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Ermias Beyene * , Dejene Laemancho , Belayneh Bufebo

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Woody Species Diversity, Structure, and Management of Parkland Agroforestry along Agroecology: The Case of Tembaro Special District, Central Ethiopia

Dejene Laemancho, Belayneh Bufebo and Ermias Beyene *

College of Agricultural Sciences, Wachemo University, P.O. Box 667, Hossaina, Ethiopia; dejenelmethiopian@gmail.com; belaytumma@gmail.com

* Correspondence: ermiasbeyene16@gmail.com

Abstract: Parkland contributes economic, social, and ecological benefits worldwide. However, parklands degradation is an encounter to biodiversity loss needs generating information on woody species. This study was aimed to investigate woody species composition, diversity, structure, and management of parklands along Agroecology, and farmers' wealth status. Multistage sampling technique was employed. Highland Bede Kebele, and midland Durgi Kebele were randomly selected. A total of 60 quadrats with size of 100m x 50m were used for inventory. A total of 276 respondents were used. Species richness, Shannon, Simpson, and evenness diversity indices were subjected to one-way ANOVA, and independent t-test for comparison STATA V. 17.0. Of 31 woody species, (16 families in 26 genera) observed, 26 woody species belonging to 13 families in 22 genera from midland while 18 woody species belonging to 12 families in 16 genera from highland parklands were observed. Species richness 6.8, 3.7; Shannon 1.82, 1.68; Simpson 0.85, 0.73; evenness 0.83, 0.7 were observed in midland, and highland parklands, respectively. Poorly regenerated stands were observed along Agroecology. Pruning, pollarding, coppicing, lopping, cutting, fertilizing, watering were common management practices. In conclusion, woody species diversity, and structure were affected by Agroecology, and socioeconomic factors needing intervention to enhancing woody species conservation.

Keywords: agroecology; diversity indices; parkland agroforestry; regeneration; tree management; woody species

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1. Introduction

Recently, deforestation, anthropogenic activities, and climate change are mainly causing woody species diversity loss, and altered climate across the globe [1,2], ever increasing population increasing the demand for woody and non-wood products, agricultural expansion, low agricultural productivity are some of the major factors increasing the challenges [3,4]. The net forest cover of Ethiopia declines from 15.11 million hectare (ha) in 1990 to 12.5 million hectare (ha) in 2015 [5]. These reasons are becoming attractive potential areas to investigating and documenting the current status of woody species composition, and structure of the stands at large agricultural ecosystems [2].

Agroforestry is an alternative strategy for the conservation of forest – dependent plant species through providing habitats for them [2,3]. It is defined as an interface between agriculture and forestry [6]. The most commonly practiced agroforestry practices across different Agroecosystems of Ethiopia are parkland agroforestry practice, hedgerow intercropping, homegarden agroforestry practice, woodlots, and riparian zone vegetation [7]. Parkland agroforestry is mixtures of trees and shrubs that farmers select for certain functions and cultivate together with staple food crops [7,8].

The ultimate goal of establishing parkland agroforestry practice by retaining, and introducing the multipurpose trees, shrubs, or vines is for the crop facilitation [9,10]. Parkland agroforestry trees and/or shrubs provide multiple products and services including increased agricultural crops productivity due to the positive effect of trees/shrubs on the soil properties [3], timber, fodder, fuelwood, medicine, host to endangered indigenous species, i.e., *Cordia africana*, *Erythrina brucei*, *Acacia abyssinica*, *Croton macrostachyus*, *Olea europeae*, *Sesbania sesban*, *Millettia ferruginea*, extra in Lemo district of Southern Ethiopia [2], mitigating deforestation, land degradation, and climate change [11–13]. Despite the fact, woody plant species are being extremely threatened because of environmental and anthropogenic factors such as altitude, slopes, soils, and climate change [14–16], deforestation, overexploitation, improper natural resources management [17,18].

Ethiopia has diverse environmental, and climatic conditions that have resulted in diverse flora and fauna [19]. It has around 6000 species of the higher plants, and among this 10 % are endemic. However, most of these plant species are being threatened at alarming rate due to human, and environmental threats: these can influence the potential of woody species existing in the farming systems to provide various ecosystem services and benefits [16,20]. The major driving forces for the threats of woody plant species are deforestation, agricultural expansion, population pressure, illegal settlement, illegal logging, free grazing, and overexploitation of woody plants [21,22].

Trees are the essential part of the agricultural ecosystems, they have a range of the provisional and regulatory services that support farmers' livelihood. In Ethiopia, these scattered multipurpose trees retained and planted in the various land-uses such as in the communal lands, croplands, coffee plantation, homesteads, woodlots, roadsides, and life fencings [3,4]. The variation in the distribution pattern and diversity of woody plant species across each land – use would happen due to agro-climatic variation [18,23]. These factors can significantly contribute to the loss of biodiversity and also unstable stand structure so that investigating the current status of woody plant species across the farmers' wealth status, and an Agroecology is very important for the sake of conserving endangered tree species [8,24].

Agroforestry tree species need technical as well as indigenous management practices applied to them to boost overall functions of the systems [2,4]. The management practices applied for the different woody species in agroforestry practices shall vary, and some unique management practices applied for specific trees in a specific culture and region [10,23].

Parkland agroforestry practice contributes the economic, socio-cultural, and ecological functions [2,25]. Nowadays, parkland agroforestry degradation has become the major problem due to ever increasing human population accelerating demand to the additional arable land, climate change causing the variation in temperature, humidity, and rainfall, and inclusion of the cash crops favoring monoculture type agriculture worldwide [26]; legal and illegal cutting of scattered trees and shrubs across the globe [21]; shortening the fallow phase due to the continuous tilling of the same land which results insufficient, and lack of regeneration [27]. Woody plants are being threatened due to clearing by humans, agricultural expansion [4]; overexploitation of plants, and plant parts [24].

Farmers has been practicing traditional agroforestry practice in Tembaro Special District of Central Ethiopia (CERS) for decades. However, the woody plants are under threats pressure due to population pressure, deforestation, unwise utilization of natural resources, and illegal cutting of trees in the study area. Indigenous knowledge of farmers how to manage their trees in agroforestry systems could be eroded as a result of decline in species abundance, and richness [8,28]. Literatures indicated that no previous study has been conducted on woody species diversity, structure, and management practices of parkland agroforestry practice along Agroecology, and the farmers' wealth status. This is also the case of Tembaro Special District, Central Ethiopia.

Hence, investigating the composition, diversity, and structure of woody species at any ecosystem is mostly essential to have better understanding of woody plant species for the conservation purposes at the large scale agricultural ecosystems [10,29]. In general, the information on the population structure, distribution pattern, and their composition are very helpful for the better understanding of the current status of woody species, i.e., stable or not [11,15,30]. The study was aimed: (i) to determine and comapre woody species composition, and diversity of parkland agroforestry practice along Agroecology, and the farmers' wealth status in the study areas; (ii) to estimate the population structure of woody species along Agroecology in parkland agroforestry

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practice of the study areas; And (iii) to assess farmers' management practices applied on woody species of parkland agroforestry practice, and the objectives of management practices in the study areas of Central Ethiopia.

2. Materials and Methods

2.1. Study area Description

The present study was conducted in Tembaro Special District of Central Ethiopia. It is located at 7° 10' 0'' N - 7° 26' 0'' N latitude, and 37° 21' 30'' E -37° 36' 30'' E longitude (Figure 1). The altitude ranges from 1400 m.a.s.l to 2700 m.a.s.l in the study district. The district has 20 kebeles, i.e., kebele is a lower administrative unit. The annual temperature of the study area ranges from 20°C to 30°C.The mean annual rainfall is estimated to be 935 mm to 1,877 mm. The common soil type of the study district is alfisols. The soil textures is clay to loam texture with the PH value from 5.5 to 6.7. The inhabitants of Tembaro Special District was estimated 145,946 [31]. *Cordia africana*, *Albiza gummifera*, *Croton macrostachyus*, *Erythrina brucei*, *Erythrina abyssinica*, *Ficus species*, *Milletia ferruginea*, *Gravellea robusta*, etc. are common trees integrated in agroforestry. The mixed farming system is common in the district.

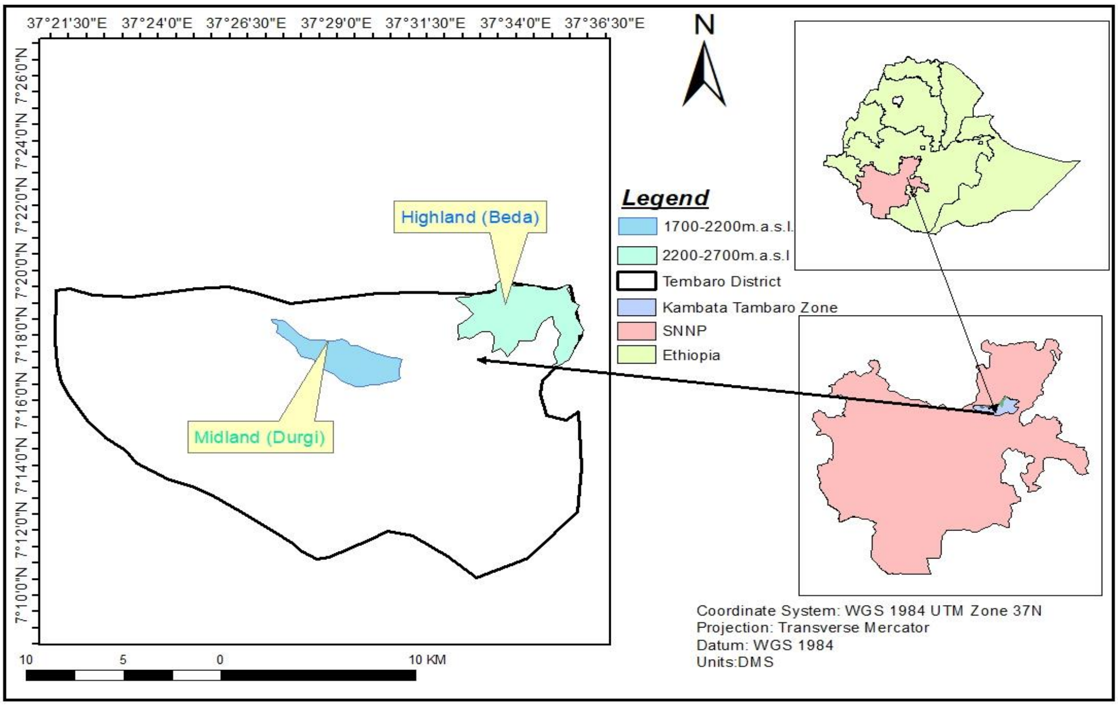

Figure 1. Map of the study area.

2.2. Sampling methods

2.2.1. Selection of the study area

The main Agroecological zones are recognized in Ethiopia, based on altitude: highland (2300 – 3200 m.a.s.l), midland (1500 – 2500 m.a.s.l), and lowland (500 – 1500 m.a.s.l) [32]. According to Zemede [32], the study district was stratified into three Agroecological zones: namely highland (*Dega*), midland (*Weinadega*), and lowland (*Kolla*) based on their altitudinal ranges. Then, two Kebeles (Kebele is the lowest administration unit of Ethiopia), namely, Beda kebele from highland, and Durgi kebele from midland were selected purposively based on the existence of parkland agroforestry practice.

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2.2.2. Households and Key informants selection

2.2.2.1. Households for questionnaire

The multistage sampling technique was employed for the purpose of this study. The unit of investigation in this study was a household (HH), and hence, household heads was taken to represent their respective households.

Firstly, the study district was stratified into three Agroecological zones as highland, midland, and lowland based on their altitudinal ranges by adopting the approach of [32]. Then, two kebeles, namely, Beda kebele from the highland, and Durgi kebele from the midland Agroecological zones were selected purposefully based on the presence of parkland agroforestry practice.

Secondly, the total farm households of each kebele were stratified based on the local wealth categories as rich, medium, and poor. The wealth stratification was done by using local wealth category such as tropical livestock unit (TLU), annual income, off-farm activity, land size in hectare. This was achieved with the help of key informants.

Finally, the sample size required for household questionnaire was determined by the following sampling formula adopted from [33].

$$n = \frac{no}{1+\frac{no-1}{N}} \qquad no = \frac{z^2pq}{e^2} \qquad \text{\_\_\_\_\_\_ equation 1}$$

$$no = \frac{(1.96)^2 \, x \, 0.5 \, x \, 0.5}{(0.05)^2} = 384.16$$

$$n = \frac{384.16}{1+\frac{384.16-1}{981}} = 276.25 \approx 276$$

A total sample size used for household questionnaire was 276.

n1 = 519 households (HH), n2 = 462 households (HH)

N = n1 + n2 = 519 + 462 = 981

n1 is a total households present in Beda kebele (highland) while n2 is a total households present in Durgi kebele (midland).

N is a total households found in the two study kebeles, i.e., Bede kebele, and Durgi kebele.

Where, n is the total sample size, z is 95 % confidence interval limit i.e., 1.96, p is the estimated proportion of an attribute that is present in the population, in this case, p is 50 %, i.e., 0.5 q is equivalent to 1-p (1-0.5 = 0.5), e is the desired level of precision, i.e., 95 % or 0.05, N is the total number of population (in this case the total households in the two kebeles), no is the desired sample size when the population is larger.

Table 1. The total sample size (n = 276) was randomly selected from the three wealth groups in the study area.

Kebele Administration	Sample size from each wealth category			
	Rich	**Medium**	**Poor**	**Total**
Beda Kebele (n = 146)	45	47	54	146
Durgi Kebele (n = 130)	39	41	50	130
Total	84	88	104	276

The data collection was started after the initial discussions had been made with the district's officials, kebele leaders, development agents (DAs), key informants, and selected households to explain the purpose of the data survey, and obtain permission to conduct the present study. Firstly, the household questionnaires were developed to collect the relevant information on management practices applied by farmers on woody species existing in parkland agroforestry

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practice. Accordingly, the interview was conducted on randomly selected household heads from each wealth class to collect management, and objectives of applying these management practices by farmers in parkland agroforestry practice.

2.2.2.2. Key informants (KI) selection

The key informants (KIs) are individuals who have lived for a long period of times in the Kebele, and the people who are knowledgeable about woody species identification, and wealth category. The selection of key informants was done by the snowball method [34]. Then, a total of 20 key informants were selected for this study. The purpose of selecting KI's was be to stratify households by wealth categories, and the study is also supported by key informant interview for validation purpose.

2.2.2.3. Woody species inventory in parkland agroforestry practice

Reconnaissance survey was conducted in order to have the general overview of the study area. In order to have a representative sample size the district was stratified based on their altitudinal ranges [15,35]. The two Kebeles, namely, Beda Kebele from highland (*Dega*), and Durgi Kebele from midland (*Weinadega*) were selected purposively for inventory. Equal sampling technique was used for woody species inventory in agroforestry systems by adopting the approach of [2].

A rectangular plot of 100 m x 50 m (0.5 ha) was laid within each randomly sampled household farm, and randomly selected [36], for woody species inventory along Agroecology. A total of '60' quadrats (30 quadrats from each Agroecology, and 20 quadrats from each wealth class) were used for the inventory. Woody species which have multiple stems at 1.3 m height was considered as a single individual, and the DBH of the largest stem was taken. A woody species with multiple stems or forked below 1.3 m height was recorded as a single individual separately. Then, on each quadrat or plot woody species seedlings (< 2.5 cm diameter), saplings and shrub (2.5 - 5 cm diameter), trees and shrub (≥ 5 cm diameter) were recorded by complete count of each [36,37]. For the shrubs, the diameter was measured at 15 cm from the ground (D at 15 cm) [38]. For all woody species the diameter was measured by measuring tape and recorded. Woody species identification was done in the field using their local name with the help of key informants. The botanical nomenclature was assigned by following useful trees and shrubs for Ethiopia [39,40].

2.3. Data Analysis

2.3.1. Statistical Analysis

The household data collected through interviewing was analyzed by frequency, interpreted, and presented in tabular form. For comparison, the computed diversity indices, basal area (g = m^2 per plot, and g = m^2 ha^{-1}), and density (number of stems per plot, and number of stems $ha^{-1)}$ between highland, and midland Agroecological zones were subjected to independent t-test at $P < 0.05$ level by STATA V. 17.0. On the other hand, the computed diversity indices of woody species in parkland agroforestry practice along Agroecology among the farmers' wealth categories were subjected to one-way analysis of variance (ANOVA) following the linear model (GLM) procedure at $P < 0.05$ using STATA V. 17.0. For the statistical significance difference, Tukey's HSD test was used to separate the means at $P < 0.05$.

2.3.2. Woody species diversity analysis

In order to investigate woody species diversity, Shannon-Weiner index, Simpson's index, species richness, and Sorenson index of similarity were computed. Shannon Weiner diversity index was be calculated as following [41,42].

The Shannon-Wiener function (commonly referred as Shannon diversity index) was calculated as follows:

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$$H' = -\sum_{i=1}^{s} p_i \times \ln p_i \qquad \text{\_\_\_\_\_\_\_\_\_\_\_ equation 2}$$

Where, H' = Shannon diversity index, p_i = proportion of individuals found in the i[th]

Species S = the number of species, i = 1, 2, 3…, S .

The Shannon evenness [41,43] was calculated accordingly to the following mathematical relation

$$J = \frac{H'}{H'_{max.}} = \frac{\sum_{i=1}^{s} p_i \times \ln p_i}{\ln s} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_equation 3}$$

Where, J = Equitability (evenness) index H', p_i, S and i as explained above. Evenness or equitability, a measure of similarity of the abundant of the different woody species, assumes a value between 0 and 1 with 1 being complete evenness.

Simpson's diversity index, other popular diversity index was calculated as:

$$D = 1 - \sum pi^2 \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ equation 4}$$

Where D is Simpson's diversity index and p_i is proportion of individuals found in the i^{th} species.

The Sørensen coefficient of similarity (Ss) is given by the following formula:

$$Ss = \frac{2a}{2a+b+c} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_equation 5}$$

The coefficient is multiplied by 100 to give a percentage. Where Ss is Sørensen similarity coefficient, *a* is number of species common to both selected sites along agroecology, *b* is number of species in area 1, and *c* is number of species in area 2.

2.3.3. Population Structure of Woody Species Analysis

Woody species structure was determined using quantitative analysis parameters such as diameter class distribution, density (number of stems per hectare (ha^{-1})), and basal area (m^2 ha^{-1}) along the two Agroecological settings. Woody species regeneration status can be determined using diameter class distribution of species in a particular location [44]. Diameter class distribution (DBH = cm) was analyzed and estimated using diameter class categories 1 = 0-5.99, 2 = 6-10.99, 3 = 11-15.99, 4 = 16-20.99, 5 = 21-25.99, 6 = 26-30.99, 7 = ≥ 31 (Lu et al., 2010).

Basal area (g) is the cross-sectional area of tree estimated at diameter breast height (DBH = 1.3 m), which is expressed in m^2.

$$g = \frac{\pi\,(DBH^2)}{4} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_equation 6}$$

Where g = Basal area in m^2 per hectare

(d) = diameter at breast height (cm), π = 3.14

Importance value index (IVI) is used as a measure of woody species composition that combines frequency, abundance, and dominance importance values. The ecological importance of woody species was evaluated using relative frequency, relative abundance, and relative dominance parameters [41].

IVI (%) = Relative abundance + Relative frequency + Relative dominance ___equation 7

$$\text{Relative abundance (RA)} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100$$

$$\text{Relative dominance (RD)} = \frac{\text{Dominance of a species}}{\text{Dominance of all species}} \times 100$$

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$$\text{Relative frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100$$

3. Results and Discussion

3.1. Woody species composition, and diversity

A total of 31 woody species belonging to 16 families in 26 genera were recorded from the two Agroecological zones of parkland agroforestry practice in the study area (Supplementary S1). Of 31 woody species, 18 woody species belonging to 12 families in 16 genera were recorded in highland parkland agroforestry (Supplementary S1). While 26 woody species belonging to 13 families in 22 genera were recorded in midland parkland agroforestry in the study area (Supplemetary 1). Fabaceae was the most diverse family encompassed of 10 woody species in 7 genera, followed by Euphorbiaceae encompassed of 3 woody species in 3 genera, followed by Myrtaceae encompassed of 3 woody species in 2 genera, followed by Rosaceae encompassed of 2 woody species in 2 genera, and the rest families encompassed one species in one genera each (Supplementary S1). Fabaceae family was the most dominant and diverse family along agroecology could be due to its resistance to the disturbance, and capable to adapt local environmental conditions. This is supported by previous studies from other parts of the country [45] who reported Fabaceae family was the higher in woody species composition in Gununo watershed of Wolaita zone, Southern Ethiopia; Fabaceae family was the dominant south-eastern rift valley escarpment of Ethiopia [46].

Among 31 woody species, 74.2 % were trees while 25.8 % were shrubs in the two agroecological zones of parkland agroforestry (Supplementary S2). This is in line with finding of [4] reported dominated trees in farmlands in changing landscape. Only a few woody species were exotic while the most dominant ones were indigenous woody species in parkland agroforestry.

The result revealed that midland parkland agroforestry was more diverse than highland parkland agroforestry. This variation in woody species composition between the two agro-ecological zones in the study area is attributed to agro-ecological characteristics which particular woody species adapt, age of trees/shrubs, socio-economic factors affecting tree retaining and planting, and farmers' management strategy. Previous studies from other areas of the country confirmed that woody species composition, and structure can be varied because of elevation variation, and soil type/depth [22,23,29,30], management approaches applied by the local people in agroforestry practices would affect woody species composition [2].

Woody species richness, Shannon wiener diversity, Simpson, and evenness by agroecology, and farmers' wealth status were shown in (Tables 2 and 3). Shannon diversity index, Simpson diversity index, species richness, and evenness were higher in midland than highland, and significantly different at $P < 0.05$ (Table 2). The higher Shannon diversity index in midland parkland agroforestry indicating the higher species richness. The higher Simpson diversity index values shows that the higher abundant woody species were recorded in the midland parkland agroforestry. The higher diversity indices values from midland confirm more diverse woody species conservation in this particular agroecology. Variation in woody species richness between the highland, and midland might be due to soil type, socioeconomic factors, and farmers' preferences to plant or retain trees/shrubs in their farmlands. This is in agreement with finding of [18] who revealed that environmental conditions, and farmers' tree planting activities can affect species richness between different geographical locations. The extent of human and livestock disturbance could made the difference in woody species diversity conservation between the highland, and midland parklands.

The higher mean values of diversity indices of woody species from the midland parkland agroforestry showed that woody species those found in the midland were more resistant to sever anthropogenic disturbances, animal browse, and they would adapt environmental variability than the highland agroecology. This is in consistent with finding of [4,47] who argued that the variation in the woody species diversity may be because of human activities, and topography. The observed dissimilarities between the two agroecological zones of the study area are attributed to difference in woody species composition, and structure which could be due to dissimilarity in soil moisture

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availability, nutrient availability, woody species adaptability to a specific agro-climatic conditions, socioeconomic factors such as land size, and shape, income, tropical livestock unit, and farmers' management strategy. Previous studies conducted by [23] stated that woody species diversity related to elevation, and farmers' species selection, [2,16,17] who revealed that difference in woody species composition and diversity associated with species adaptability to soil type, moisture, and tree management in agroforestry practices. Farmers' tree management strategies could made variation in the woody species composition, diversity, and regeneration in agroforestry systems [2,7]. The lower woody species conservation in highland parkland might be due to the tendency of farmers remove trees, and shrubs from their parkland agroforestry to reduce shade, and light competition. This is in line with the finding of [35] who revealed that farmers remove 30 % of canopy from their coffee-based agroforestry to decrease competing vegetation, and enhance coffee crop productivity.

Table 2. Mean (±Std) diversity indices of woody species in the two agroecological zones of parkland agroforestry independent t-test P < 0.05.

Sites	Agroecology	Richness	Shannon	Simpson	Evenness
Beda	Highland	$3.7^{a} \pm 1.6$	$1.68^{a} \pm$ 0.23	$0.73^{a} \pm 0.037$	$0.7^{a} \pm 0.05$
Durgi	Midland	$6.8^{b} \pm 1.8$	$1.82^{b} \pm 0.15$	$0.85^{b} \pm 0.061$	$0.83^{b} \pm 0.04$
Overall mean		5.25 ± 1.7	1.75 ± 0.19	0.79 ± 0.049	0.76 ± 0.045

Within the column, mean values with different letters indicate significant difference at (p < 0.05) between agroecological zones

Diversity indices were computed for rich, medium, and poor in Beda kebele (highland), and Durgi kebele (midland). Species richness, Shannon, Simpson, and evenness showed significant difference among farmers' wealth groups (Table 3). These diversity indices were the higher for rich than medium, and poor household's parkland agroforestry in Beda kebele (highland), and Durgi kebele (midland). This could be due to wealthy households can purchase expensive seeds to raising seedlings, and seedlings, larger land size in hectare, retaining, and planting trees in their parkland agroforestry rather than cutting as compared to medium, and poor households in both sites. Previous studies indicated that woody species diversity is affected by farmers' wealth category [2–4]. The poor households had the lower landholding size in hectare (ha) than medium, and rich ones resulting the low woody species diversity. In contrary, [27] reported farmers' wealth categories did not affected species composition, and diversity.

Table 3. Mean (± Std) diversity indices of woody species in parkland agroforestry among farmers' wealth groups.

Sites	Agroecology	Wealth	Richness	Shannon	Simpson	Evenness
Beda	Highland	Poor	$3.1^{a} \pm 1.7$	$1.58^{a} \pm 0.06$	$0.53^{a} \pm 0.05$	$0.61^{a} \pm 0.07$
		Medium	$4.7^{b} \pm 1.5$	$1.64^{b} \pm 0.20$	$0.62^{b} \pm 0.07$	$0.73^{b} \pm 0.10$
		Rich	$6.4^{c} \pm 1.2$	$1.72^{c} \pm 0.21$	$0.71^{c} \pm 0.04$	$0.80^{c} \pm 0.05$
Durgi	Midland	Poor	$3.9^{a} \pm 1.8$	$1.69^{a} \pm 0.15$	$0.67^{a} \pm 0.08$	$0.63^{a} \pm 0.31$
		Medium	$6.5^{b} \pm 1.6$	$1.92^{b} \pm 0.16$	$0.74^{b} \pm 0.02$	$0.75^{b} \pm 0.24$
		Rich	$8.5^{c} \pm 2.1$	$2.17^{c} \pm 0.18$	$0.91^{c} \pm 0.03$	$0.86^{c} \pm 0.11$

Within the column, mean values with different letters indicate significant difference at (p < 0.05) among wealth groups

Similarity of woody species

Similarity of woody species between the sites was analyzed, and the Sørensen quantitative index indicated moderate species similarity (37.14 %) between Beda kebele (highland), and Durgi kebele (midland) at the study district (Figure 2).

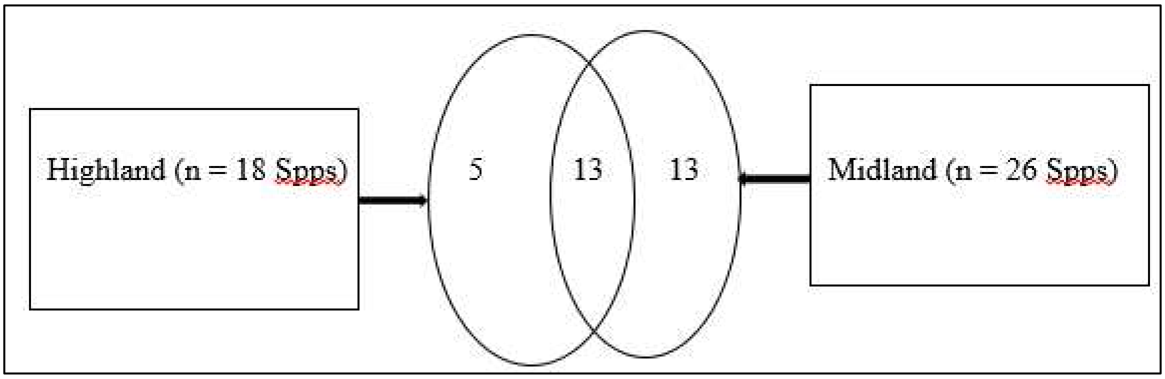

Figure 2. Venn diagram showing species richness at the two agroecological zones in the study area.

3.2. Woody Species Population Structure in parkland agroforestry along agro-ecology

3.2.1. Diameter class distribution, density, and basal area

Population structure of woody species was analyzed, and estimated using diameter (cm) class distribution in percent, density (number of stems per plot, ha^{-1}), and basal area ($g = m^2$ per plot, ha^{-1}). Seven diameter classes were identified in highland of Beda kebele, and midland of Durgi kebele. Distribution of population structure of woody species showed J-shape, in which, there are a low number of individuals in the lower diameter class but increases towards the higher classes in highland parkland agroforestry (Figure 3). Distribution of population structure of woody species showed partially Bell-shape in midland, in which, the dominance of individuals were observed in the middle diameter classes but the low number of individuals were in the lower, and higher diameter classes (Figure 4). The low number of individuals in the lower diameter classes across altitudinal gradients might be selective removal of trees, and shrubs from the farmlands, higher human and animal disturbances causing poor regeneration of trees, and lack of seedlings to plant in the parkland agroforestry. This is in line with finding of [18,46] who stated that removing shade trees from coffee-based agroforestry to reducing completion results the low number of individuals in the lower diameter classes in Southwestern Ethiopia. The J-shape indicates unstable natural and artificial regeneration of woody species in the midland parkland agroforestry. Similarly, Partially Bell-shape indicating unstable regeneration status of woody species in midland parkland agroforestry in the study area. This is supported by [2] reported J-shape in parkland agroforestry indicates poor regeneration status of population stand in semi-arid of Lemo district, Southern Ethiopia. In contrary, [9] reported inverted-J shape in farmland tree species. [29] who revealed that partially Bell-shape in parkland agroforestry showed poorly regenerated stand.

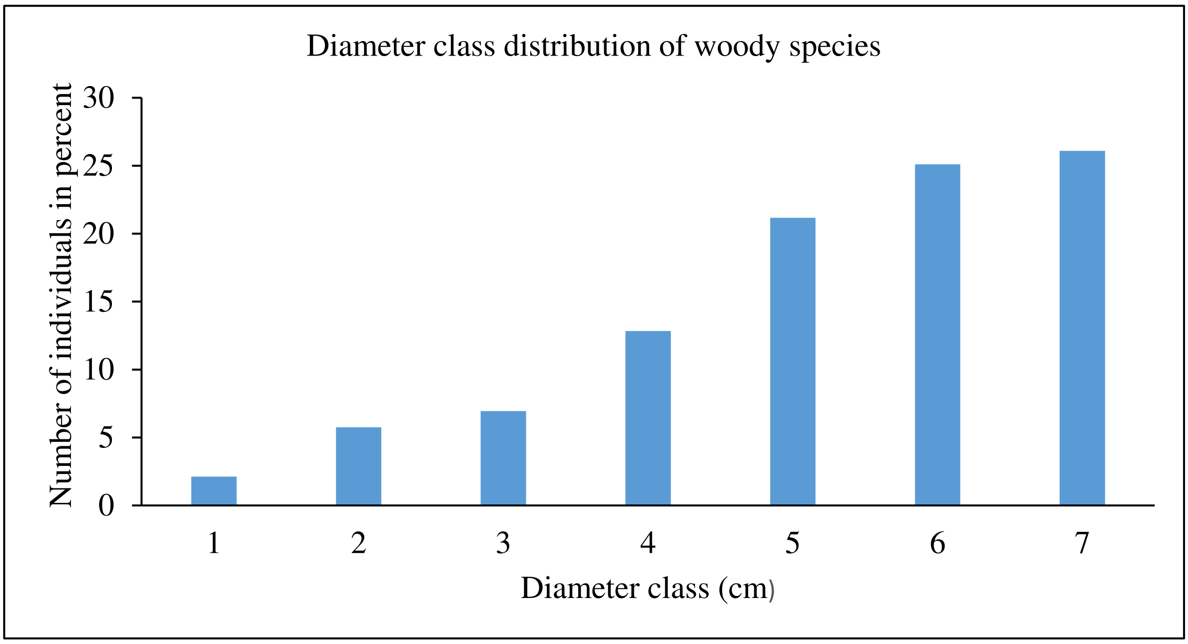

Figure 3. Diameter class distribution in highland parkland agroforestry of Tembaro Special district.

Diameter (cm): 1 = 0 -5.99, 2 = 6-10.99, 3 = 11-15.99, 4 = 16-20.99, 5 = 21-25.99, 6 = 26-30.99, 7 = ≥ 31

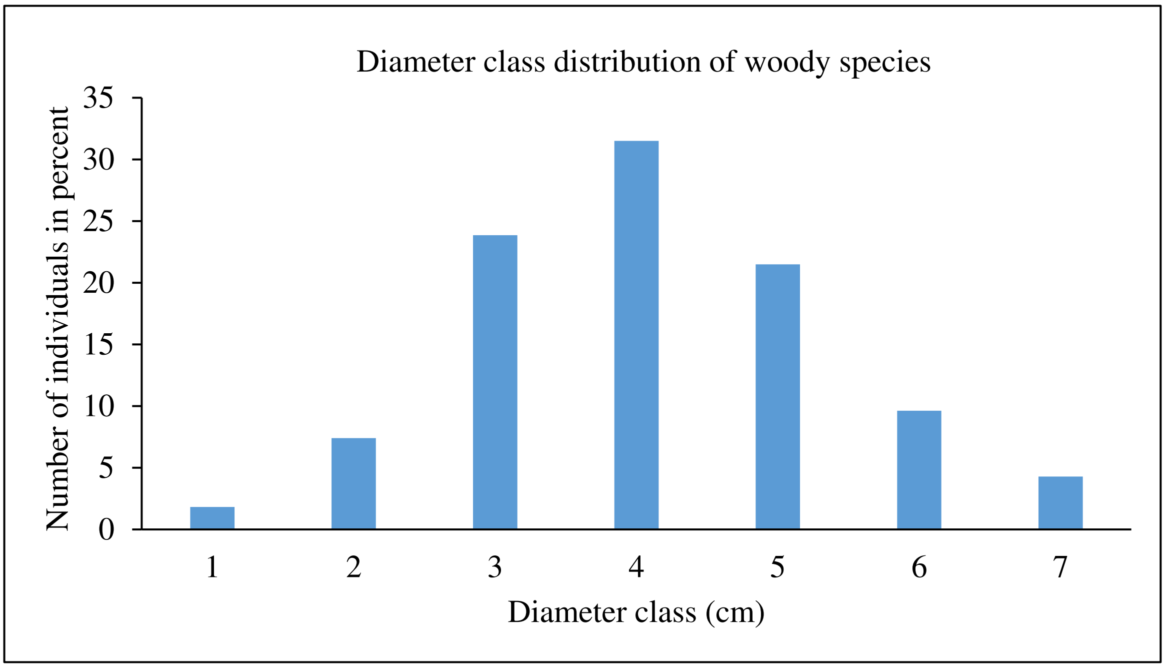

Figure 4. Diameter class distribution in midland parkland agroforestry of Tembaro Special district. Diameter (cm): 1 = 0-5.99, 2 = 6-10.99, 3 = 11-15.99, 4 = 16-20.99, 5 = 21-25.99, 6 = 26-30.99, 7 = ≥ 31.

The low number of individuals of *Cordia africana* (Partially Bell-shape), and *Croton macrostachyus* (J-shape) was in the lower diameter classes while the higher number of individuals were in the lower classes for *Acacia saligna*, and *Erythrina brucei* , which showed inverted J- shape curve in highland parkland agroforestry (Figure 5). Diameter class distribution of *Erythrina brucei* was showed inverted J-shape while *Acacia abyssinica*, and *Croton macrostachyus* were showed J-shape, *Acacia decurrens* was showed partially Bell-shape in midland parkland agroforestry (Figure 6). Inverted J-shape confirming good regeneration status of trees while partially Bell-shape, and J-shape confirming poor regeneration status of individual trees across altitudinal gradient in parkland agroforestry. Previous studies conducted in other areas of the country by [23,44,48] Gochera et al. (2020) who reported reversed J-shape indicates a good natural regeneration status of stand, on the other hand, Bell-shape, and J-shape indicates instable population stand.

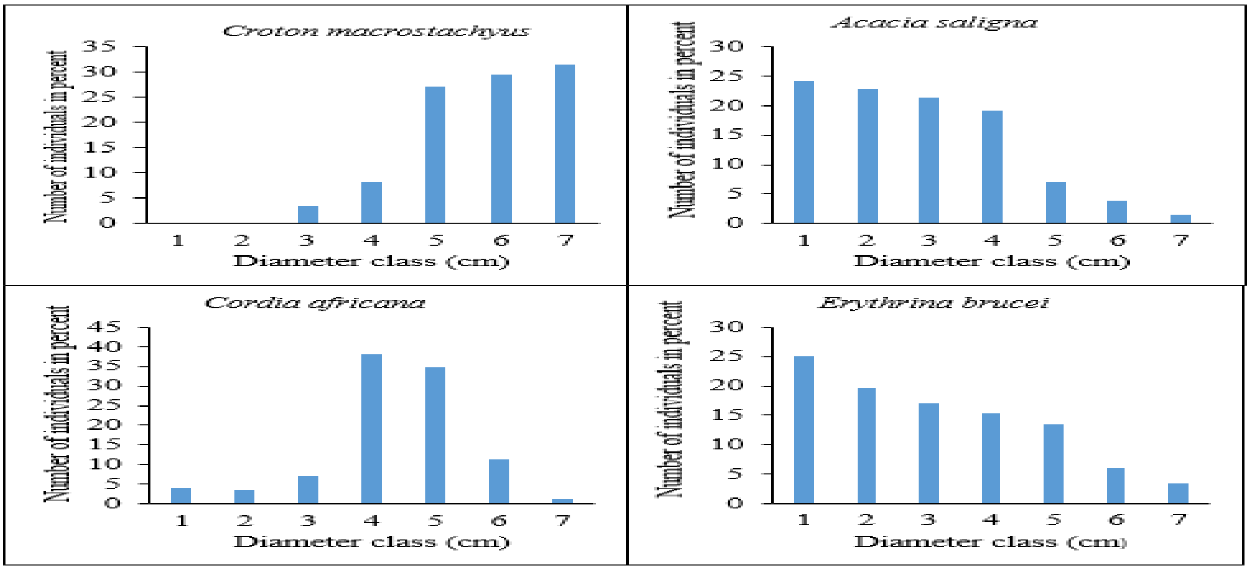

Figure 5. Diameter class distribution of woody species with top IVI in highland parkland agroforestry in the study area. Diameter (cm): 1 = 0-5.99, 2 = 6-10.99, 3 = 11-15.99, 4 = 16-20.99, 5 = 21-25.99, 6 = 26-30.99, 7 = ≥ 31.

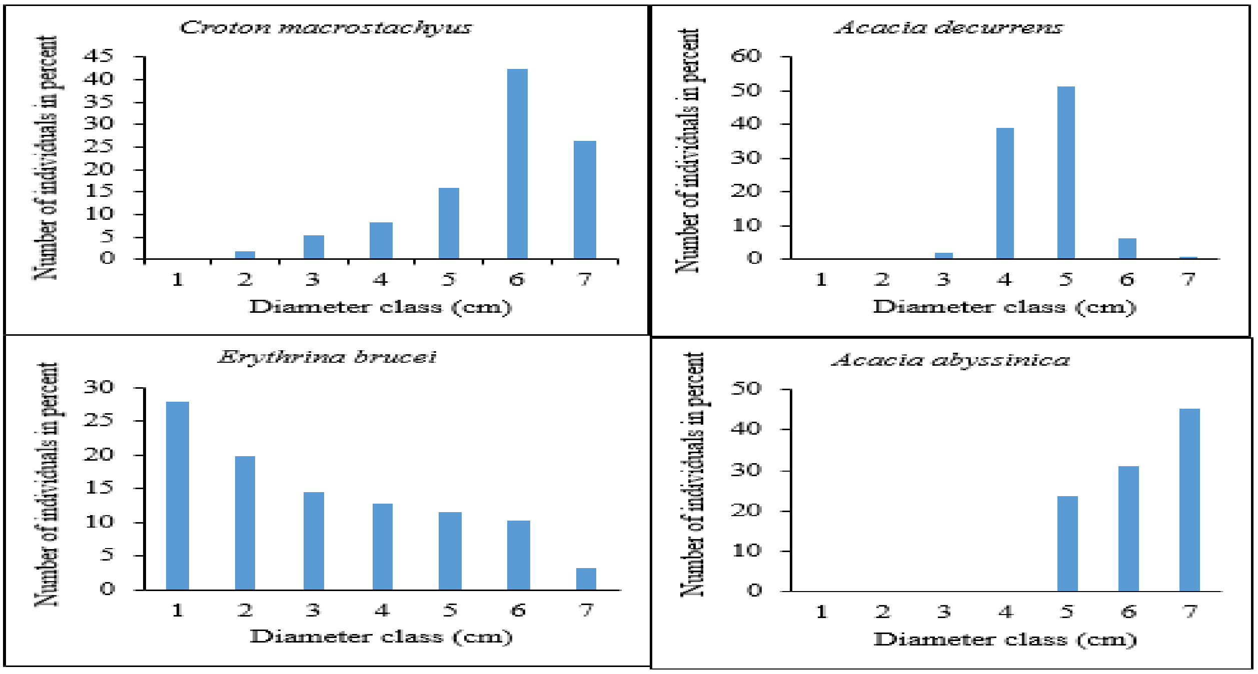

Figure 6. Diameter class distribution of woody species with top IVI in midland parkland agroforestry in the study area. Diameter (cm): 1 = 0-5.99, 2 = 6-10.99, 3 = 11-15.99, 4 = 16-20.99, 5 = 21-25.99, 6 = 26-30.99, 7 = ≥ 31.

The density (number of stems per plot, and per ha), and basal area (g = basal area in m^2 per plot, and per ha) were significantly different between the two agro-ecological zones of parkland agroforestry practice in Tembaro Special District, Central Ethiopia at $P < 0.05$ level (Tables 4 and 5). The mean density of midland parkland agroforestry was the higher over highland parkland

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agroforestry. The two Agroecological settings have the low mean density per ha when compared to other agroforestry practices. This might be increased disturbance by human, and animals, and continuous tilling the same land affecting regeneration in parkland agroforestry system. This is supported by [9,11,12,24]. There is significant difference between highland, and midland parkland agroforestry in terms of basal area (m^2 per plot, ha^{-1}) of woody species in the study area at $P < 0.05$ (Table 5). This variation of basal area across Agroecology could be due to difference in composition, age structure, environmental variability including altitudinal ranges, temperature, humidity, soil type and soil texture, selective cutting of trees and shrubs from the system, and farmers' trees management. This is in agreement with finding of [15] revealed that environmental variables would affect structure of woody species; [9] reported farmers tree selection affects basal area of farmland trees in semi-arid of Ethiopia.

Table 4. Mean (± Std) density (number of stems) of woody species per plot, and ha in parkland agroforestry in the study area using independent t-test.

Sites	Agroecology	Stem per plot	Stem per hectare
Beda	Highland	$11.37^a \pm 4.51$	$86.32^a \pm 39.81$
Durgi	Midland	$16.82^b \pm 6.13$	$130.70^b \pm 41.59$
Overall mean		14.09 ± 5.32	108.51 ± 40.7

Small letters across the column indicate significantly difference at (P < 0.05) between the two agroecological zones

Table 5. Mean (± Std) basal area ($g = m^2$) of woody species per plot, and ha in parkland agroforestry in the study area using independent t-test.

Sites	Agroecology	Basal area per plot	Basal area per hectare
Beda	Highland	$0.26^a \pm 0.14$	$1.97^a \pm 1.43$
Durgi	Midland	$0.39^b \pm 0.19$	$2.98^b \pm 1.35$
Overall mean		0.32 ± 0.16	2.47 ± 1.39

Small letters across the column indicate significantly difference at (P < 0.05) between the two agroecological zones

3.2.3. Importance value index (IVI) of woody species

Importance value index (IVI) is very significant to compare the ecological significance of species and its economic importance. Importance value index confirms the dominance, occurrence, and abundance of a particular species in relation to other associated species in a specific geographical location [41]. In order to evaluate ecological, and other benefit of each woody species recorded in the two agroecology of parkland agroforestry in the study area, their importance value index (IVI) was calculated and presented (Supplementary S1). Of all woody species, *Croton macrostachyus* (33.03 %), *Acacia saligna* (27.84 %), *Cordia africana* (23.86 %), *Erythrina brucei* (23.34 %), and *Acacia abyssinica* (23.08 %) were the top ranking in highland parkland agroforestry (Supplementary S2). Of all woody species, *Croton macrostachyus* (42.69 %), *Acacia decurrens* (32.85 %), *Erythrina brucei* (20.16 %), *Acacia abyssinica* (18.82 %), and *Cordia africana* (17.2 %) were the top ranking in midland parkland agroforestry (Supplementary S1). Woody species with higher IVI is associated with relative frequency, and abundance in each agroecology, farmers' species preference to plant, and retain in their parkland agroforestry, their products and services, and species adaptability to agroecology. Previous studies conducted by [2,7,23] reported that species with higher IVI in agroforestry systems are directly associated with farmers' species preference to grow on farmlands, benefits obtained from them, and woody species capable to adapt a particular agro-climatic factors. The most dominant, and important species to smallholder farmers in agroforestry practices have higher importance value index (IVI) [4,49].

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3.3. Management practices of woody species in parkland agroforestry

Farmers have a tradition of integrating woody species with staple food crops on-farms in the study area. Trees, and/or shrubs in parkland agroforestry practice demand different types of management practices in both agro-ecological zones of the study area. The most frequently appeared management practices employed by farmers on woody species in parkland agroforestry practice along Agroecology were including pruning, fertilizing, pollarding, lopping, coppicing, cutting, and watering (Table 6). This is supported with finding of [49] who revealed that farmers have been applying different management practices including pollarding, coppicing, lopping, composting, and pruning on woody species in traditional agroforestry practices; [2,50] reported farmers had indigenous knowledge on how to manage plant species in their farmlands to minimizing competition among the different components, and other uses.

Farmers employed different management practices on woody species in parkland agroforestry for the objectives of reducing competition, growth, fuelwood, fodder, timber quality, soil conservation, and other use values (Table 6). For example, farmers prune retained and planted trees to reduce competition for light, prune roots to reduce below-ground competition such as water, and nutrients, increase timber quality, and also to obtain other use values. This is in agreement with the finding of [4] who stated that farmers in Arsi Negele practice pruning of indigenous trees, and shrubs to reduce the impact on agricultural crops, fuelwood, getting fodder for livestock, for fencing, and for sales of fuelwood. Fertilizing, and watering were done in parkland agroforestry for increasing soil fertility, and soil moisture content in both study sites. Coppicing for growth, reduce resources competition with adjacent crops, sales, and other uses. This is in line with studies conducted in other areas in the country by [2,49,50].

Table 6. Management practices of woody species applied by farmers in parkland agroforestry, and management objectives in the study area.

Tree/Shrub Species names	Number of respondents and management activities							Objectives
	Pruning	Fertilizing	Pollarding	Lopping	Coppicing	Cutting	Watering	
Eucalyptus globulus	18	11	7	-	19	-	2	1, 2,4,7
Eucalyptus camaldulensis	28	-	5	-	39	-	1	1,2,4,7
Juniperus procera	4	-	-	-	-	-	-	1, 4,7,8
Erythrina abyssinica	17	-	11	-	18	-	-	1, 2,3
Erythrina brucei	8	-	9	-	10	-	-	1,5, 8
Cordia africana	4	-	12	7	17	-	-	1,2,3,7
Grevillea robusta	21	-	4	6	5	-	-	1, 2,7
Croton macrostachyus	19	-	17	13	12	-	-	1,2,3,4,6,7
Acacia decurrens	-	2	-	-	14	-	-	1, 2,3,5,7
Sesbania sesban	15	-	-	-	-	-	-	1,3, 5
Ficus sur	4	-	4	15	3	-	-	1,3,6,7
Ficus vasta	2	-	8	4	13	-	-	1, 3,8
Jatropha curcas	10	-	-	-	-	-	-	1,3
Syzygium guineense	-	-	3	-	6	-	-	1,2, 3
Millettia ferruginea	-	-	9	-	5	-	-	1,2, 3
Celtis africana	7	-	-	-	-	-	-	1,7
Olea europaea	5	3	10	-	-	-	-	1,3, 4, 5,8
Acacia abyssinica	-	-	6	8	12	-	5	1,2, 3, 4,8
Albizia gummifera	-	-	-	5	9	-	-	1,2, 5, 6,8
Entada abyssinica	-	-	13	-	6	-	-	1
Euphorbia abyssinica	-	-	-	-	-	7	-	8
Podocarpus falcatus	6	-	-	-	-	-	-	1,3
Prunus africana	3	-	-	-	-	-	-	1, 3
Acacia saligna	6	2	-	-	2	3	-	1,2,3,7
Hagenia abyssinica	2	-	-	-	-	-	-	1,8

Vernonia amygdalina	-	-	-	-	3	-	-	1,3,5
Total	179	18	118	58	193	10	3	

Keys for objectives: 1 = to reduce competition, 2 = for growth, 3 = to reduce shade, 4 = for fuelwood, 5 = for fodder, 6 = soil conservation, 7 = for timber quality, 8 = other use

4. Conclusions

This study provides evidence on woody species composition, diversity, structure, and management along agro-ecology, and farmers' wealth status in Tembaro Special District, Central Ethiopia. Woody species composition, and diversity was influenced by Agroecology, and farmers' wealth status in the study area. The parkland agroforestry practice is diverse and host for threatened multipurpose indigenous tree species including *Cordia africana*, *Prunus africana*, *Millettia ferruginea*, *Croton macrostachyus*, *Syzygium guineense (Wild.) DC.*, *Podocarpus falcatus*, *Hagenia abyssinica*, *Acacia abyssinica*, and *Olea europaea*. Midland parkland agroforestry practice comprised of the higher number of woody species with higher diversity indices than highland parkland agroforestry. Diversity indices were the higher in rich household parkland agroforestry practice than medium, and poor ones.

The overall diameter class distribution pattern of woody species in highland parkland agroforestry practice showed J-shaped curve indicating poorly regeneration population stand. On the other hand, partially Bell-shaped curve was observed in midland parkland agroforestry practice indicates unstable regeneration status of the stand. Diameter class distribution of *Acacia saligna*, and *Erythrina brucei* showed inverted J-shaped curve while partially Bell-shaped for *Cordia africana*, and J-shaped curve for *Croton macrostachyus* in highland parkland agroforestry. Diameter class distribution of *Croton macrostachyus*, and *Acacia abyssinica* showed J-shaped curve while partially Bell-shaped curve for *Acacia decurrens*, and inverted J-shaped curve for *Erythrina brucei* in midland parkland agroforestry. Density (number of stems per hectare), basal area (g = m^2 per hectare) were higher in midland parkland agroforestry practice than highland parkland agroforestry practice.

Farmers have been applying management practices on woody species in their parkland agroforestry practice for the purpose of reducing shade effects, competition with adjacent crops, for growth, timber, fodder, fuel wood, construction materials, and soil and water conservation. The farmers manage these woody species through pruning, fertilizing, pollarding, lopping, coppicing, cutting, and watering in the parkland agroforestry practice to get different benefits or objectives.

The results suggested that composition of the multipurpose woody species in parkland agroforestry practice is affected by Agroecology, and the socioeconomic factors requiring inclusion of indigenous trees and/or shrubs such as *Erythrina brucei*, *Acacia abyssinica*, *Millettia ferruginea*, *Croton macrostachyus*, *Cordia africana*, *Sesbania sesban*, extra in order to enhance woody species diversity conservation in each Agroecology thereby boosting associated crops productivity. Further investigation should be done on contribution of parkland agroforestry practice for climate change adaptation, and mitigation, and supporting livelihoods of the smallholder farmers along Agroecology.

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Conflicts of interest: The authors declare no conflicts of interest.

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