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Woody species composition and structure of asasa moist afromontane forests of the central highlands of Ethiopia

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Abstract
Woody species composition and structural analysis were investigated in Asasa forest which was once part of the Jibat forest. We used transect line to locate a sample plot of 20x20m from which vegetation data was collected. On each sample plot, height and diameter at breast height (DBH) of individual trees ≥5 cm and with height greater than 2 m were recorded. Seedlings and saplings of the woody species encountered in the subplots were recorded. Plant communities were identified using R-software. In addition structural and diversity analysis was conducted in the forest. We found that, a total of 115 woody plants species were recorded representing 47 families and 87 genera. Out of these plant species identified 59.13% species are trees, 33.03% are shrubs and 2.61% are lianas. From the total family the most dominant is Fabaceae with 13 species and 9 genera followed by Asteraceae and Rosaceae families with 6 species each and 1 genus and 4 genera respectively. Five plant community types were identified for our study forest. The forest is dominated by the lower diameter class indicating the dominance of newly growing plants due to the exploitation of the forest for construction. We recommend the need for appropriate forest management practices to sustainably use the resource base as it is detached from the continuous forest of Jibat.

Keywords: asasa forest; plant community type; humid forest, jibat

Introduction

Ethiopia is endowed with a diverse vegetation types due to the variation in climate, topography and soils (EPA, 1997; Friis 2009; Kebede *et al*. 2016; Belay *et al*., 2018) [10, 15, 3]. These vegetation types are under intense pressure due to a number of proximate and underlying factors (Lambin *et al*. 2001; Alelign *et al*. 2007; Senbeta *et al*. 2014) [18, 2, 27]. Despite the pressure, the forest resources of Southwestern Ethiopia are home to various plant and animal species that serve as biodiversity centers. In addition, these forests are providing ecosystem services at different scales and magnitudes. Such benefits of forest resources cannot be realized unless much of the forest fragments are studied for their diversity, structure and composition for better management practices (Alelign *et al*. 2007; Wassie *et al*. 2010; Senbeta *et al*. 2014; Belay *et al*., 2018) [2, 27, 3].

One of the remnant forests which were not studied well with regard to its vegetation structure and composition was Asasa forest. Asasa forest was separated from the continuous forests of Jibat through the expansion of settlement, cultivation and grazing. The time of its separation was not well known but it is predicted from various studies conducted through land use/land cover dynamics conducted for over four decades (Tolessa *et al*. 2016) [32]. Given its location from the district village (Shenen) and isolation from the continuous forests of Jibat, assessment of the vegetation characteristics of our study was not conducted. Hence this research focused on the analysis of species composition and structure of Asasa forest and its implication for biodiversity conservation.

Study area and methods

Study area

Asasa Forest is located at about 196 km west of Addis Ababa and 94 km from Ambo to the southwest and approximately 24 km apart from Jibat forest to the western part. According to the information obtained from Jibat-Gedo Forest and Wildlife Enterprise, the study area covers an area of 3558 ha. Asasa Forest is situated within 37˚19’13.9”- 37˚31’13.3”E and 8˚20’09.6”- 8º 37’09.6”N(Jibat- Gedo Forest and Wildlife Enterprise District, 2005).The altitudinal range of study area varies from 1970-2302 m.s.l. Average monthly temperatures are between 14.4 - 16.2 °C with average minimum and maximum temperatures of 8.8 °C and 21.6 °C respectively. Data from a meteorological station near Jibat forest indicate an average rainfall of 1800mm/yr. There are two peaks rainfall periods (March and August). The ‘spring’ peak is related to moist winds from the Indian Ocean, the ‘summer’ peak arises from warm winds from the southwest (Tamrat 1994) [31].

The vegetation type of Asasa forest is humid afromontane forest vegetation types (Tamrat, 1993) [30]. The forest is heavily disturbed due to extensive grazing within the forest and selective harvesting of the resource for various purposes such as firewood and construction materials among others. The forest is completely surrounded by agricultural land, settlement and grazing land that has resulted in the isolation of the forest which could potentially affect dispersal and future diversity of species.

Vegetation data collection

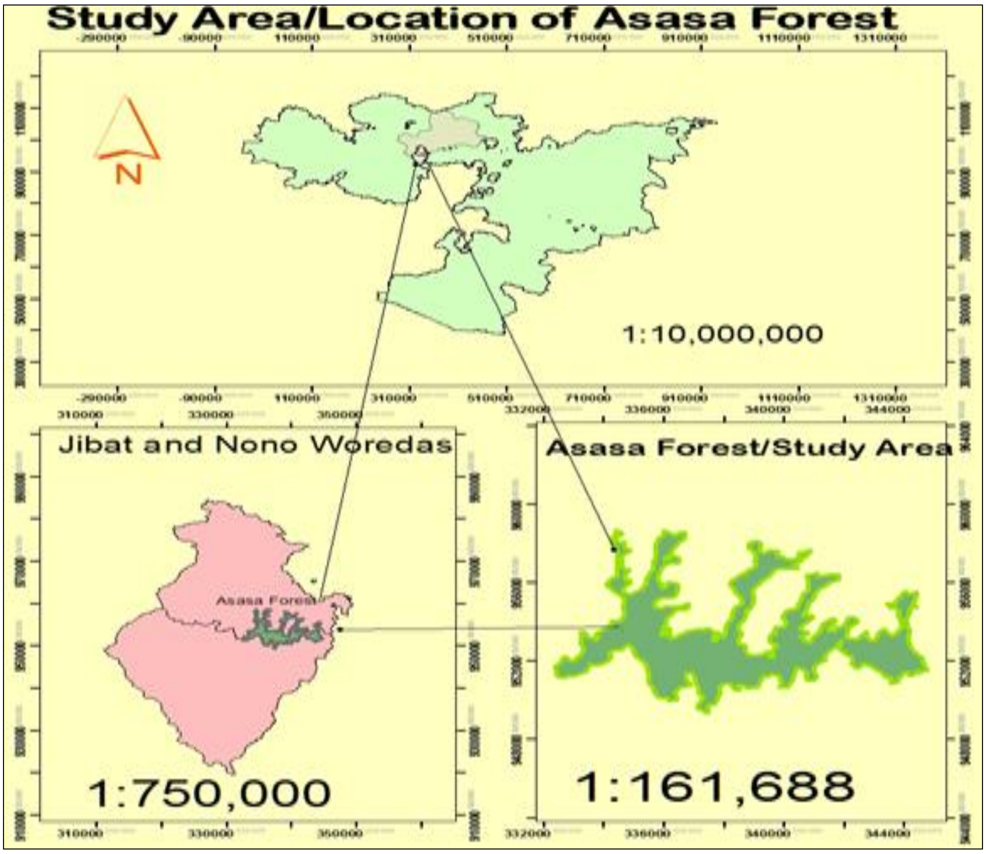

Fig 1

Before the start of the actual research work, a reconnaissance survey was carried out in September 2017 in order to gain a general understanding of the characteristics of the study area, collect baseline information, observe vegetation distribution and disturbance and identify the possible sampling sites. Plots with 20x20m were established along transect line which runs east-west direction to take in to account for the heterogeneity of the forest. The distance between each sample plots was 500m and a total of 50 sample plots were identified in the forest for vegetation analysis.

In each sample plot, height and diameter (DBH) of individuals of trees ≥5 cm and with height greater than 2 m were recorded. If the tree branched at 1.30 m height, the diameter were measured separately for each branches and averaged. All lianas encountered in the sample plots and shrubs in subplots were recorded. The saplings with height greater than 1.5 m and seedlings with height ≤ 1.5 m of all trees were gathered in the entire 9 m^2 (3 m x3 m) subplots. To assess regeneration status of the vegetation, seedlings and saplings of the woody species encountered in the subplots were computed. Plant species that occur outside the sample plots, but inside the study area were recorded as present for woody plant diversity to produce a more complete list of the plants in the vegetation area. The diameter (DBH) of woody plant were measured by using caliper, however, when a tree was larger a diameter tape was used and the height of woody plant were measured by using Suunto clinometer. Cover abundance was calculated as the area of the ground within a quadrate which is occupied by the above ground parts of each species when viewed from above (canopy cover) visually estimated as percentage.

The vernacular names of plant species were given by two local peoples who know the local name of the species then detail identification of species were done by expert and recognition of researcher by remembering taxonomic classification, using different reference and referring the volumes of flora of Ethiopia and Eritrea. The nomenclature of plant names follows the Flora of Ethiopia and Eritrea (Edwards *et al.*, 1995; 1997) [8, 9].

Data processing and analysis

Vegetation classification

A hierarchical agglomerative cluster analysis was performed using R- software version 3.2.1 (McCunne and Grace, 2002; R Core Team, 2014) [20, 25] to identify plant communities. The abundance data of the species was used in this analysis.

Structural data analysis

All individuals of the vegetation data structures gathered from all the 50 sample plots in this study were analyzed by using distribution of Diameter at Breast Height (DBH), height, density and Importance Value Index (IVI). The density of woody species and basal area of the vegetation were computed on hectare basis.

Important value index (IVI) was computed for all woody species based on relative density (RD), relative dominance (RDO) and relative frequency (RF) to determine their dominance position.

$$IVI = RD + RF + RDO \quad \text{……… (1)}$$

Where RD is Relative density, RF is Relative frequency and RDO as Relative Dominance

$$\text{Density} = \frac{\text{Number of individuals of species in sampled area}}{\text{Sum of all sampled area}} \quad \text{………… (2)}$$

$$\text{RD} = \frac{\text{Number of individuas of species in sampled area}}{\text{Total number of individuals of all species}} \text{ X } 100 \quad \text{…….. (3)}$$

$$\text{F} = \frac{\text{Number of quadrats in which a species occur}}{\text{Total number of quadrats}} \text{ X}100 \quad \text{…..... (4)}$$

$$\text{RF} = \frac{\text{Frequency of species}}{\text{Total frequency of all species}} \text{ X } 100 \quad \text{…….. (5)}$$

$$\text{BA} = \pi \, (d/2)^2 = (\text{DBH}/2)^2 \text{ X } 3.14 \quad \text{…….. (6)}$$

Where d is diameter at breast height

$$\text{Dominance} = \frac{\text{Total of basal area}}{\text{Area}} \quad \text{…….. (7)}$$

DBH was classified into five classes based on the similar interval between them and gradual decrease in higher DBH class. Therefore DBH class distribution of woody plant are: Class 1(5-15 cm), Class 2 (15.1- 25 cm), Class 3 (25.1 – 35 cm), Class 4 (35.1 – 45 cm), and Class 5 (≥ 45.1cm).In addition, height was classified into four size classes based on the highest density of species in the lower boundary class and the percentage distribution in each class also computed. Therefore height class distribution of trees as: Class 1(2 - 15 m), Class 2(16 – 29 m), Class 3(30 – 43 m) and class 4(≥ 43 m).

Woody plant diversity analysis

Shannon - Wiener (1949) index of species diversity was applied to quantify species diversity and richness. This method is one of the most widely used approaches in measuring the diversity of species. The two main techniques of measuring diversity are richness and evenness. Richness is a measure of the number of different species in a given site and can be expressed in a mathematical index to compare diversity between sites (Woldu, 1985) [34].

Shannon-Wiener diversity index is calculated as follows.

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad \text{...... (9)}$$

Where, H' = Shannon diversity index, S = the number of species, P_i = the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of total cover and Ln = logbase_n

Evenness (J) which is equal to H/Hmax is a measure of the relative abundance of the different species making up the richness of an area. Evenness compares the similarity of the population size of each of the species present. Where, H'= Shannon –Wiener Diversity Index, H max=lnS.

Shannon’s Equitability (EH) or Evennessis given by:

$$\text{EH} = \text{H'/Hmax} = \text{H/lnS} \quad \text{… (10)}$$

The value of EH is between 0 and 1 with 1 being complete evenness. If the species are evenly distributed then the H’ value would be high. So the H’ value allows us to know not only the number of species but how the abundance of the species is distributed among all the species in the community (Kent and Coker, 1992).

Results and Discussion

Floristic composition and diversity

A total of 115 woody plants species were recorded representing 47 families and 87 genera (Supplementary material S1). Out of these 115 plant species identified 69(59.13%) species were trees, 42(33.03%) were shrubs and 4(2.61%) were lianas. This composition and diversity is larger than the forest of Kuandisha afromontane forests of northwestern Ethiopia (Berhanu *et al*., 2016), Arero dry afromontane forest of the southern Ethiopia (Shiferaw *et al*. 2018) [28] and moist evergreen afromontane forests of the southwestern Ethiopia (Hundera *et al*. 2012) [14] but less than the forest fragments of Northern Ethiopia (Wassie *et al*. 2010; Zegeye *et al*. 2011) [36]. From the total family the most dominant is Fabaceae with 13 species and 9 genera followed by Asteraceae and Rosaceae families with 6 species each and 1 genus and 4 genera respectively. In Ethiopia similar studies shows Fabaceae is the leading family (Alelign *et al*. 2007; Gole *et al*., 2008; Didita *et al*., 2010; Mohammed *et al*. 2013; Dibaba *et al*. 2014; Mulugeta *et al*. 2015; Berhanu *et al*. 2016; Belay *et al*. 2018) [2, 13, 7, 23, 6, 24, 3] but with differences in other families, that is, Asteraceae and Roaceae are the next diverse family in our study forest. The dominance of Fabaceae and Asteraceae could be attributed to their efficient and successful dispersal mechanisms and adaptation to a wide range of ecological conditions. Out of the plant species identified, 8 were endemic species. Of these four was trees and four was shrubs.

The species of plants are less than the number recorded in Jibat forest which is also regarded as humid afromontane forests (Tamrat 1994; Burju *et al*. 2013) [31, 5]. Despite the higher number of species recorded in this forest the separation and isolation of Asasa forest has significant impact on the future diversity which could be affected by further fragmentation, degradation and deforestation problems.

The number of endemic species identified in our study forest was similar with other studies elsewhere in Ethiopia (Mulugeta *et al*., 2015) [24]. Based on the IUCN Criteria of level of threat, four species are least concern (LC), three species have been assessed as near threatened (NT) and one species is vulnerable (VU) (Table 1).

Table 1: List of endemic species in the study area with their conservation status

Species Name	Family	Habit	IUCN Category
Acanthus sennii	Acanthaceae	S	NT
Millettia ferruginea subsp. ferruginea	Fabaceae	T	NT
Erythrina brucei	Fabaceae	T	LC
Lippia adoensis.	Verbenaceae	S	LC
Solanum marginatum	Solanaceae	S	LC
Vernonia leopoldi	Asteraceae	S	LC
Ekebergia capensis	Meliaceae	T	VU
Rhus vulgaris	Anacardiaceae	T	NT

Forest structure

Woody species frequency and density

Results from the computed frequency values of different species were classified into four DBH classes as: 1= 5 - 15, 2= 15.1-25, 3= 25.1-35, 4= >35.1. The result showed that 72.13% of the total woody species were distributed in the lowest DBH class one and two whereas in the next two DBH classes, 22.32% and 6.25% of the species were distributed respectively. The highest frequency value was recorded for *Podocarpus falcatus (*17.36*)* whereas the least was recorded for *Rhus vulgaris* (10.54) and *Cordia Africana* (10.54). Our study corroborates with others studies elsewhere (Mohammed *et al*. 2013) [23].

Plant community types

Five plant community types were identified from the hierarchal cluster analysis using R-software version 3.2.3 computer programme (Fig. 2) using Summary of synoptic values of top 52 plant species (Table 2). The vegetation classification was done by using the cover abundance value estimate of each species included in the analysis. Distribution of the five plant community types (C1= Community Type 1, C2= Community Type 2, and C3= Community Type 3, C4= Community Type 4, C5 = Community Type 5) along with their altitudinal range was given in Table 2. The plant community types were named by two characteristic species that have highest mean cover abundance estimate in each community (Table 2). Our analysis have shown five plant community types in Asasa forest which is lower than the eight plant community types identified in Jibat forest from which this forest was separated long years back through human activities (Tamrat, 1993; Tamrat 1994) [30, 31] and greater than moist montane forests of southwestern Ethiopia (Dibaba *et al*. 2014; Mulugeta *et al*., 2015; Meragiaw *et al*. 2018) [6, 24, 21] but similar plant community types with the afromontane forest fragments in northern Ethiopia (Aerts *et al*. 2006) and moist afromontane forests of south central and western Ethiopia (Yeshitela and Bekele 2002; Kebede *et al*. 2013; Kebede *et al*. 2016) [35, 16, 15].

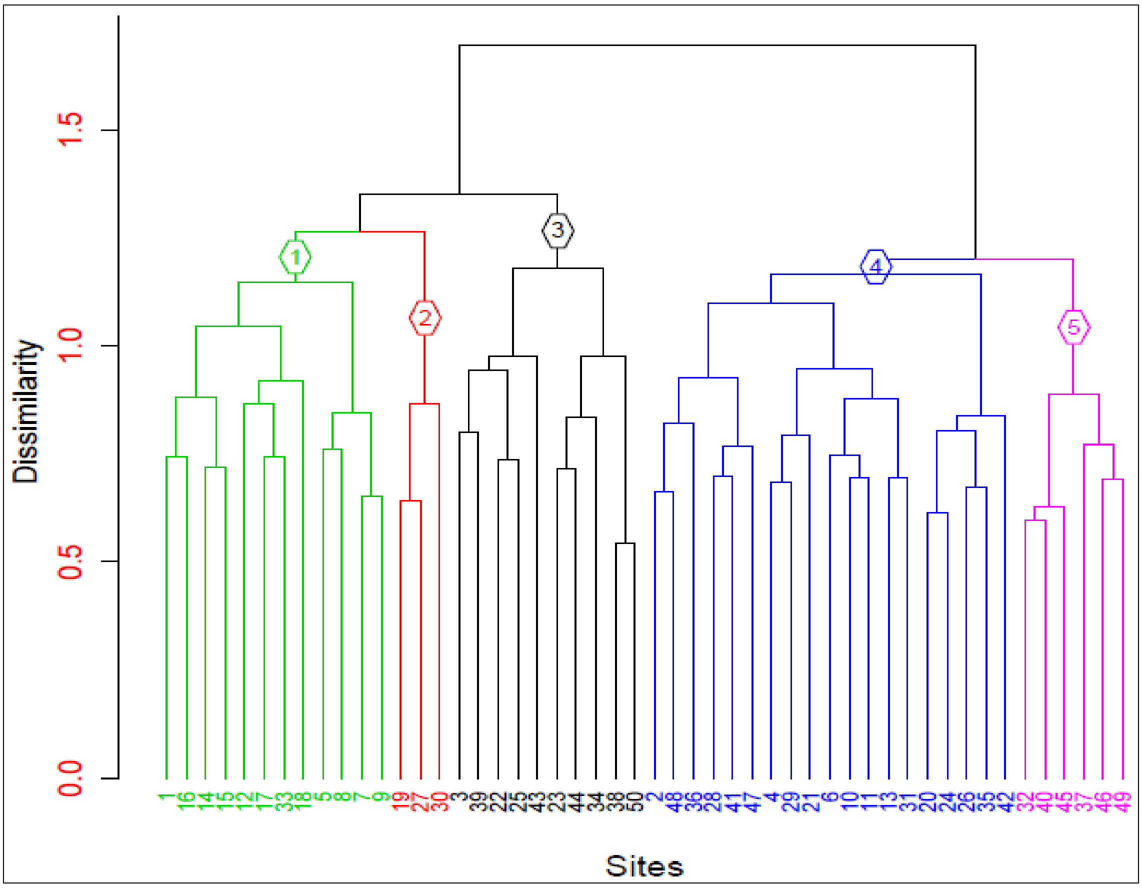

Fig 2: Dendrogram showing plant community types of the study area

Table 2: Synoptic table of species with synoptic values with >1 in at least one plant community type (C1: community type 1, C2: community type 2, C3: community type 3, C4: community type 4, C5: community type 5)

Name of species	C1	C2	C3	C 4	C5
Buddleja polystachya	3.08	0.00	0.00	0.00	0.00
Syzygiumguineense	2.92	0.00	0.00	0.00	0.00
Maytenus obscura	1.50	0.00	0.00	0.00	0.00

Lippia adoensis	1.25	0.00	0.00	0.00	0.00
Euclea divinorum	1.08	0.00	0.00	0.00	0.00
Ficus thonningii	1.00	0.00	0.00	0.00	0.00
Bersama abyssinica	1.25	1.00	1.50	0.00	0.00
Gardenia ternifolia	1.33	1.21	0.00	0.00	0.00
Olinia rochetiana	1.83	1.05	1.00	0.00	0.00
Prunus africana	0.00	4.42	0.00	1.33	0.00
Millettia Ferrugina	0.00	2.11	0.00	0.00	2.67
Olea capensis	1.92	1.37	1.00	0.00	0.00
Acacia sieberiana	0.00	1.00	0.00	0.00	0.00
Pittosporum viridiflorum	0.00	1.00	0.00	0.00	0.00
Stereospermum kunthianum	0.00	1.16	0.00	0.00	0.00
Calpurnia aurea	0.00	1.05	1.10	0.00	0.00
Celtis africana	0.00	1.05	0.00	0.00	0.00
Allophylus macrobotrys	1.17	0.00	2.80	0.00	0.00
Apodytes dimidiata	0.00	1.26	3.00	0.00	1.67
Croton macrostachyus	0.00	1.21	3.60	0.00	0.00
Dombeya torrida	0.00	1.21	1.20	0.00	0.00
Euphorbia ampliphylla	0.0	0.00	1.20	0.00	0.00
Ficus sur	0.00	1.16	2.30	0.00	1.83
Hagenia abyssinica	0.00	0.00	1.20	0.0	0.00
Maytenus arbutifolia	1.83	0.00	1.00	2.00	1.00
Acacia abyssinica	0.00	0.00	0.00	5.67	0.00
Acacia negrii	1.75	0.00	0.00	3.00	0.00
Combretum adenogonium	1.67	1.47	1.60	2.00	0.00
Rhus vulgaris	1.58	1.37	1.20	3.33	1.17
Caesalpinia decapetala	1.25	1.16	0.00	2.00	0.00
Cupressus lusitanica	0.00	0.00	0.00	2.00	0.00
Dodonaea angustifolia	0.00	0.00	0.00	1.33	0.00
Dovyalis caffra	0.00	0.00	0.00	1.33	0.00
Erica arboria	0.00	0.00	0.00	3.00	0.00
Eucalyptus globulus	0.0	0.0	0.00	2.00	0.00
Flacourtia indica	0.00	0.00	0.00	5.33	0.00
Myrsine africana	0.00	0.00	0.00	1.67	0.00
Myrsine melanophloeos	0.00	0.00	0.0	1.67	0.00
Nuxia congesta	0.00	0.00	0.00	2.00	0.00
Oxyanthus speciosus	0.00	0.00	0.00	1.00	0.00
Rosa abyssinica	0.00	1.05	0.00	1.67	0.00
Trema orientalis	0.00	0.00	0.00	3.00	0.00
Maytenus gracilipes	3.08	0.00	1.80	0.00	3.17
Podocarpus falcatus	2.58	3.74	1.00	0.00	5.50
Cordia africana	1.58	0.00	1.50	1.67	1.83
Rubus apetalus	1.17	1.68	2.80	0.00	2.50
Albizia schimperiana	0.00	3.68	1.00	0.00	4.33
Ekebergia capensis	0.00	1.95	0.00	0.00	5.00
Erythrina brucei	0.00	0.00	0.00	0.00	3.17
Gnidia glauca	0.00	0.00	0.00	0.00	1.50
Maesa lanceolata	0.00	0.00	0.00	0.00	1.00
Teclea nobilis	0.00	1.11	1.30	0.00	1.33

Species diversity, richness and evenness

Shannon-Wiener diversity index was computed for the five plant community types of the woody plant of Asasa forest (Table 3). Community type two had the highest species richness followed by community type three whereas the least species rich community is community type four. However, evenness which measures the relative abundance of different species present in each community showed relatively the highest value for community type four followed by community one and the lowest was community type two.

The diversity of species in our study forest is similar to other studies in Ethiopia (Meshesha *et al*. 2015) [22]. Community type two is found to be having the highest species rich as compared to others and hence the podocarpus species and milletia are dominantly found in this particular forest. In general species diversity, richness and evenness varied between plant communities which corroborates other studies (Masresha *et al*. 2015; Meragiaw *et al*. 2018) [19, 21].

Table 3 Shannon–Wiener Diversity Index for woody plant of Asasa Forest

Table 3

Community type	Species richness	Diversity (H)	Evenness (J)
C1	63	3.84	0.93
C2	82	3.93	0.89
C3	69	3.89	0.92
C4	23	2.98	0.95
C5	36	3.24	0.90

Vegetation structure

Diameter and height class distribution

The general categories of the DBH class distribution of the tree species was calculated based on the sampled area. The

Density of trees with DBH ≥ 5 cm in the study area is 853/ha (Table 4). Tree density were classified into five DBH classes as: Class 1(5 – 15 cm), Class 2 (15.1- 25 cm), Class 3 (25.1 – 35 cm), Class 4 (35.1 – 45 cm), and Class 5 (≥ 45.1 cm). The diameter and height class distribution shown in the study area is indicating an inverted J-shaped distribution which is similar to other studies of diameter class distribution in Ethiopia (Wassie *et al.* 2010; Mohammed *et al*. 2013; Tadele *et al*. 2014; Meshesha *et al.* 2015; Mulugeta *et al*. 2015) [23, 29, 22, 24].

Table 4: Stem density ha^{-1} distribution of woody plants of Asasa Forest in different DBH classes

Ro.no	DBH class	No.of individual	density /ha	% density
1	5 -15	790	395	462.9
2	15.1 -25	268	134	157.0
3	25.1 – 35	228	114	133.6
4	35.1 – 45	218	109	127.7
5	≥ 45.1	202	101	101

About 64 woody species having 1706 individuals were selected to describe the structure of Asasa Forest. Woody species in this study area were categorized into four height classes which were conventionally established (Figure 3). The categories of height class are Class 1(2 – 15 m), Class 2(16 – 29 m), Class 3(30 – 43 m) and class 4(≥ 43 m). As height class size increase the density of tree species decreased (Figure 3). This means, there are higher number of individuals in the lower size and a gradual decrease towards the upper size trees indicating continuous representation of individuals in all height classes.

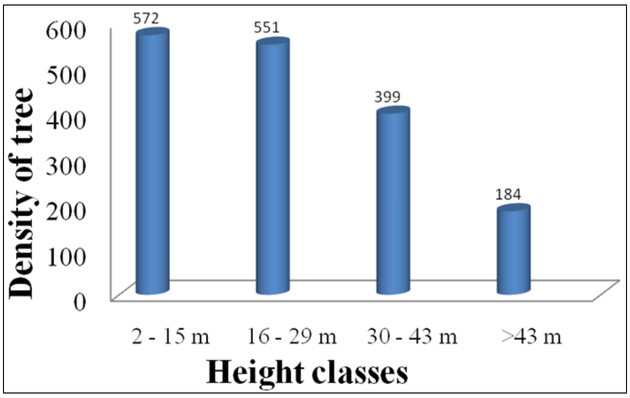

Fig 3: Density ha^{-1} of woody species of Asasa Forest in four height classes

Basal area and dominance

Total basal area of the forest was 27.10 m^2 ha^{-1} for woody species ≥ 5 cm in DBH and ≥2 m in height. *Allophylus macrobotrys, Juniperus procera, Podocarpus falcatus, Ficus vasta, Erythrina brucei and Ficus thonningii*constitute 63.38% of total BA in the Asasa Forest. Species like*Croton macrostachyus, Olea capensis L. subsp. Macrocarpa, Albizia schimperiana, Prunus africana and Rubus apetalus*although they have high density but their basal area is not as high as their density (Supplementary, S2). Based on the value of dominance and relative dominance the dominant species of woody vegetation were described in Supplementary, S2. The basal area of Asasa forest is nearly similar to that of the moist evergreen afromontane forests of the southwestern Ethiopia (Hundera *et al*. 2012; Dibaba *et al*. 2014) [14, 6] but greater than the value recorded for Zengena forest of the northwestern Ethiopia (Tadele *et al.* 2014) [29].

Population structure of representative species

The analysis of selected woody species in the study area resulted in six different patterns of population structures, and one species was taken to show its corresponding pattern (Figure 4). The first population pattern was represented by species distributed in all DBH class and shows the up down U- shape (Fig. 4a). *Albizia schimperiana* was taken as representative species in this pattern. The other species showing this pattern were *Allophylus macrobotrys, Apodytes dimidiata, Celtis africana, Cordia africana, Buddleja polystachya, Croton macrostachyus, Erythrina brucei and Ficus thonningii.*

The second population pattern was represented by species absent in the first class and having the highest density in the second DBH class and decreasing in the higher DBH class (Fig. 4b). The speciestaken as representative to show this pattern is *Ekebergia capensis*. The other Species showing this pattern were *Dombeya torrida, Juniperus procera, Millettia ferruginea, Olea capensis L. subsp. Macrocarpa, Podocarpus falcatus, Prunus africana* and *Rubus apetalus*. The third population pattern represented by *Diospyros abyssinica* was shown by the species having hight density in the DBH class one and decreasing towards the DBH class two and then ending in the DBH class three (Fig. 4c). Species showing this pattern were *Vernonia amygdalina, Trema orientalis, Sclerocarya birrea, Sapium ellipticum* and *Syzygium guineense.* The fourth population pattern was represented by the species which had the highest density in the DBH class two and decreasing towards the highest DBH class (Fig. 4d). This population pattern was represented in all the DBH classes. Species showing this pattern were *Ficus sur, Euclea divinorum, Ficus vasta, Gnidia glauca, Myrica salicifolia, and Myrsine melanophloeos*was taken to represent the population structure shown by the species. The fifth population pattern was shown by the species having the highest density in the DBH class one and relatively higher density of individuals in the second DBH class, but decreasing towards the higher DBH classes (Fig. 4e). *Teclea nobilis* and *Vepris dainellii* showed this population pattern. But in the first DBH class, density was not far apart from the highest density recorded in the DBH class two, whereas it was gradually decreasing towards the higher classes. The six population pattern represented by *Acacia abyssinica* was shown by species having the highest density in the DBH class one and decreasing through interruptions towards the higher DBH classes (Fig. 4f).

Species showing this pattern were *Acacia albida, Acacia sieberiana, Bersama abyssinica, Dovyalis abyssinica and Cupressus lusitanica.*

Our analysis have shown five plant community types in Asasa forest which is lower than the eight plant community types identified in Jibat forest from which this forest was separated long years back through human activities (Tamrat, 1993; Tamrat 1994) [30, 31] and greater than moist montane forests of southwestern Ethiopia (Dibaba *et al.* 2014; Mulugeta *et al*., 2015; Meragiaw *et al*. 2018) [6, 24, 21] but similar plant community types with the afromontane forest fragments in northern Ethiopia (Aerts *et al*. 2006) and moist afromontane forests of south central and western Ethiopia (Yeshitela and Bekele 2002; Kebede *et al*. 2013; Kebede *et al*. 2016) [35, 16, 15].

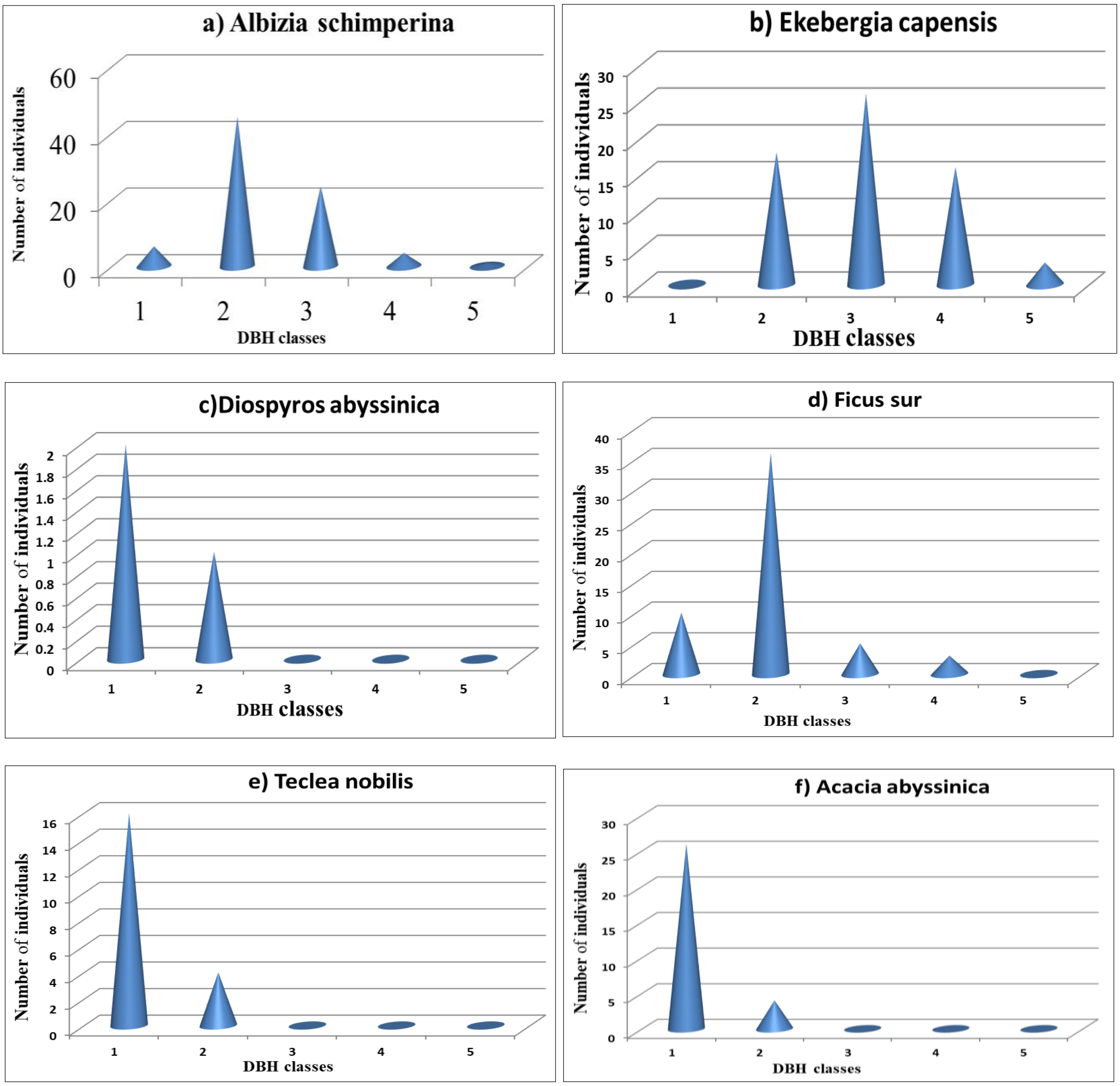

Fig 4: (a - f) Six representative patterns of tree species population structures in Asasa Forest where DBH classes are: 1) 5 -15 cm, 2) 15.1 - 25 cm, 3)25.1 - 35 cm, 4) 35.1 - 45 cm, 5) ≥45.1 cm

Regeneration

Out of the 64 analyzed woody plant the total density of seedlings is 1025/ ha (36.66%), density of saplings are 918/ ha (32.83%) and density of mature tree is 853/ha (30.51%) were recorded and included in the analysis. Comparison made on total density of seedlings, saplings and mature trees of selected sixty four woody plants showed little variation between them. The ratio of seedlings to saplings is 1.12, seedlings to mature trees is1.2 and saplings to mature trees were 1.08. The density of seedlings is the highest for *Podocarpus falcatus*and a number of species in the forest showed no seedlings. Species that has no seedling include *Ehretia cymosa Thonn., Ficus thonningii Blume, Grevillea robusta R. BR.Hypericum quartinianum A.Rich, Juniperus procera Hochst.ex Endl., Myrica salicifolia A. Rich., Rhamnus staddo A.Rich., Salix mucronata Thunb. (S. subserrata Willd.), Sclerocarya birrea*and*Vernonia amygdalina Del.*.Such absence of seedlings for the species requires special attention to improve regeneration through appropriate forest management practices to reduce local level extinction.

Importance Value Index (IVI)

The IVI of the species varied from the highest 21.79 to 0.41 when it is calculated for the sixty four species identified with the forest (Supplementary material, S3). Two species, that is, *Allophylus macrobotrys Gilg*and *Podocarpus falcatus (Thunb.) R. B. ex. Mirb* had IVI greater than 20 while *Diospyros abyssinica (Hiern) F.* White and *Ehretia cymosa Thonn* has IVI less than 0.5. Three species such as *Allophylus macrobotrys Gilg*and *Podocarpus falcatus (Thunb.) R. B. ex. Mirb* and *Albizia schimperiana Oliv.* Contributed more than 50% of the IVI for the forests. The basal area of Asasa forest is nearly similar to that of the moist evergreen afromontane forests of the southwestern Ethiopia (Hundera *et al*. 2012; Dibaba *et al*. 2014) [14, 6] but greater than the value recorded for Zengena forest of the northwestern Ethiopia (Tadele *et al*. 2014) [29].

Conclusion

The study has shown 115 plant species representing 47 families and 87 genera. Fabaceae and Asteraceae were found to be the most dominant families followed by followed by Asteraceae and Rosaceae. The study forest was also an important reservoir of endemic plants. About eight endemic plant species were identified which could serve as an important source of biodiversity center.

The variation in species composition and diversity among communities could be associated with different factors, such as altitude, anthropogenic impacts and soil properties. The presence of relatively higher percentage of lower diameter size in the forest indicated that Asasa Forest is at a stage of secondary regeneration. Analysis of population structure of most common species of trees and shrubs revealed different patterns of population structure, indicating a high variation among species population dynamics. Accordingly, seven community types were recorded in Asasa Forest. Analysis of regeneration of some selected woody species revealed that some tree species have lower seedling and sapling stages while others are represented by more seedling, sapling and mature stages in the forest. The results suggest that remnant forest patches in the central highlands of Ethiopia host several woody plant species that are almost disappearing in other areas due to deforestation. We recommend the need for sustainable forest management practice to improve regeneration and increase the use of the forest.

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Authors' contributions

All authors collected data and fully participated in data analysis and manuscript writes up

Conflict of interest

The authors declare no conflict of interest

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