which the naturalness or the integrity of the ecosystem and human disturbance features were used as a basis for landscape description of intact (nondisturbed with no signs of significant human activity) and disturbed landscapes that consisted of relatively flat mid-slope areas with settlements and human activities [16, 17].

Based on the above idea, a total of 12.7 hectares of the forest reserve was surveyed, consisting of 9.5 ha of the intact part and 3.2 ha of the disturbed part that constituted less than 5% of the total reserve area. The vegetation community landscape was further categorized and subdivided into ridge top, mid-slope, and valley bottom topographic positions, following Mligo [18].

Fieldwork was started with a reconnaissance of the intact and disturbed parts of the forest reserve [13]. This was intended to plan the stratification of sample sites based on naturalness and intactness or extent of human disturbance on the forest reserve [13, 17]. The nondisturbed areas were considered to be at least 1 km away from the motorable paths and half a kilometer from the footpaths. This guided the laying of transects and establishment of plots during data collection [19]. The sampling was proportional, with the sampled disturbed part being a third of the total area sampled. The number of transects was 40% for the disturbed and 60% for the intact portion of the forest.

Indeed, a large forest area (intact) required more transects and quadrats to adequately represent the various features for studying the tree species abundance, BA, and density and to ensure sufficient representative samples of all patches [19]. Such a large number of transects enabled proper calculation of average densities, BA, and so on, without any compromise as far as the assumption of statistical data analysis was concerned.

A total of 15 transects, each 2 km long, were laid throughout the study area: nine in the intact part and six in the disturbed part of the forest reserve. Along each transect, nested quadrats (alternating on either side of each transect) were laid out systematically at 100-m intervals [13]. The intertransect distance was 600 m, and the interplot distance was 100 m (Figure 2 [13]).

Within the 25 × 25 m plot, smaller plots of 10 × 10 m and 5 × 5 m were nested to sample mature trees, saplings, and seedlings, respectively [20]. In this study, seedlings were considered young trees with root collar diameter (rcd) between 1 and 2.9 cm, and data were obtained from the 5 × 5 m plots; saplings were defined as having diameter at breast height (dbh) between 3 and 9.9 cm, and data were collected from 10 × 10 m plots (Table 1 [13]).

Mature trees were considered trees with a dbh of ≥ 10 cm, and the data were recorded from 25 × 25 m plots throughout the inventory [20]. The total number of plots for the entire sampled area for both intact and disturbed parts of the reserve was 203, of which 152 were in the intact part and 51 were in the disturbed part of the forest reserve. The dbh of the trees was measured using either a vernier caliper (for smaller trees) or a tape measure

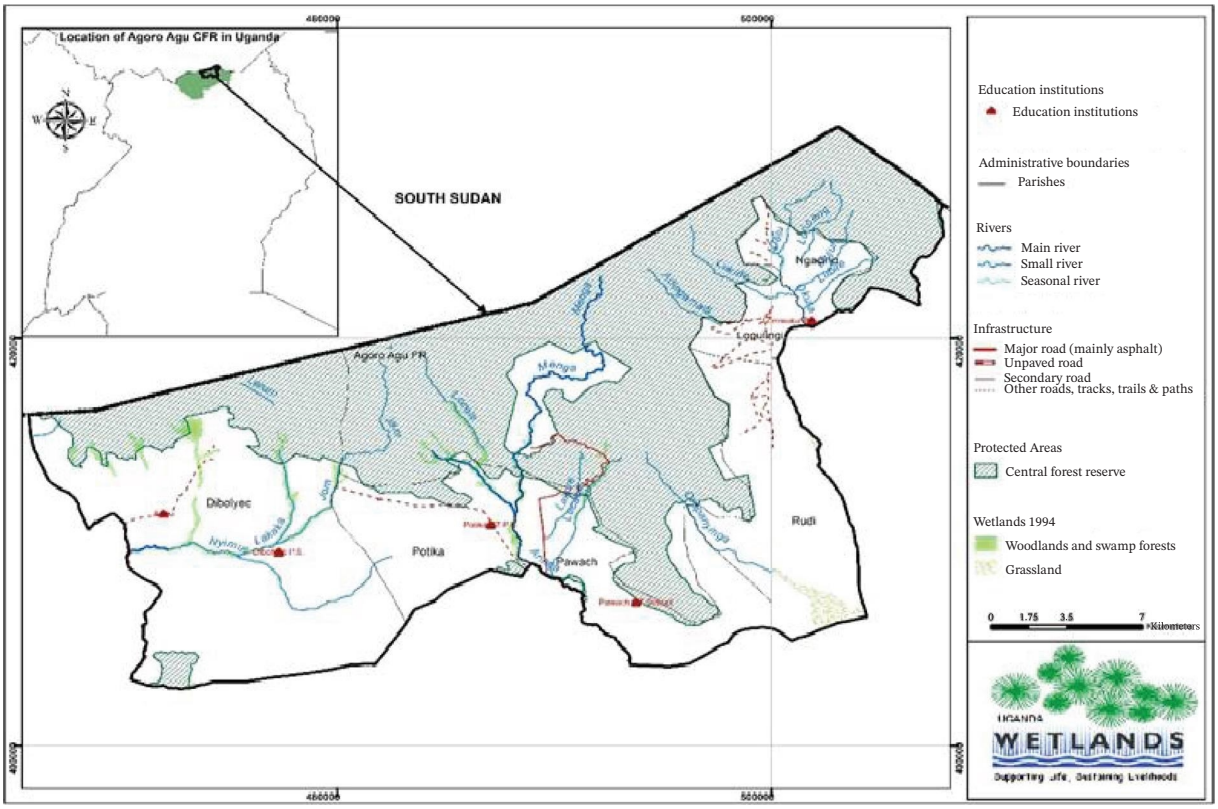



**FIGURE 1** | Map of Agoro-Agu central forest reserve, adapted from Okullo et al. [13].

(for very big trees) and recorded under different diameter class sizes (Table 1). Specimens of unidentified trees were collected and taken to Makerere University Herbarium for identification [13].

The density of seedlings, saplings, and adult trees was calculated as the total number of stems divided by the sampled area, and community parameters such as frequency, BA, and density were quantitatively analyzed [21]. The number of individuals of all adult trees was recorded in different diameter classes, namely, 10–19.9 cm; 20–20.9 cm, 30–30.9 cm, 40–40.9 cm, 50–50.9 cm, 60–60.9 cm, and $\geq 70$ cm to understand the abundance and density distribution of tree species in the area [1].

## 2.3 | Measurement of Environmental Variables

In each plot, slope position, slope angle, canopy cover, and drainage were all measured and recorded [22], and collected soil samples were dried under room temperature and stored in polythene bags ready for their soil physical and soil chemical analysis [23].

Soil physical and chemical properties: Soil samples were collected using a soil auger by sinking it into the soil up to 10 cm depth at five different points (at the four corners and center of each plot measuring $25 \times 25$ m following the method by Bansal et al. [24]. The collected soil samples were then mixed to make a composite representative sample [17]. From this, 0.5-kg representative soil samples from each plot were wrapped in paper bags, coded, shade-dried, and transported to Makerere University for chemical and textural analyses. The chemical and textural analyses were done for pH, particle size, organic carbon content, and other mineral contents such as N, available P, and the exchangeable bases (Al, K, Na, Ca, and Mg) following the Hoang and Coelli [25] method.

Slope position and slope angle: This was recorded as valley bottom, midslope, or ridge top using simple observation of slope position in forested areas following Chuyong et al. [26]. The slope angle was measured from the center of the bigger plot of $25 \times 25$ m using a Suunto clinometer calibrated in degrees [27]. The readings were used to classify the slope as

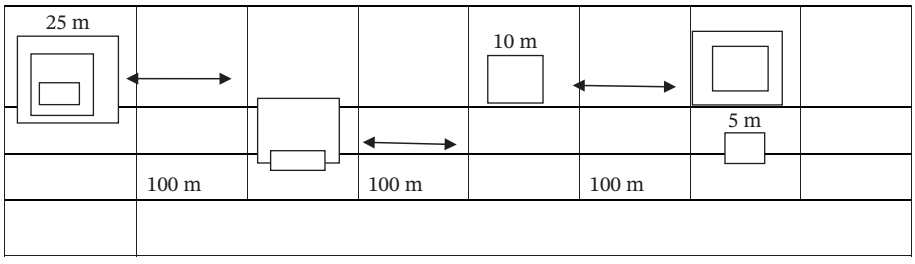



**FIGURE 2** | Diagrammatic presentation of plot layout along transects [13].

**TABLE 1** | Plot size, diameter class size, and tree category.

| Plot size (m) | Diameter size class in dbh/rcd (cm) | Tree category assessed |
|---|---|---|
| $25 \times 25$ | $\geq 10$ | Adult/mature trees |
| $10 \times 10$ | 3–9.99 | Saplings |
| $5 \times 5$ | 1–2.99 | Seedlings |

*Note:* Adapted from Dibaba et al. [20] and Okullo et al. [13].

flat ($\leq 5\%^{\circ}$), moderately steep (5%–35%°), and very steep (above 35%°) [13].

Canopy cover: Canopy cover was estimated by dividing the plot into four quadrats, and from each quadrat, the estimate of the canopy was determined using a densitometer [28]. The average canopy cover of the plot was calculated by adding readings from the four corners of the plot and the average figure per plot obtained by dividing by four [28].

Drainage: Drainage was recorded through the observation of the presence of permanent and seasonal streams/rivers or the absence of the drainage system [29]. This idea was that the presence of drainage may influence the tree species population structure, density, and distribution.

## 2.4 | Data Analysis

### 2.4.1 | Analysis of BA and Tree Density by Size Classes

The field inventory data for the tree analysis were tallied into observed stem diameter classes and grouped into seedlings (rcd 1.0–2.9 cm), saplings/(3–9.9 cm dbh), and mature trees (> 10 cm) based on the grouping by Okullo *et al*. and Dibaba *et al*.[13, 20]. They were then summarized by the number of species, stand density (trees) per hectare, and BA per hectare [1].

### 2.4.2 | BA

The BA of trees was calculated using the following formula:

$$\mathrm{BA} := \frac{\{1/4(3.14 \times \mathrm{dbh}^2)\}\mathrm{m}^2}{1000}. \quad (1)$$

The dbh size class graphical distribution was established by plotting the number of individuals for each diameter size class against the respective size classes to produce the stand abundance curves [30].

### 2.4.3 | Analysis of Environmental Factors Influencing Tree Abundance and Density Distribution

Environmental factors are important determinants for species spatial pattern distribution in an area [31]. To estimate the influence of environmental factors on tree species, we used information on topography, climate, and soil factors [31]. Environmental factors analyzed included soil, physical, and chemical properties. Soil samples were air-dried and passed through a 2-mm-mesh sieve for physicochemical properties. While soil particle size distribution was determined by the pipette method, soil pH was measured with a glass electrode using a soil-to-solution ($H_2O$ or 1 M KCl) ratio of 1:5, hereafter denoted as pHw and pHk, respectively. Electrical conductivity (EC) was measured using the supernatant at a soil-to-water ratio of 1: 5 [32].

Total carbon (TC) and total nitrogen (TN) contents were determined by a dry combustion method using an NC analyzer [33]. Available P was determined by the Bray II method [34]. The contents of exchangeable bases (Ca, Mg, K, and Na) were extracted twice with 1 M ammonium acetate at pH 7.0 [35]; while CEC was determined by the steam distillation method, exchangeable Al, H, and $NH_4$ were extracted with 1 M KCl [36].

The soil physical properties (sandy, loam, organic carbon, and clay soils) and other environmental factors, such as drainage, canopy, and slope position, were then assessed in terms of their relative importance to the tree species density and composition. Canonical Correspondence Analysis (CCA) was performed in the PAleontological STatistics (PAST) software, Version 4.03, to explore these relationships and determine the strength of the environmental variables using the length of the arrows and the eigenvalues [31, 37]. Automatic forward selection of environmental variables was done to determine the variables that were more significant than the rest [38] to help provide insights into the tree population structure and distribution in AACFR.

## 3 | Results

### 3.1 | Tree Abundance and Density Distribution

#### 3.1.1 | Diameter Size Class Distribution

There was a decline in the number of trees with increasing diameter size classes (Figures 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f)). The age structure of the tree population in the intact part of the reserve conforms to the reverse J shape for most tree species (Figures 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f)). The tree species such as *Vachellia hockii*, *Combretum molle*, *Albizia grandibracteata*, *Terminalia schimperiana*, *Hagenia abyssinica*, and *Grewia mollis* showed *an* inverse J curve in the population structure and fair regeneration status in both the intact and disturbed parts of the reserve, with most having a higher number of seedlings than saplings in both parts of the reserve.

Seedling recruitment was higher in the disturbed part than in the intact part of the reserve, except for a few forest species whose recruitment was exclusive to the intact part of the reserve only in lower size classes, and the number gradually declined as the size classes increased. Generally, bigger individuals of dbh $\geq$ 40–50 cm were few in most species (Figures 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f)).

In a disturbed site, *C. molle*, *V. hockii*, and *A. grandibracteata* similarly registered higher numbers of individuals in lower size classes. While the curves do not conform to the reverse J shape, they show a sudden drop in pattern. The size classes of rcd of 1–2.9 cm and dbh of 1–9.9 cm were of higher proportions for most of the species in the disturbed part than in the intact part of the reserve. The tree species of size classes of dbh 10–29.9 cm and dbh $\geq$ 30 cm were comparatively more in the intact part of the reserve than in the disturbed part (Figures 3(a), 3(b), 3(c), 3(d), 3(e), and 3(f)).

The higher size classes of dbh $\geq$ 40 cm were exclusive to the intact part of the reserve. This consisted of tree species such as *H. abyssinica*, *A. grandibractaeta*, *Syzygium cordatum*, *Dombeya*

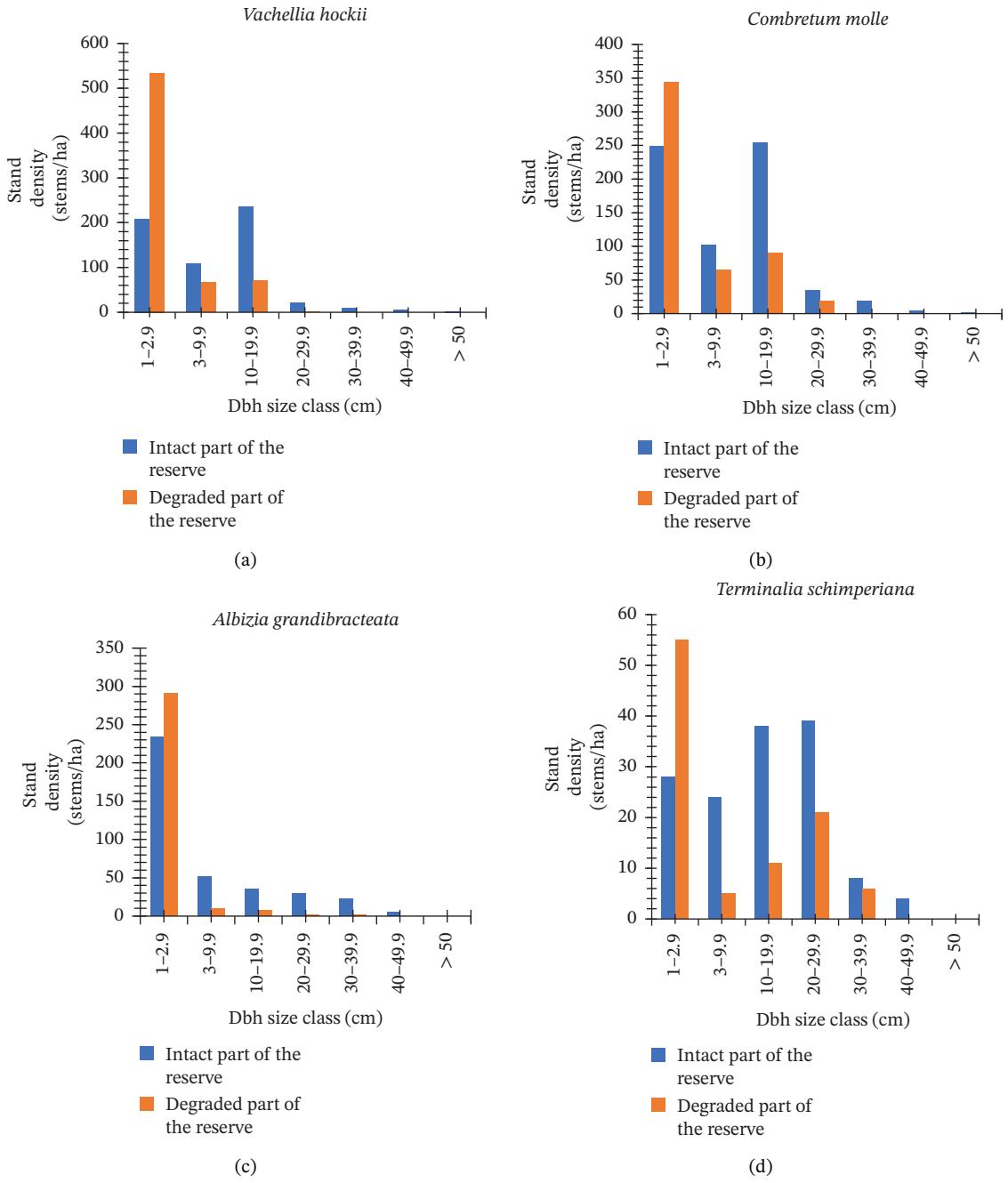



**FIGURE 3** | (Continued)

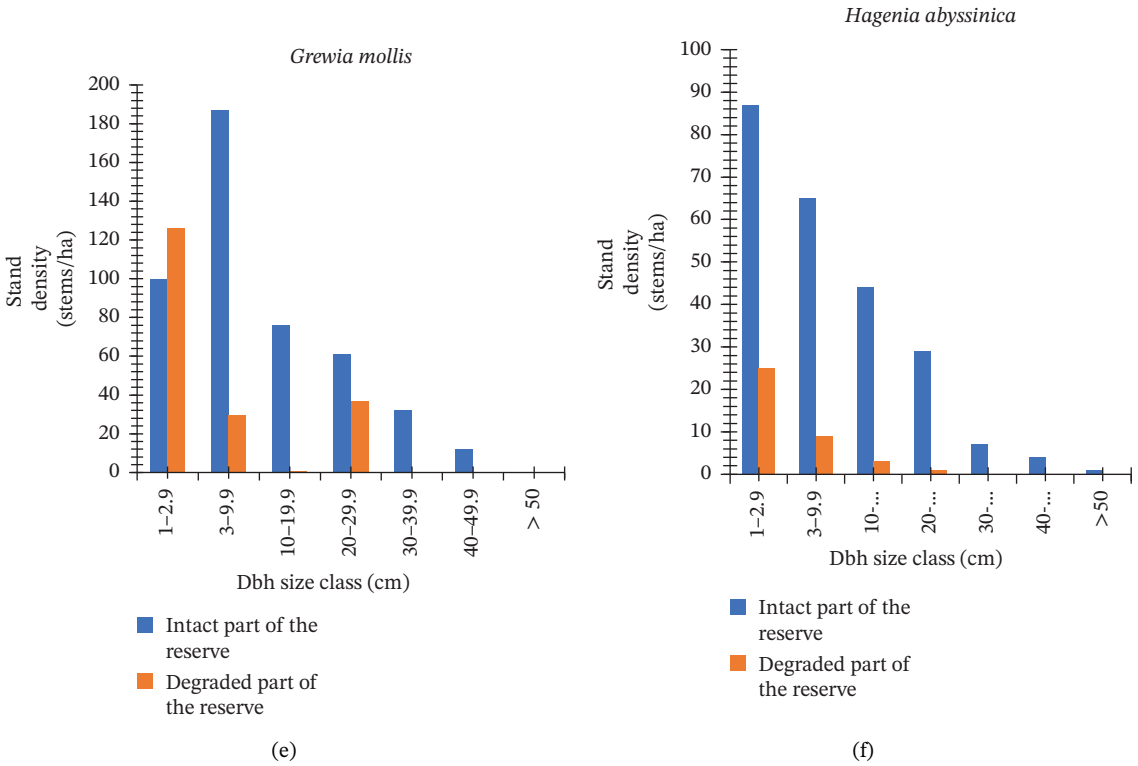



**FIGURE 3** | (a–f): Stand density by diameter size classes of the first six tree species in the intact and disturbed parts of the reserve.

*torrida*, *Shirakiopsis elliptica*, and *T. brownii*, each contributing to 5.7% of the stands. Other tree species with dbh ≥ 70 cm included *Lovoa swynnertonii* (dbh = 95 cm), followed by *Euphorbia candelabrum* (dbh = 80 cm), *V. macrostachya*, *Entada abyssinica*, *A. grandibracteata* (dbh = 75 cm), and *Mimusops bagshawei* (dbh = 70 cm).

### 3.1.2 | Density Distribution of Diameter Size Classes Along the Topographic Gradient

The density distribution of diameter size classes along the topographic gradient (ridge top, mid-slope, and valley bottom) also displayed a reverse J–shape for many species such as *V. hockii*, *C. molle*, and *A. grandibracteata* (Figures 4(a) and 4(b)). It is worth noting that similar species in the ridge top did not conform to the reverse J–shaped pattern and thus an abnormality in the growth pattern (Figure 4(c)).

The density of size classes (rcd 1–2.99 cm) and (3–9.99 cm) was more in the mid-slope, followed by the valley bottom, and least in the ridge top (Figures 4(a), 4(b), and 4(c)). On the other hand, the stand density proportion of mature trees of size classes (dbh≥ 10–29.9 cm) was comparatively higher in the mid-slope and lowest in the ridge top. For example, *A. grandibracteata*, *V. hockii*, and *V. macrothyrsa*, and their stand density size classes of dbh ≥ 40 cm were completely absent in the ridge top and were more in the valley bottom.

### 3.1.3 | BA and Size Class Distribution in Intact and Disturbed Parts of the Forests

The mean BA was higher in the intact part of the reserve (96 $m^2$/ha) than in the disturbed part (15.8 $m^2$/ha) and was significantly different ($p \leq 0.05$), although the number of stands was higher in the disturbed part. The disturbed part had more stand individuals but predominantly smaller trees of dbh 1–9.9 cm. The size classes of 10–19.9 cm and 20–29.9 cm, however, contributed more to the BAs of the intact part than in the disturbed part of the reserve (Figure 5).

The size classes with dbh ≥ 50 cm were least in the disturbed part of the reserve, but its contribution to the BA of the intact part of the reserve was significant. In terms of size class contributions, dbh ≥ 30 cm contributed 56% and 22% of the total BAs for the intact and disturbed parts of the reserve, respectively. Although dbh 1–2.9 cm, dbh 3–9.9 cm had the highest stand density, they had the least BA contribution in both the intact and disturbed portions of the reserve. *V. hockii* and *C. molle* were the most important and dominant tree species across the entire study area (intact and disturbed parts and even along topographic positions).

### 3.1.4 | BA and Size Class Distribution by Topographic Gradient

Along the topographic gradient, the BAs of the class sizes 10–19.9 cm and 20–29.9 cm were higher in the mid-slope, followed by the valley bottom, and lowest in the ridge top (Figure 6). While the BA was highly significantly different for the valley bottom and mid-slope ($p \leq 0.01$) and also for the valley bottom and ridge top ($p \leq 0.01$), it was not significantly different for the mid-slope and ridge top ($p = 0.16$).

### 3.1.5 | Stand Density

Stand density of the encountered tree species indicated considerable variations between intact and disturbed parts of the forest reserve (Table 2). The average stand density ranged from 272 trees $ha^{-1}$ to 679 trees $ha^{-1}$ for the intact part and disturbed

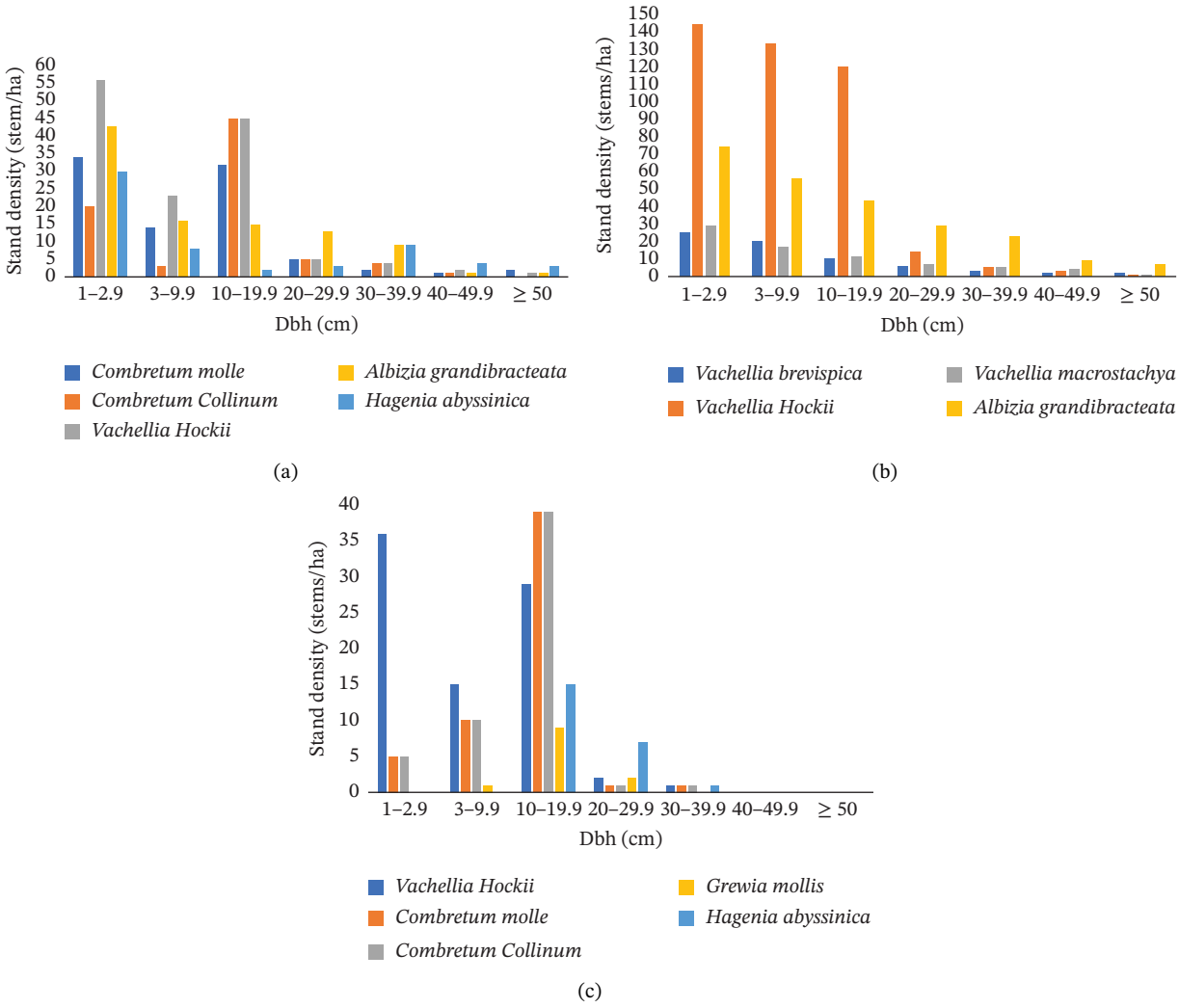



**FIGURE 4** | (a–c): Diameter size classes by the stand density along the valley bottom, mid-slope, and ridge top.

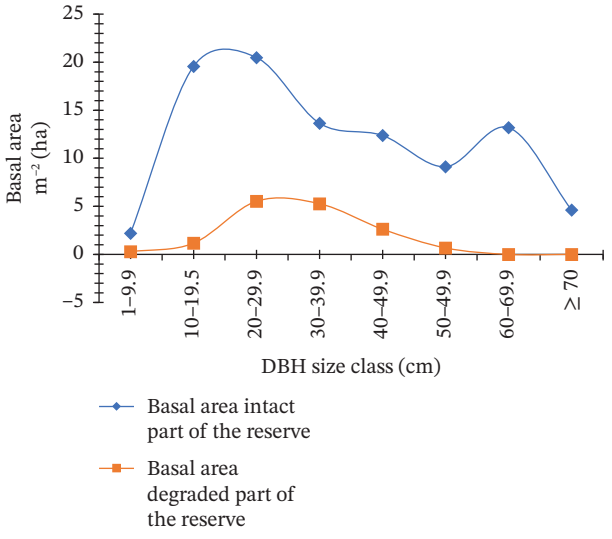



**FIGURE 5** | Basal area in the intact and disturbed parts of the reserve by dbh size classes.

parts of the reserve, respectively. *C. molle*, *V. hockii*, and *A. grandibracteata* contributed more to the average stand density in both intact and disturbed parts of the reserve (Table 2).

The density distribution of diameter size classes along the topographic gradient has been presented only for the intact parts of the forest, as the disturbed parts were mostly located on the bottom slope and were easily accessible to surrounding communities. Hence, the density distribution gradient along the slope for the disturbed parts was markedly altered and could no longer be analyzed.

The stand density of different tree species varied considerably along topographic positions (Table 3). Along topographic gradients, the stand density was highest in the mid-slope (679 trees $ha^{-1}$), followed by the valley bottom (272 trees $ha^{-1}$), and least in the ridge top with 208 trees $ha^{-1}$ (Tables 3(a), 3(b) and 3(c)). Overall, the mid-slope stand tree density (679 trees/ha) was significantly different ($p = 0.01$) from the valley bottom with an average stand density of 273 trees/ha, which was also significantly different ($p = 0.02$) from the ridge top with 208 trees/ha.

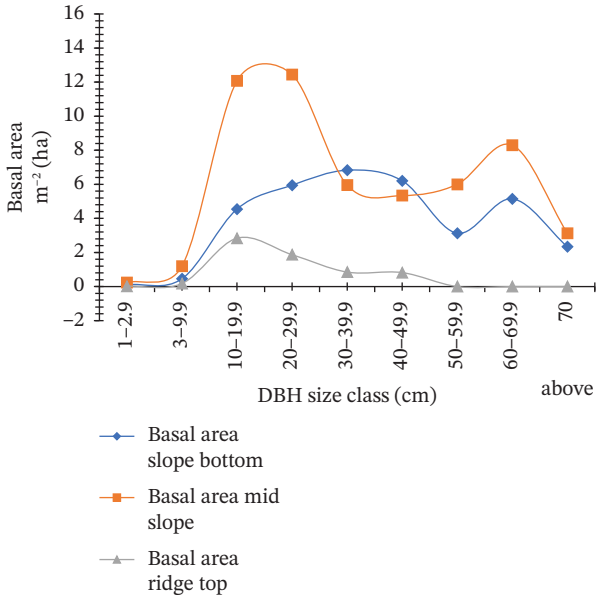



**FIGURE 6** | Basal area contribution by size classes in the topographic location (valley bottom, mid-slope, and ridge top).

## 3.2 | Environmental Factors Influencing Tree Species Abundance and Density

### 3.2.1 | Soil Physical and Chemical Properties

The soil physical and chemical properties varied with sites. Whereas the intact part shows high values of soil PH, organic carbon, N, and C:N, the disturbed part of the reserve, in contrast, registered high values for sand, clay, and exchangeable bases. Along topo-positions, the average values for organic carbon (%), nitrogen (ppm), phosphorus (ppm), and sandy soil decreased upslope with the ridge top having the least (Table 4).

On the other hand, clay soil, silt, and other exchangeable soil minerals ($Na^+$, $K^+$, $Ca^{2+}$ & $Mg^{2++}$) content showed the reverse. While nitrogen had values ranging from 0.26 to 0.33 ppm and varying signifianctly ($P \leq 0.05$) with topositions, the organic matter content ranged from 3.97% to 4.68% and didnot avry significantly with topositions. The soil C:N ratio ranged from 11.06 to 20.35. It was highest in the valley bottom, while the organic carbon concentration varied significantly. The soil pH ranged from 5.95 to 6.1 with a mean of 6.00, increasing up slope (Table 4).

### 3.2.2 | Tree Canopy Cover

The canopy cover varied significantly across the two sites, with the intact part of the reserve being more closed (ranging from canopy cover area 35%–80%) than the disturbed portion of the reserve ranging from 10% to 21%. Along the topographic gradient, the valley bottom had the densest canopy cover, ranging between 50% and 80%, followed by the mid-slope, which ranged between 35% and 65%, and the least was the ridge top, ranging between 10% and 21%.

### 3.2.3 | CCA

The CCA relationships between tree species abundance/density and the environmental variables (such as drainage, sandy soil, loam soil, clay soil, canopy, and slope position) are displayed using an ordination diagram with arrow length indicating the strength of each variable (Figures 7(a), 7(b), and Figure 8).

For the valley bottom, mid-slope, and ridge top of the intact parts of AACFR (Figure 7), the first CCA axis (Axis 1) was most strongly negatively correlated with soil depth (positively), followed by Na, clay, pH, K, Mg, and altitude (negatively). The second axis (Axis 2) showed positive correlations with P and OC and negatively correlated with canopy, drainage, loamy sand, and slope angle. The items and values for the first two axes had low values of 0.160 (for Axis 1) and 0.147 (for Axis 2). The CCA also revealed low cumulative

**TABLE 2** | Density distribution of trees in the intact and disturbed parts of the reserve.

| Tree species | Basal area/ha | | Density (stems $ha^{-1}$) | | Relative density | | Relative dominance | |
|---|---|---|---|---|---|---|---|---|
| | Intact | Disturbed | Intact | Disturbed | Intact | Disturbed | Intact | Disturbed |
| *Combretum molle* R.Br. ex G.Don | 06.09 | 02.53 | 756 | 2134 | 18.56 | 24.49 | 07.19 | 21.75 |
| *Vachellia hockii* De Wild | 06.28 | 01.17 | 657 | 1529 | 16.15 | 17.55 | 07.14 | 09.64 |
| *Terminalia schimperiana* Hochst. | 04.37 | 03.37 | 330 | 509 | 08.11 | 05.85 | 07.46 | 16.33 |
| *Albizia grandibracteata* Taub | 09.74 | 00.36 | 170 | 696 | 04.17 | 07.99 | 13.69 | 03.61 |
| *Grewia mollis* Juss | 01.63 | 00.41 | 268 | 488 | 06.57 | 05.60 | 02.13 | 02.83 |
| *Ficus sycomorus* L. | 02.08 | 00.98 | 146 | 146 | 03.60 | 01.68 | 03.88 | 10.54 |
| *Annona senegalensis* Pers. | 03.85 | 00.31 | 126 | 422 | 03.11 | 04.85 | 04.68 | 02.41 |
| *Bridelia micrantha* (Hochst.) Baill. | 03.12 | 00.26 | 63 | 406 | 01.55 | 04.66 | 01.86 | 02.23 |
| *Vitex doniana* Sweet | 02.59 | 00.73 | 79 | 127 | 01.94 | 01.46 | 02.60 | 03.71 |
| *Stereospermum kunthianum* Cham. | 02.91 | 00.08 | 128 | 329 | 03.14 | 03.78 | 00.16 | 00.84 |
| Subtotal | **42.65** | **10.20** | **2723** | **6786** | **66.9** | **77.89** | **50.79** | **73.89** |
| *p* Value (*F*-test prob) | **0.02*** | | **0.01**** | | **0.53ns** | | **0.10ns** | |

*Note:* The bold values are subtotals of basal area/ha, density (stems $ha^{-1}$), relative density, and relative dominance of the respective intact and disturbed parts of the reserve. The calculated significant values indicated by *p* values (*F*-test prob) are given for values of each subtotal between intact and disturbed portions.
nsNot Significantly different.
*Significantly different.
**Highly significantly different.

**TABLE 3** | Density distribution of trees along topographic positions for the intact part of the reserve.

| Tree species | Basal area/ha | Density/ha | Relative density |
|---|---|---|---|
| **a) Valley bottom** | | | |
| *Pleurostylia capensis* Loes | 02.74 | 273 | 06.41 |
| *Albizia grandibracteata* Taub | 02.43 | 476 | 11.20 |
| *Vachellia hockii* De Wild. | 01.47 | 371 | 08.73 |
| *Entada abyssinica* Steud. ex A Rich. | 02.45 | 320 | 07.54 |
| *Ficus barteri* Sprague | 01.75 | 156 | 03.67 |
| *Combretum molle* R.Br. ex G.Don | 01.36 | 383 | 09.00 |
| *Balanites aegyptiaca* (L.) Delile | 00.61 | 5.00 | 00.12 |
| *Vachellia macrothyrsa* Harms | 00.75 | 256 | 06.03 |
| *Terminalia brownii* Fresen. | 01.69 | 150 | 03.54 |
| *Grewia mollis* Juss. | 00.24 | 283 | 06.66 |
| Sub-total | **15.49** | **2674** | **62.89** |
| **b) Mid–slope** | | | |
| *Combretum molle* R. Br. ex G. Don | 04.03 | 958 | 24.35 |
| *Vachellia hockii* De Wild | 00.25 | 726 | 18.46 |
| *Entada abyssinica* Steud.ex A rich | 07.28 | 132 | 03.35 |
| *Grewia mollis* Juss | 01.19 | 308 | 07.84 |
| *Albizia grandibracteata* Taub | 02.12 | 81 | 02.07 |
| *Stereospermum kunthianum* Cham. | 00.50 | 220 | 05.61 |
| *Terminalia schimperiana* Hochst. | 02.22 | 94 | 02.38 |
| *Terminalia brownii* Fresen. | 03.07 | 35 | 00.88 |
| *Vachellia brevispica* Harms | 04.15 | 16 | 00.41 |
| *Combretum collinum* Fresen. | 01.11 | 94 | 02.40 |
| Sub-total | **25.91** | **2664** | **67.75** |
| **c) Ridge top** | | | |
| *Vachellia hockii* De Wild. | 0.67 | 954 | 41.07 |
| *Combretum molle* R.Br. ex G.Don | 0.87 | 559 | 24.04 |
| *Myrianthus holstii* Engl. | 0.80 | 98 | 04.23 |
| *Maytenus senegalensis* (Lam.) Exell | 0.12 | 158 | 06.81 |
| *Stereospermum kunthianum* Cham. | 0.05 | 180 | 07.77 |
| *Lannea schimperi* (Hochst. ex A.Rich.) Engl. | 0.44 | 30 | 01.30 |
| *Grewia mollis* Juss. | 0.21 | 16 | 00.70 |
| *Hagenia abyssinica* (Bruce) J.F.Gmel. | 0.63 | 20 | 00.88 |
| *Proteas madiensis* Oliv. | 0.01 | 44 | 01.91 |
| *Bridelia micrantha* (Hochst.) Baill. | 0.06 | 24 | 01.03 |
| Sub-total | **3.86** | **2085** | **89.74** |

*Note:* The bold values are not significance values but subtotals for respective basal area /ha, density /ha, and relative density of trees along topographic positions for the intact reserve.

percentage variance for species–environment relations data (Axis 1 = 23.8%; Axis 2 = 45.7%) for both axes.

For both disturbed and intact parts of AACFR (Figure 8), the first CCA axis (Axis 1) was most strongly positively correlated with canopy, drainage, slope angle, and altitude, followed by soil depth (negatively). The second axis (Axis 2) showed strong negative correlations with K, P, Mg, Na, N, CN, and OC. The items and values for the first two axes had low values of 0.02 (for Axis 1) and 0.01 (for Axis 2). The CCA also revealed high cumulative percentage variance for species–environment relations data (Axis 1 = 100%; Axis 2 = 38.7%) for both axes. Even then, the CCA had positive values for species–environment correlations in Axis 1 (0.604) and Axis 2 (0.624), respectively.

The summary produced by the Monte Carlo permutation indicated that species abundance and environmental variables were significantly correlated with axis 1 ($p = 0.024$) and

**TABLE 4** | The soil physical and chemical properties in the Agoro-Agu forest reserve.

| Variable | Units of measurements | Degraded part of the reserve | Intact part of the reserve | Overall | Intact part of the reserve | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Mean | Mean | Valley bottom | Mid slope | Ridge top | min | Mean ± STDVE | Max | *p* value |
| pH | %ge | 05.98 | 05.99 | 06.00 | 5.95 | 5.91 | 6.1 | 5.91 | 05.99 ± 0.10 | 06.10 | $0.08^{ns}$ |
| O.C | %ge | 02.55 | 04.10 | 04.10 | 4.68 | 3.65 | 3.97 | 3.65 | 04.10 ± 0.53 | 04.68 | $0.43^{ns}$ |
| N | Ppm | 00.17 | 00.27 | 00.27 | 0.23 | 0.33 | 0.26 | 0.23 | **00.27 ± 0.51** | 00.33 | $\mathbf{0.04}^{*}$ |
| C:N | — | 08.62 | 15.56 | 15.19 | 20.35 | 11.06 | 15.27 | 11.06 | 15.56 ± 4.56 | 20.35 | $0.38^{ns}$ |
| P | Ppm | 14.76 | 08.78 | 08.78 | 13.95 | 6.1 | 6.29 | 6.1 | 08.78 ± 4.48 | 13.95 | $0.37^{ns}$ |
| Na | me/100 g(cmoles/kg) | 00.23 | 00.12 | 00.12 | 0.11 | 0.11 | 0.14 | 0.11 | **00.12 ± 0.01** | 00.14 | $\mathbf{0.01}^{**}$ |
| K | me/100 g(cmoles/kg) | 00.70 | 00.63 | 00.63 | 0.63 | 0.61 | 0.65 | 0.61 | **00.63 ± 0.02** | 00.65 | $\mathbf{0.02}^{*}$ |
| Ca | me/100 g(cmoles/kg) | 04.98 | 04.66 | 04.66 | 4.87 | 4.31 | 4.8 | 4.31 | 04.66 ± 0.31 | 04.87 | $0.25^{ns}$ |
| Mg | me/100 g(cmoles/kg) | 02.24 | 01.91 | 01.91 | 1.82 | 1.86 | 2.06 | 1.82 | 01.91 ± 0.13 | 02.06 | $0.10^{ns}$ |
| Sand | %Texture | 63.11 | 63.09 | 63.10 | 64.95 | 62.6 | 61.72 | 61.72 | 63.09 ± 1.67 | 64.95 | $0.14^{ns}$ |
| Clay | %Texture | 18.67 | 18.84 | 18.80 | 17.26 | 18.4 | 20.87 | 17.26 | 18.84 ± 1.85 | 20.87 | $0.15^{ns}$ |
| Silt | %Texture | 18.51 | 18.07 | 19.10 | 17.79 | 19 | 17.42 | 17.42 | 18.07 ± 0.83 | 19.00 | $0.67^{ns}$ |

*Note:* The bold values with $^{*}$are statistically significant at $p \leq 0.05$, and the bold values with $^{**}$are statistically highly significant at $p \leq 0.01$, and the unbold values with ns are not statistically significant.

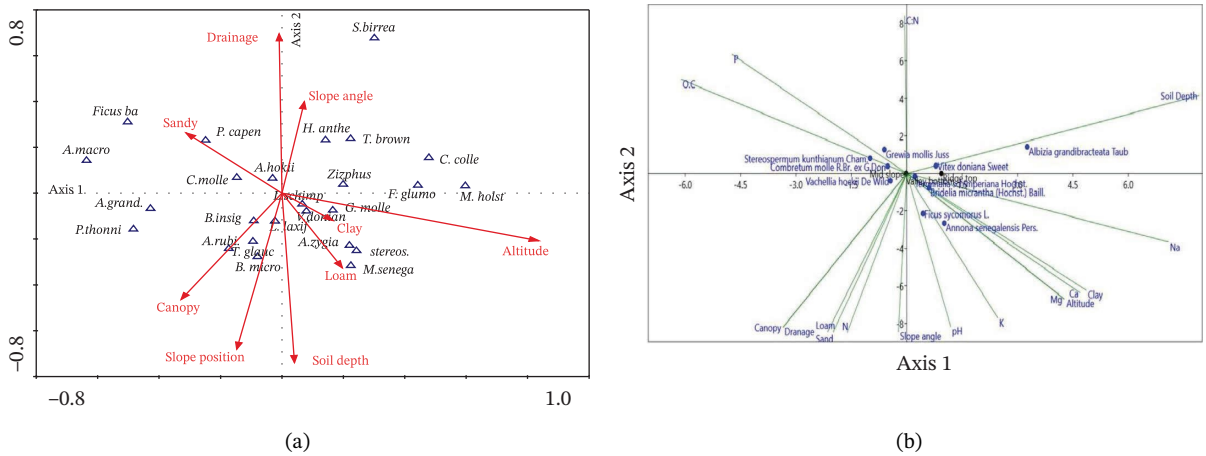



**FIGURE 7** | (a) Canonical correspondence analysis (CCA) ordination diagram for the relationship between environmental variables and tree species diversity in an intact forest. (b) Canonical correspondence analysis (CCA) ordination diagram for the relationship between environmental variables and tree species abundance in the valley bottom, mid-slope, and ridge top of the intact parts of AACFR.

the overall value of $p = 0.004$ (Table 5). The forward selection of environmental variables revealed that sandy soil was more significant than the rest of the variables. This was followed by canopy cover, slope position, and drainage. Other variables, such as slope angle, loam, and clay, appeared less significant (Table 6).

## 4 | Discussion

### 4.1 | Abundance and Density Distribution of Tree Species in the Reserve

#### 4.1.1 | Size Class Distribution of Trees

The results revealed that the studied intact and disturbed forest parts, as well as all topographic positions, contain different tree species, which fulfill critical ecological as well as economic functions [39]. The trend in the size classes displays the histograms showing reverse J–shaped patterns for most tree species in the intact part of the reserve (Figure 4). This is because a stable forest allows for continuous regeneration and growth, resulting in a high number of saplings and a declining number of larger trees. On the other hand, disturbances interrupt this cycle, preventing the establishment of new trees. Thus, the decline exhibited in the number of individuals with increasing size classes (Figure 4) is not uncommon in the population structure of such a reserve [40].

Other similar displays are observed along topographic positions and more especially in the valley bottom and mid-slope (Figure 5). The inverted J-shaped curve depicts many individuals in the lower size classes, which gradually decline with an increase in size classes. This pattern has a large number of individuals at the seedling stage and a smaller number of individuals at the sapling and adult stages, with typical inverted J-shaped curves. The inverted J-shaped pattern indicates that these species have a high capacity for regeneration [17], an indication that changes in environmental factors can increase to stimulate germination, and selective cutting is also being performed in the area [41]. The dominance of small-sized individuals in such forests is also good if the regenerating individuals can be well managed. It also indicates low recruitment potential due to the selective cutting of large tree individuals and good seedling recruitment with a high sapling development potential, which is important for future population self-maintenance of such a forest reserve [1].

Generally, bigger size classes above dbh 50 cm were very few. This probably defines the characteristics of savannah woodland trees. The patterns such as these are indicative of the intactness of the reserve with virtually no or limited anthropogenic disturbances. According to Maua et al. [30], such occurrences are likely to happen due to the extreme location, coupled with difficult terrain and limited accessibility. In addition to anthropogenic factors being associated with this difference in the population structure, frequent human interference could also lead to disturbance of the ecosystem, community, or population structure and related changes in resource availability [17, 42].

Even then, an exponential drop in size class density distribution with increasing dbh describes a growing cohort of trees that may have experienced a past disturbance [43]. For AACFR, this disturbance could have been due to the resettling population and erosion forces on the ridge top[44]. Although such an exponential drop was reported to be common in some natural forests [45]; other scholars, including Attua et al. [46], have also observed that the sharp decrease witnessed in the disturbed part of the reserve and the ridge top site could be indicative of the poor vegetation structure, thereby posing a great threat to the future of

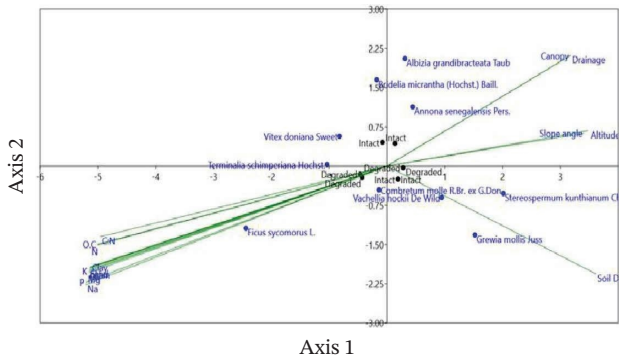



**FIGURE 8** | Canonical Correspondence Analysis (CCA) ordination diagram for the relationship between environmental variables and tree species diversity in both disturbed and intact parts of AACFR.

**TABLE 5** | Summary of values of canonical correspondence analysis (CCA) results in the first two ordination axes and weighted correlation matrix for the environmental variables.

| Axes | 1 | 2 | 3 | 4 | Total inertia |
|---|---|---|---|---|---|
| Eigen values | 0.160 | 0.147 | 0.096 | 0.063 | 10.720 |
| Species environment correlations | 0.604 | 0.624 | 0.573 | 0.528 | |
| Cumulative % variance of species data | 1.500 | 2.900 | 3.800 | 4.400 | |
| Cumulative % variance of species–environment relation | 23.800 | 45.700 | 60.000 | 69.400 | |
| Sum of all eigenvalues | | | | | 10.720* |
| Sum of all canonical eigenvalues | | | | | 00.673* |

*Significant ($p \leq 0.05$).

forests' potential of providing ecosystem services and economic contribution to the country's gross domestic product [47].

### 4.1.2 | BAs of Trees in the Reserve

The low BA witnessed in the disturbed part of the reserve (Figure 6) could be due to deforestation as most mature trees could have been harvested for timber, fuel wood, and land clearance in cultivatable land [48]. On the other hand, the high BA of the intact part of the reserve indicates both a high level of performance of trees and the maturity level of forest stands [49]. Whereas the BA performance in the intact part of the reserve was good, a greater contribution to the BA appears to be from the size classes 10.0–30.0 cm (Figure 6).

Although such a class range would generally be considered smaller trees when compared to other forest reserves elsewhere, Gebeyehu et al. [39] noted that a high proportion of trees in the savannah woodland reserves, such as this one, would consist largely of smaller trees. Subsequently, size classes within 10.0–30.0 cm are now common features of savannah woodland reserves, including AACFR.

### 4.1.3 | Tree Abundance and Stand Density

Tree abundance and stand density can be affected by natural and anthropogenic disturbance or soil conditions [3]. The disturbed part of the reserve had higher abundance and stand density, probably due to many regenerating individuals of the pioneer species. Due to the limited options, poor people living in the vicinity of the disturbed lower slope forests depend heavily upon trees for timber, fodder, fuel wood, and poles. The problem with this kind of disturbance is that forests do not have enough time for recovery, as the human onslaught never stops [17]. According to Gray et al. [50], the high stand abundance and density of trees in the disturbed part of a forest reserve is a demonstration of the potential of tree regeneration and vegetation renewal.

Changes in diameter distribution are also characteristic of disturbed forests. In the case of adult forests with a reverse J diameter structure that are subjected to high grading, these differences may be significant (i.e., dbh $\geq 5$, $\leq 60$ cm), with potential gaps in some diameter classes over dbh 60 cm and a low frequency of individuals in the intermediate diameter classes. This is most probably the result of forest interventions involving the extraction of larger-diameter trees from commercial species, making the majority of highly disturbed forests composed of trees significantly below an established cut diameter, such as those of dbh $< 60$ cm [46]. If damaging human activities occur at regular intervals, forest stands may become severely disturbed, especially if their stock of commercially low-value species is very low [42].

Whereas the record of stand abundance and density encountered in this study appears lower than those of Amazon tropical forests, the density of 272–679 trees $ha^{-1}$ recorded for AACFR looks comparable to tree stand density for other forest reserves in East Africa. While Eilu et al. [51] recorded 479 trees $ha^{-1}$ (for Bwindi, Budongo, and Kibale forests) in Western Uganda, Kayombo et al. [52] recorded 354.10 trees $ha^{-1}$ (for Image Forest Reserve situated in Kilolo District, Iringa Region in the Southern Highlands of Tanzania), Shirima et al. [53] recorded 281–382 trees $ha^{-1}$ in Nyange Forest Reserve (in Miombo woodland), and Kigomo et al. [54] recorded 313 to 761 trees $ha^{-1}$ for Aberdare Afromontane forest ranges in Kenya. Since the average stand abundance and density for AACFR fall within the overall average for most

**TABLE 6** | Variables explaining species–environment correlations using automatic forward selection.

| Marginal effects | Explained before selection ($\lambda 1$) | Conditional effects | Explained after selection ($\lambda 2$) | | |
|---|---|---|---|---|---|
| Variables | $\lambda 1$ | Variables | $\lambda 2$ | $p$ | $F$ |
| Sandy soil | 0.49 | Sandy soil | 0.45 | 0.005** | 5.91 |
| Canopy | 0.35 | Canopy | 0.31 | 0.004** | 3.65 |
| Slope position | 0.3 | Slope position | 0.19 | 0.002** | 2.97 |
| Drainage | 0.18 | Drainage | 0.08 | 0.356 | 2.15 |
| Clay | 0.11 | Loam | 0.04 | 0.387 | 1.22 |
| Loam | 0.08 | Clay | 0.03 | 0.402 | 1.2 |
| Clay soil | 0.23 | Loam | 0.03 | 0.583 | 1.05 |

**Significant ($p \leq 0.01$).

tropical forest reserves, designation of appropriate conservation measures is needed to help protect and enhance the regeneration of the already disturbed parts of the reserve.

Tree species such as *V. hockii*, *C. molle*, and *A. grandibracteata* had high abundance and stem density, probably due to their high regeneration potential and competitiveness that enabled them to slowly dominate the vegetation types [55]. Along the topographic gradient, the low abundance and stand density in the ridge top is an indication that ridge top (Table 3(c)) conditions are unfavorable for the establishment of a large number of trees except for those with specific features that can survive in such an environment [56]. Ridge top condition represents a more leached soil and impoverished soils due to erosion activities [57]. The high abundance and stand density in the valley bottom and midslope (Tables 3(a) & 3(b)) is probably due to a good congenial environment, which provides for the growth of many trees [58].

### 4.2 | Environmental Factors Affecting Tree Species Abundance and Stand Density Distribution

While the distribution patterns of tree species and the community composition of mountain ecosystems can be influenced by dramatic changes in environmental conditions over short altitudinal distances [31], human exploitation may also impose constraints that lead to environmental modification, causing shifts in species ranges and thus influencing species composition [17, 31]. Just as in other studied Afromontane areas, the effects of environmental factors on species abundance and density variation in AACFR are similar to those on community change, implying that the species variation is significantly correlated with altitude, elevation, soil type, slope, and aspect [59].

Since altitude, slope, and aspect are among the important environmental factors that determine species composition, abundance, and density distribution along topo-positions/topogradients [31], the variation in the exposure (aspect) at the ridge top can result in varied abundance patterns and density status of tree species between the three topographic positions. CCA confirms a relatively high correspondence between plots and soil or topography factors [17]. As has also been reported by Chitiki [60], the CCA results indicated that altitude, slope, available amounts of phosphorus, nitrogen, calcium, pH, organic matter, and soil texture, including sand and clay, were the most important factors for the abundance and density distribution of trees in various plots (Figures 7(a) and 8).

Furthermore, the results showed that species abundance and density distribution are significantly explained by the variation in pH and phosphorus (P) nutrients. AACFR study sites occupy areas of acidic to slightly acidic (i.e., pH between 5 and 6). According to Page et al. [61], this result suggests that soil pH is a substantial driver of species abundance, composition, and density distribution in such an afromontane forest. Apart from that, altitude and topographic aspects also determine the distributions of woody species compositions and communities [4, 17].

The physical and chemical properties of the sampled soils varied with sites and topo-positions. Whereas the intact part of the reserve revealed high values of soil pH, organic carbon, N, and C:N, the disturbed part, in contrast, registered high values for sand, clay, and exchangeable bases (Table 4). The low organic carbon and humus in the disturbed part of the reserve could be due to disturbance factors such as cutting of trees for poles, firewood, and charcoal, and clearance for cultivation and settlements, which left the land bare [3]. On the other hand, the availability of nitrogen, soil carbon, and phosphorus in the intact part of the reserve could be due to the undecomposed humus content [61]. Since the relationship between soil properties and climate, as well as topography, can never be inseparable [31], any huge changes to the ecosystem may have knock-on effects on the whole forest system [62].

According to Rashad et al. [63], humus is responsible for the acidity of the soil. For instance, the existence of high humus in the intact part of the reserve accounts for the moderate level of soil acidity (pH = 6.1) and can also be a result of limited biotic stress in the soil. Humus and cation-rich soils are known to support fast-growing and light-tolerant species such as *A. grandibracteata*, *Combretum*, and *Acacia* species [64]. Besides, high nutrient regimes consisting of phosphorus, organic carbon, and nitrogen can also have strong relationships in the occurrences and density distribution of certain tree species [65]. Even then, Wilpert [64] expresses uncertainties and points out that the relation between species occurrence and soil properties remains hard because soil properties are expected to change as trees grow.

In this study, the CCA gave very low eigenvalues (Table 5) for Axes 1 and 2 as compared to the values for other studies in the Albertine Rift forests [51]. Low eigenvalues are normal in such a reserve and do not impair the significance of species environment relations [31]. According to Lolila et al. [31], such low eigenvalues usually indicate short gradients with no clear partition in tree species in such a reserve. Apart from showing a weaker influence of species environmental relations, such as low eigenvalues, also tends to suggest that there could be many issues unexplained by this CCA [66]. This is partly because most trees in such a reserve could be involved in broad niche overlap without clear site preference [67].

Although the CCA results do not provide clear species environmental relations, the CCA ordination diagram (Figure 7(b)) shows that *V. hockii*, *V. macrothyrsa*, *Ficus barteri*, and *Pleurostylia africana* are strongly correlated with sandy soil and canopy cover. An automatic forward selection of the key environmental variables (Table 6) also shows that much of the variance is significantly explained by sandy soil ($p = 005$) and canopy cover ($p = 004$), more than the rest of the variables. Since sandy soil has impaired soil nutrients and is always poorly drained, it is likely to support the growth and establishment of *Vachellia* species [68].

Canopy cover may also be significant in such a reserve as a result of gaps opening by anthropogenic activities like the clearance of trees for firewood, building poles, and opening land for cultivation and settlement. A lot of growing space and resources are made available when the gap enlarges, and that may either promote the coexistence of many species with higher diversity or few species with relatively higher stand density [69]. Much as such observations and statements could show some significance in the species environment relations, the effects of such environmental variables are not always easy to observe, measure, and hard to rely on their explanations [42]. It also indicates that the individual contribution of each environmental factor has important and independent effects on the tree stand structure in a wide variety of tropical forest communities [70].

## 5 | Conclusions and Recommendations

### 5.1 | Conclusions

The tree abundance population structure in AACFR displayed an inverse J-shaped pattern with a large number of juveniles relative to medium and larger (mature) trees in the intact part of the reserve. This confirms the existence of natural regeneration and population stability, which can guide the designation of a future conservation plan for the reserve.

The observed differences in stand abundances/density, population structure, and regeneration levels in both parts of the reserve can be attributed to the impact of both anthropogenic disturbance and other factors, such as slope, soil type, canopy cover, and other environmental factors that usually influence natural growth characteristics of different tree species in savannah woodland forests like AACFR.

The significant differences and variations in the abundance, BA, and densities of different tree sizes in both intact and disturbed parts of AACFR indicate that disturbance has a measurable impact on forest structural attributes in AACFR. That means the disturbed parts of the forest have been degraded and thus require monitoring of forest quality and restoration, as recommended in the paper.

The unclear compositional differences along topographic gradients, where all the dominant species tend to be fairly common in both parts of the reserve, suggest that species–habitat preferences in AACFR appear relatively weak. This implies that the identified environmental variables could not solely be used to account for the variation in the tree species abundance and density distribution in the reserve unless further in-depth studies are undertaken.

The large and significant variation in tree species and community patterns explained by environmental factors suggests a need for site-specific evaluation of biodiversity conservation plans in the AACFR.

### 5.2 | Recommendations

Since understanding tree species abundance, density distribution, composition, community structure patterns, and their underlying environmental factors is worthwhile when considering the conservation of montane subtropical forests, the findings of this study may be useful for the formulation of forest restoration policy interventions to sustain the tree species abundance and the functioning in the afromontane forests of AACFR and similar ecosystems elsewhere.

Considerable management options that limit continuous degradation, such as the enforcement of environmental laws, tree enrichment planting, and ex situ conservation, should be undertaken to restore, particularly, the abundance status of trees in the disturbed part of AACFR. This is expected to enhance the conservation of less-abundant tree species and the sustainable use of the forest genetic resources in AACFR.

Since the effects of site condition modification as a result of human-induced disturbance vary with location and the existence of flora composition, depending on the ability of tree species to adapt either at a small scale or to massive changes, human-induced disturbances should be discouraged to maintain highly abundant tree species and sustained use of the forest community structure in AACFR.

To minimize human impacts on AACFR, awareness creation and training on the value of forest resources and the ecological consequences of deforestation are required for the community.

Comprehensive further research should be established that integrates remote sensing with intensive field data collection to monitor and compare forest recovery in intact versus disturbed forests in AACFR, with an investigation involving measuring both ecological attributes, including density distribution of diameter size classes along topographic gradient, and socioeconomic factors influencing such distributions in AACFR.

There is also a need to constantly monitor the population dynamics of tree species that either appear to have low regeneration potential or are not represented in the disturbed part of the reserve as a way of maintaining the natural stability of tree species in AACFR.

#### Author Contributions

Assoc. Prof. John Bosco Lamoris Okullo guided the formulation of the aim and methods of the study. He supervised data collection, analysis, and report writing, including drafting, reviewing, and polishing of the manuscript. He took the lead in corresponding with the journal editors.

Mr. Sylvano Afai conceptualized and developed the research idea, formulated the goals, developed a full proposal, and participated directly in the validation of the data collection instrument, data collection, data analysis, and writing and reviewing of the draft manuscript, including reanalyzes, reviews, and editing.

Dr. Grace Nangendo guided the conceptualization and development of the research proposal, assisted with sourcing of funding and acquisition of funds from USAID through WCS, guided polishing of methodology, mobilizing communities, supervising GIS data entry and analysis, reviewing draft manuscript, and polishing the manuscript as requested.

Prof. James Kalema assisted in the conceptualization and drafting of the proposal/methodology, supervised data collection, analysis, report write-up, drafting, and polishing of the manuscript.

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#### Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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