FLORISTIC COMPOSITION, DIVERSITY AND STRUCTURE OF SIX FOREST PATCHES, NORTHWEST ETHIOPIA

Abiyot Berhanu*[1], Sebsebe Demissew[2]

Ethiopian Biodiversity Institute, P.O.Box 30726, Addis Ababa, Ethiopia

Department of Plant Biology and Biodiversity Management, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia.

ABSTRACT: The study was undertaken with the general objective of investigating the composition, diversity and structure of six forest patches in northwestern Ethiopia. Vegetation data were collected from 154 sampling plots of each 400 m^2 (20 m × 20 m). Species frequency, density, basal area, dominance, importance value index and population structure of the forest patches were analyzed using descriptive statistical tools. Floristic diversity and evenness were computed using Shannon diversity and evenness indices, respectively. The variations of floristic richness, density and basal area among the forest patches was tested using One-Way ANOVA in PAST software Package. The results of the study revealed that the study area harbored 212 species (122 woody and 90 herbaceous) belonging to 169 genera and 79 families. The Shannon diversity index and evenness values of the study area were 3.7 and 0.8, respectively. The highest number of species were recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiki, Kidamaja and Degera forests. The density, basal area and dominance of woody species were 2172.1 stems ha^{-1}, 41.2 m^2 ha^{-1} and 23.1 m^2 ha^{-1}, respectively. There were no significant variations of floristic richness, density and basal area among the forest patches. A number of tree species showed unhealthy population structure and were found to be at conservation risk. To reverse these changes, among other measures, undertaking restoration activities using locally threatened woody species is highly recommended.

Keywords: Basal area, Density, Diversity index, Importance value index, Population.

INTRODUCTION

The Ethiopian highlands particularly the Afromontane forests are among the mixed mountain and highland systems with complex zonation and they are part of the 29 biogeographic provinces of the Ethiopian/Afrotropical region of endemism (Brown and Lomolino, 1998). Moreover, the Afromontane vegetation of Ethiopia is part of the Eastern Afromontane hotspot that comprises high species richness and endemism (Friis, 1992, 2009; Friis et al., 2010). The distribution and richness of plant taxa is highly variable

*Corresponding author: abiyotmulu@gmail.com

in Ethiopia. The general trend of species richness is that the southwestern, southern and southeastern parts of Ethiopia have the highest plant species richness, even though the values found for richness in some areas reflect high collecting intensity of samples (Friis, 2009).

The size and quality of remnant forest patches of Ethiopia particularly the study area is deteriorating at an alarming rate due to various threats (Berhanu et al., 2019). Those forests which are surrounded by hostile matrices such as agricultural and grazing lands and settlement are in most cases influenced by various factors such as fragmentation, disturbance and selective logging, which lead to gradual loss of key species; the process termed more suitably as "ecological decay" (Laurance et al., 2002). Fragmentation, by breaking down continuous landscapes into smaller, isolated patches, exposes forest edges to increased windthrow and light penetration. This can lead to reduced tree density at forest edges, as documented by studies like that of Chen et al. (2009) who reported a 20% decrease in tree density within 100 meters of the edge compared to the forest interior. Disturbances, encompassing events like wildfires and invasive species infestations, further disrupt established communities by creating canopy gaps and altering resource availability (Lindenmayer and Fischer, 2011). This triggers successional changes, often favouring fast-growing, light-demanding species over shade-tolerant ones, resulting in shifts in size distribution and potentially decreasing basal area due to the presence of smaller trees (Asner et al., 2014). Selective logging, while targeting specific high-value trees, creates lasting impacts even beyond the immediate removal. Gaps in the canopy trigger regeneration of shade-intolerant species, ultimately leading to a decline in canopy height and basal area dominated by smaller trees compared to undisturbed forests (Slik et al., 2015). Additionally, logging activities themselves cause physical damage to remaining trees and understory vegetation, further contributing to structural alterations (Brockerhoff et al., 2017). Collectively, these factors exert a complex influence on forest structure, often leading to decreased tree density, reduced basal area, and shifts in size distribution towards smaller trees, creating a less diverse and potentially less resilient ecosystem (Laurance and Williamson, 2001).

The forests of northwestern Ethiopia have not been investigated except few studies that were carried out on the temporal vegetation cover dynamics and vegetation distribution modelling (Berhanu et al., 2018; 2019), genetics of a single species – *Prunus africana* (Yineger et al., 2014) and floristic study of single forest fragment – Zengena Forest (Tadele et al., 2013) and Kuandisha forest (Berhanu et al., 2017).

Thus, we hypothesized that species richness, density and basal area of the six forest patches are different despite their inclusion in the "same vegetation type"; and a number of plant species in the study area are at conservation risk. The research objectives were to investigate; (1) woody species richness and diversity of forest patches; (2) structure of the forest patches and selected woody species; and (3) importance value index of selected woody species for conservation and management interventions.

MATERIALS AND METHODS

Study area

The study was conducted in forest patches of Guangua-Illala and Kahtasa forests, northwestern Ethiopia (Figure 1). It is located in the Gojam Floristic Region, western Ethiopian highlands (Friis et al., 2010), within a newly described vegetation type, namely Intermediate evergreen Afromontane Forest (Berhanu et al., 2018).

After a reconnaissance survey, six forest patches were selected and their altitude and grid references were noted. The forest patches are located between latitudes 10^{o}47' N to 11^{o}02' N and longitudes 36^{o}32' E to 36^{o}48' E. The altitudinal range lies between 1830 and 2660 m asl. The total area of forest patches is 2,920 ha, sizes ranging from 327 to 651 ha (Table 1).

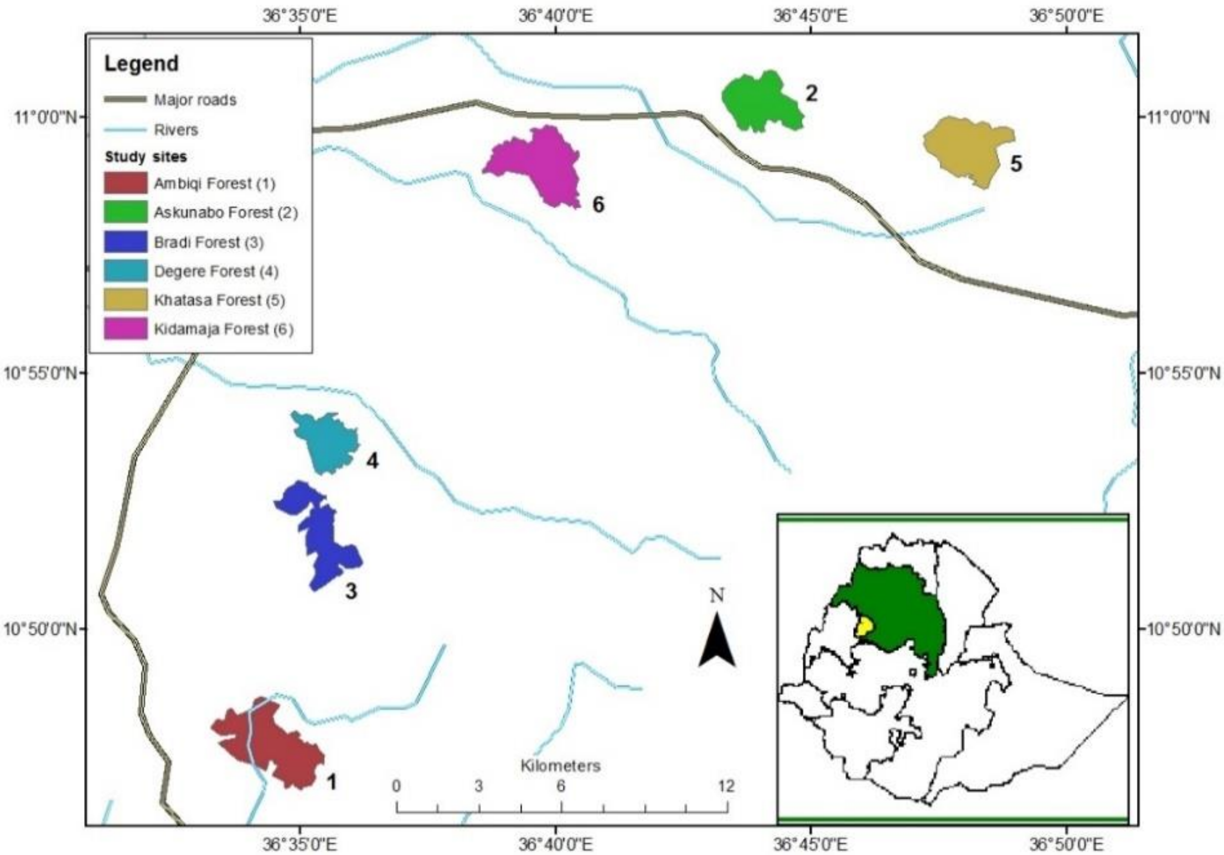


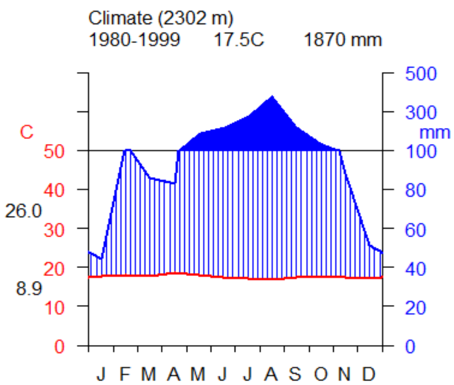
Figure 1. Map of studied forest patches in northwestern Ethiopia.

Table 1. Number and total area of plots investigated along line transects in each forest patch.

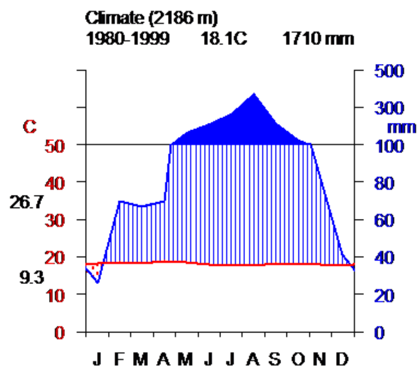
Forest patch	Ambiqi	Bradi	Degera	Kidamaja	Askunabo	Khatasa	Total
No. of Line Transects (LT)	5	7	6	5	7	6	36
Orientation of LTs	*SW-NE*	*E-W*	*SW-NE*	*SW-NE*	*SW-NE*	*SW-NE*	-
Plot Range	115-130	1-31 and 56	32-55	95-113	57-94 and 153-156	132-152	1-156*
No. of Plots (P)	16	32	24	18	42	22	154
Total Area (ha)	0.64	1.28	0.96	0.72	1.68	0.88	6.16
P/LTs (Ratio)	3.20	4.57	4.00	3.60	6.00	3.67	4.28

***** ***Note:*** *two numbers, 111 and 114 were not used as plot numbers. E - east, W – west, SW – southwest, NE - northeast*

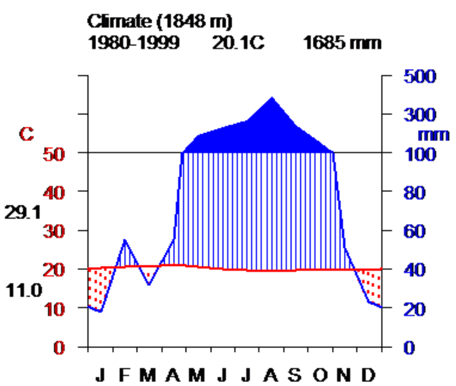
Climate: Gemechu (1977) classified the rainfall pattern of the study area as unimodal. Most of the study area gets rain for at least nine months with variable intensity. The annual precipitation ranges between 1685 and 1870 mm. The highest precipitation of wettest month (August) is 388 mm at Khatasa; while in the driest month (January) it is 18 mm at Kidamaja. The wettest months are May to October with high peaks in August; whereas the driest months are December to February for all study sites except Khatasa (Figure 2). The annual mean temperature of the study area ranges between 17º C and 22º C. The highest annual mean temperature was recorded at Kidamaja; whereas the lowest was recorded at Khatasa.



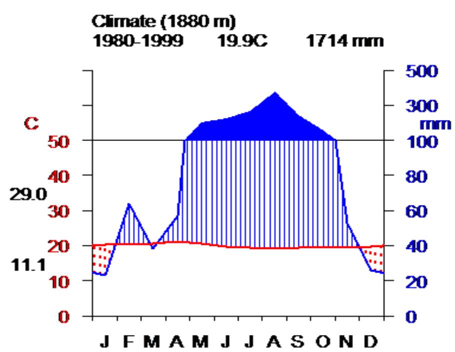
a) Khatasa (10.98375 N; 36.8062 E)



b) Askunabo (11.00299 N; 36.7307 E)



c) Kidamaja (10.98662 N; 36.65749 E)



d) Ambiqi (10.79456 N; 36.5794 E)

Figure 2. Clima diagrams for meteorological stations in the study area (Awi).

Vegetation data collection

A total of 154 sampling plots of each 400 m^2 (20 m x 20 m) were taken from all forest patches. The number of sampling plots varied per forest patch based on forest cover, altitudinal differences (gradients) and habitat variability of forest patches. The distance between two consecutive plots along a line transect was 200 m. The first line transect was aligned randomly at one side of the forest by avoiding the forest edge (at least 50 m into the forest). The distance between two parallel line transects was 300 m. The transects were laid against altitudinal gradients in order to capture representative samples of the forest.

The scientific and local names, habits and abundance for each woody species were recorded in each plot. Diameter of each woody species having a diameter of ≥ 2.5 cm at Breast Height (DBH) was measured using a tree caliper. When the boll of a tree was at breast height, diameter was measured above the tree ball. In cases where the tree or shrub branched at about breast height, DBH was measured separately for each branch that is each branch was considered as separate individual.

The heights of all individuals of woody species with DBH ≥ 2.5 cm was measured with a Hypsometer (Nikon Laser Rangefinder Forestry Pro) and meter tape as appropriate. For measuring abundance of seedlings of woody species 2 m x 2 m sub-plots, one at each corner and one at the center of each 400 m^2 quadrat (total area 20 m^2 per plot), were used. Seedling in this study is defined as individuals of a woody species having a DBH of below 2.5 cm or a height of below 1.5 m (Maria et al., 1995).

Botanical identification

All plant specimens were collected, temporarily tagged with plot numbers followed by English alphabets, pressed and transported to the National Herbarium (ETH) for identification and storage. Unidentified and identified specimens were identified and confirmed, respectively, by using the various volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Edwards et al., 1995; Phillips, 1995; Hedberg et al., 2003; Tadesse, 2004; Hedberg et al., 2006; 2009a; 2009b). Voucher specimens were deposited at the ETH and the Ethiopian Biodiversity Institute (EBI).

Data analysis

Floristic richness and diversity

Floristic richness, diversity and evenness indices and Whittaker's beta diversity index of the study area and sites were calculated using R Package 3.2 (R Core Team, 2021).

Forest structure

Frequency in this study is expressed as a percentage of the total number of plots in which individuals of a given species were recorded divided by the sum total number of the plots taken in the study area. The following formulas were used in Microsoft Excel spreadsheet programme.

$$F = \frac{P_i}{\sum_{i=1}^{s} P_i} \times 100,$$

Where, F is the frequency of a species and P_i is number of plots in which the i^{th} species (s) was recorded;

$$R_{fr} = \frac{F_i}{\sum_{i=0}^{s} F_i} \times 100,$$

Where, R_{fr} is the relative frequency of a species and F_i is frequency of the i^{th} species (s).

The study on the population structure, which is defined as the frequency distribution of individuals in arbitrarily defined DBH or height classes, was carried out for woody species based on most widely used DBH and height classes in Ethiopia (e.g. Dalle, 2015; Berhanu et al., 2017). Diameter was classified into nine classes of 5 cm interval and height into 10 classes of 5 m interval. DBH classes include: 2.5 – 7.5, 7.6 – 12.5, 12.6 – 17.5, 17.6 – 22.5, 22.6 – 27.5, 27.6 – 32.5, 32.6 – 37.5, 37.6 – 42.5 and >42.5. Height classes are ≤5, 5.1 – 10, 10.1 – 15, 15.1 – 20, 20.1 – 25, 25.1 – 30, 30.1 – 35, 35.1 – 40, 40.1 – 45 and > 45. To show the population structure, the density of individuals falling in the DBH or height classes were summed up and diagrams were produced using Microsoft Excel spreadsheet programme.

Woody species density in this study is expressed as number of individuals of a species per hectare. The density and relative density of woody species were computed in Microsoft Excel spreadsheet programme. The total species density, which is expressed as the sum total of all individuals of all species in a hectare was also computed. The relative density was calculated using the following formula:

$$R_{de} = \frac{D_i}{\sum_{i=1}^{s} D_i} \times 100,$$

Where, R_{de} is the relative density of a species and D_i is density of the i^{th} species (s);

Basal area (m^2 ha^{-1}) measured as the cross-section area of a tree at breast height, was computed from the measurement of DBH as follows in Microsoft Excel spreadsheet programme:

$B_a = \pi d^2/4$, where $\pi = 3.14$, B_a is basal area, and d is DBH (m).

However, since DBH was measured in centimeters, the formula was modified in such a way that the B_a will be in square meters. Thus, $B_a = \pi d^2/40,000$ or $0.0000785d^2$, where d is DBH in centimeters. The mean basal area of all investigated plots was converted to mean basal area per hectare.

The dominance and relative dominance were calculated as follows.

$D_o = B_i \times N_i$,

Where D_o is dominance of a species, B_i is mean basal area per species and N_i - number of individuals in the i^{th} species

$R_{do} = \frac{Do_i}{\sum_{i=0}^{s} Do_i} \times 100$,

Where, R_{do} is relative dominance and Do_i is dominance of the i^{th} species (s).

The significance of variations of richness and structure (density and basal area) among the forest patches were tested using One-Way ANOVA in PAST software Package (ver. 3.04) as these parameters are some of the most affected by disturbance and other factors (Hammer et al., 2001; Franklin et al., 2002).

Importance value index

The Importance Value Index (IVI) of a species signifies the sum of its relative density (RDE), relative frequency (RFR) and relative dominance (RDO) (Kent and Coker, 1992).

IVI = RDE + RFR + RDO.

The IVI was computed in Microsoft Excel spreadsheet programme. Consequently, woody species having the least IVI values, species which are not well represented due to disturbance or other negative factors, were prioritized for the purpose of conservation and management interventions.

RESULTS

Floristic richness and diversity

A total of 212 species belonging to 169 genera and 79 families were recorded in the study area; 208 species in sampling plots and four species outside sampling plots (Table 2). In terms of habit, 122 species were woody (Liana 24, Shrub 62, Tree 36) and 90 were herbaceous. Angiosperms were represented by 204 species, gymnosperms by one species and Pteridophytes by seven species. Among the Angiosperms, the family Asteraceae was the richest family (18 species), followed by Acanthaceae and Fabaceae (13 species each), Euphorbiaceae (12 species) and Lamiaceae (10 species). Pteridophytes were represented by four families, namely Aspleniaceae (two species), Polypodiaceae (two species), Pteridaceae (one species) and Selaginellaceae (two species). *Juniperus procera* (Cuperessaceae) was the only species in Gymnosperms.

The highest richness among the forest patches was recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forest patches. In terms of woody species richness, Askunabo was the richest, followed by Bradi, Khatasa, Degera, Kidamaja and Ambiqi forests. Khatasa forest harbored the highest richness of herbaceous species, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forests. The species, which were recorded outside sampling plots are *Echinops kebericho* Mesfin, *Erythrina brucei* Schweinf., *Guizotia abyssinica* (L. f) Cass. and *Sapium ellipticum* (Krauss) Pax. *G. abyssinica* is a cultivated crop which was collected as an escape from areas of cultivation. No significant variations of woody species richness were found among the forest patches in the study area (P > 0.05).

Table 2. Floristic richness of the six forest patches in the study area.

No.	Forest Patch	Woody Species Richness	Herbaceous Species Richness	Total Richness
1	Ambiqi Forest	55	30	85
2	Askunabo Forest	64	44	108
3	Bradi Forest	62	48	110
4	Degera Forest	56	21	77
5	Khatasa Forest	58	53	111
6	Kidamaja Forest	55	23	78
	Total	**122**	**90**	**212**

The Shannon diversity index and evenness of the study area were 3.7 and 0.8, respectively (Table 3). Among the forest patches, the highest Shannon index was observed in Bradi forest, followed by Kidamaja, Degera, Khatasa, Askunabo and Ambiqi. Shannon evenness value was also in the same order with little variations, the highest being for Bradi and Kidamaja forests and the least evenness for Ambiqi forest. The Whittaker's beta diversity index of the study area was 5.6.

Table 3. Indices of diversity and evenness of the forest patches in the study area

No.	Forest Patch	Evenness index (J)	Alpha Diversity index (H')	Beta Diversity index (ß)
1	Bradi Forest	0.81	3.35	5.45
2	Degera Forest	0.79	3.18	4.66
3	Askunabo Forest	0.74	3.08	6.48
4	Kidamaja Forest	0.81	3.24	4.88
5	Khatasa Forest	0.78	3.18	6.01
6	Ambiqi Forest	0.73	2.91	5.94
	Study area	**0.8**	**3.7**	**5.6**

Vegetation structure

Woody species frequency and density

The most frequent woody species in the study area was *Rytigynia neglecta* (83%), followed by *Croton macrostachyus* (68%), *Vepris dainellii* (62%), *Albizia schimperiana* (57%) and *Maytenus arbutifolia* (54%). Generally, about 95% of the species had below 50% frequency; 33% of the species each occurred in a single plot; while 12.5% of species each occurred in two plots. The relative frequency of species was between 0.04 and 6% with similar orders as their frequencies.

The total abundance of woody species with DBH ≥ 2.5 cm in the study area was 13380 stems; while the total density was 2172.1 stems ha^{-1}. The top most abundant species with abundance value of above 500 individuals were *Rytigynia neglecta, Rothmania urcelliformis, Deinbollia kilimandscharica, Albizia gummifera, Croton macrostachyus, Bersama abyssinica, Vepris dainellii* and *Maytenus arbutifolia*.

R. neglecta was the most abundant species with abundance of 1349 individuals and a density of 219 stems ha^{-1}. The first five species have densities of 100 stems ha^{-1} and above. Generally, 25% of the species have densities of one stem ha^{-1}. The relative density ranged between 0.01 and 10.1%, the highest being for *R. neglecta*.

The highest density was documented in Ambiqi forest (2437.5 stems ha^{-1}), followed by Degera (2340.6 stems ha^{-1}), Khatasa (2179.5 stems ha^{-1}), Kidamaja (2158.3 stems ha^{-1}), Bradi (2080.5 stems ha^{-1}) and Askunabo (2059.5 stems ha^{-1}) forests. Consequently, 22 species scored a density of 100 stems ha^{-1} or higher in all forest patches. No significant variations of the mean densities of woody species were found among the forest patches in the study area ($P > 0.05$).

Basal area and dominance

The total basal area and dominance of woody species were 41.2 and 23.1 m^2 ha^{-1}, respectively. Generally, 11 species such as *Albizia schimperiana, Prunus africana, A. gummifera, Apodytes dimidiata*, *Croton macrostachyus* and *Ekebergia capensis* scored a basal area of 1.0 m^2 ha^{-1} and above, which were among the top dominant species. Ambiqi forest had the highest basal area (57.4 m^2 ha^{-1}), followed by Askunabo (43 m^2 ha^{-1}), Khatasa (40.5 m^2 ha^{-1}), Bradi (37 m^2 ha^{-1}), Kidamaja (35 m^2 ha^{-1}) and Degera (34.5 m^2 ha^{-1}) forests. In terms of dominance, Khatasa forest had the highest dominance (28.7 m^2 ha^{-1}), followed by Ambiqi (28 m^2 ha^{-1}), Askunabo (26 m^2 ha^{-1}), Kidamaja (25.3 m^2 ha^{-1}), Bradi (23.5 m^2 ha^{-1}) and Degera (20.8 m^2 ha^{-1}). No significant variations of basal area of woody species were found among the forest patches in the study area ($P > 0.05$)

Importance value index of woody species

The importance value index of woody species in the study area ranged from 0.05 to 16.8. The highest IVI was documented for *Rytigynia neglecta*. Species such as *Albizia gummifera, A. schimperiana*, *Prunus africana, Croton macrostachyus, Rothmania urcelliformis* and *Apodytes dimidiata* were among the most important species. Generally, 50.5% of the species had IVI of below one, 12% IVI of one and 37.5% above one.

The IVI of species in the forest patches moderately varied. For example, the highest IVI of species was in Kidamaja forest (*A. schimperiana*, 47.1), followed by Khatasa (*A. dimidiata*, 38.4), Askunabo (*D. kilimandascharica*, 37.2), Degera (*R. urcelliformis*, 33.8), Ambiqi (*C. spinarum*, 32.7) and Bradi (*R. urcelliformis*, 25.2). Generally, 14 woody species had IVI values of 20 and above, while the majority had below 20 in the forest patches.

Diameter and height class distribution

The DBH and height class distribution of woody species density in the study area showed an Inverted-J shaped structure (Figure 3). All DBH classes were represented by at least some individuals even though the highest density was concentrated in DBH classes below 12.5 cm. The highest DBH was recorded for one individual of *Ekebergia capensis* (270 cm). Twenty-four individuals of seven species, namely *Ekebergia capensis, Prunus africana, Schefflera abyssinica, Albizia gummifera, A. schimperiana, Juniperus procera* and *Apodytes dimidiata* had a DBH of 100 cm and above.

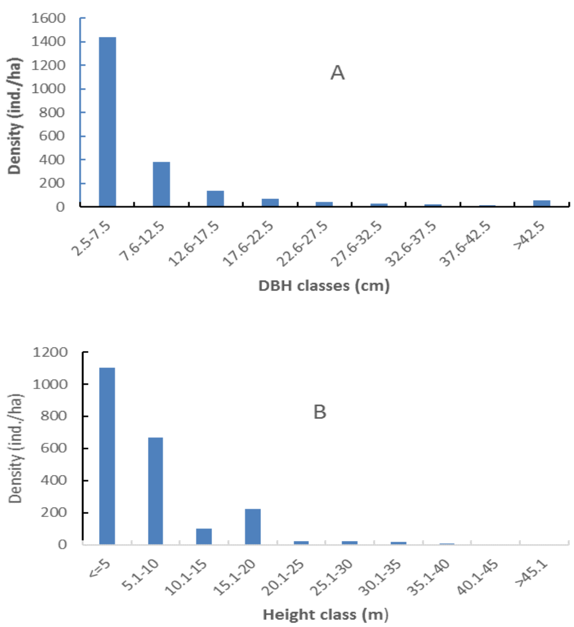


Figure 3. Distribution of population densities in DBH (A) and height (B) classes in the study area.

The height class distribution showed more or less similar pattern to DBH classes. The majority of individuals were accumulated at the lower height classes (< 10 m). In each forest patch, most individuals were accumulated in lower DBH and height classes (Figure 4).

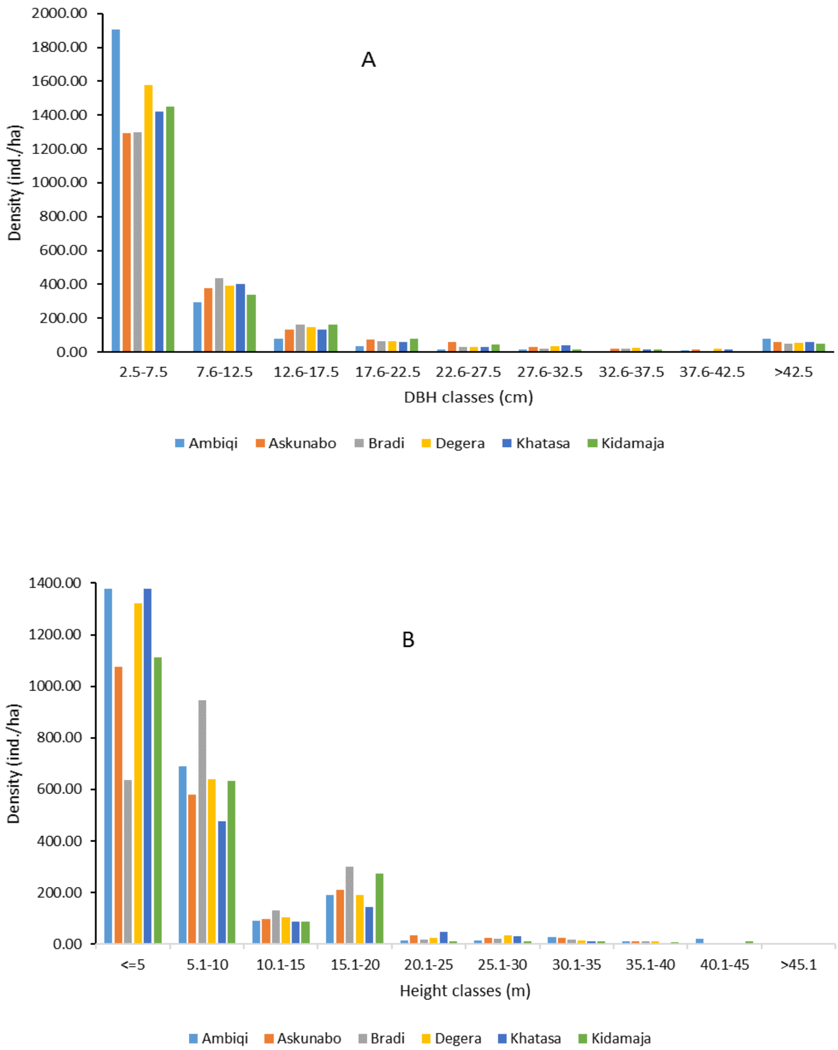


Figure 4. Distribution of population densities in DBH (A) and height (B) classes for each forest patch.

The analysis of population structure of 28 selected tree species in nine DBH classes revealed five population structure patterns (Figure 5). The first pattern was an Inverted-J shaped in which the highest number of individuals were present in lower DBH classes and their presence decreased towards higher classes. Tree species in this category were *Albizia schimperiana, A. gummifera, Celtis africana, Prunus africana, Allophylus abyssinicus, Croton macrostachyus, Euphorbia abyssinica, Ficus sur, Maytenus obscura* and

Mimusops kummel. The second pattern was unimodal/bell shaped in which a higher proportion of species were present in intermediate DBH classes and the trend decreased in both directions (lower and higher DBH classes). The species in this category were *Dracaena steudneri*, *Stereospermum kunthianum* and *Acacia abyssinica*. The third pattern was J shaped in which a higher proportion of individuals were present at higher DBH classes and the trend decreased towards lower DBH classes. This pattern was exhibited by *Apodytes dimidiata*. The fourth pattern was a Broken Inverted-J shaped where individuals were absent at intermediate or higher DBH classes. *Ehretia cymossa, Ficus thonningii, Lepidotrichilia volkensii*, *Olea capensis* subsp. *macrocarpa*, *Pittosporum viridiflorum*, *Ritchiea albersii*, *Millettia ferruginea* and *Cordia africana* were in this category. The fifth pattern lacked individuals at lower and intermediate DBH classes and some mature individuals were present at the highest DBH classes. Trees such as *Juniperus procera*, *Ekebergia capensis, Euphorbia ampliphylla, Polyscias fulva, Schefflera abyssinica* and *Syzygium guineense* exhibited this pattern.

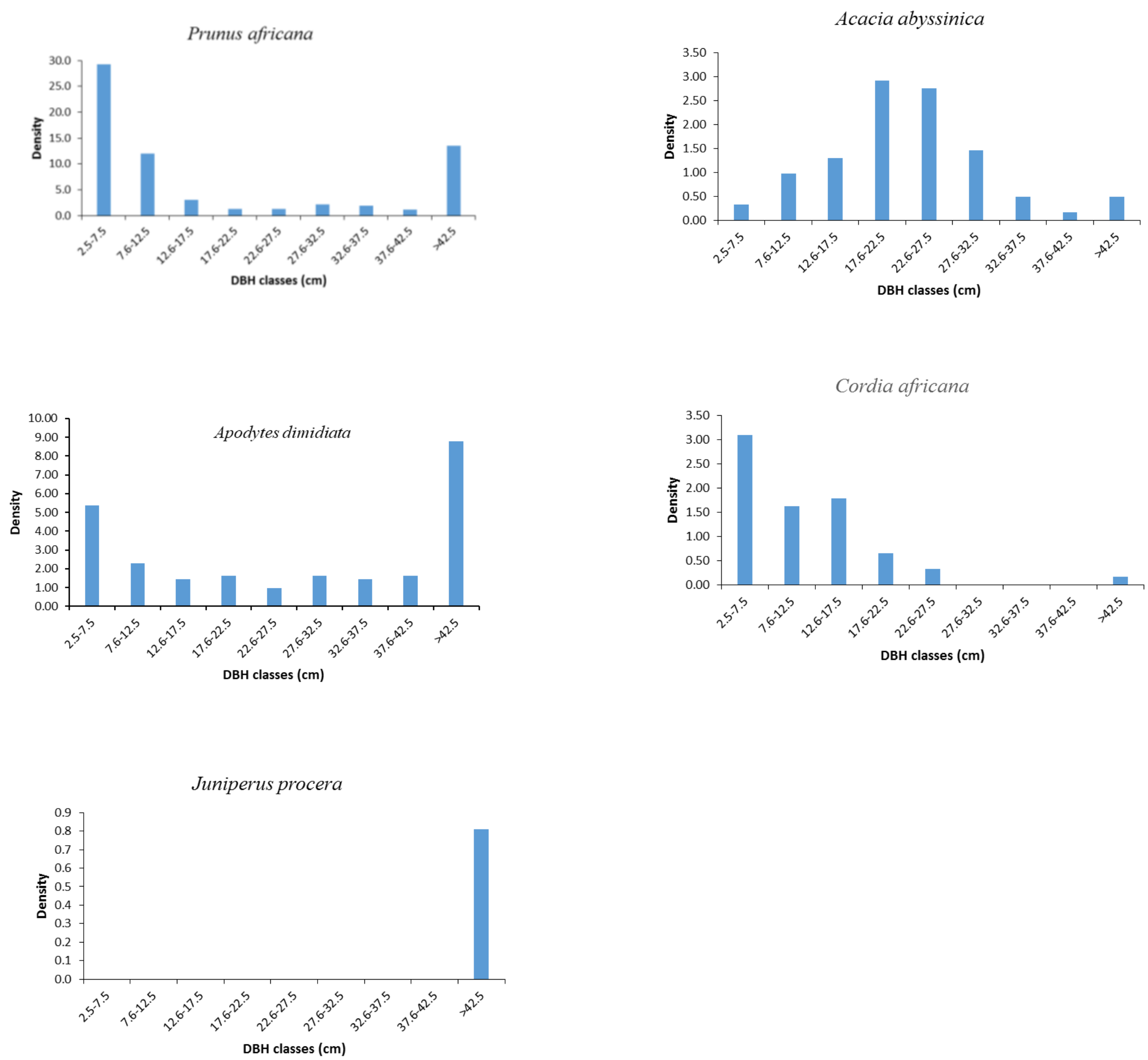


Figure 5. Representative population structure patterns of tree species in the study area.

DISCUSSION

Richness and diversity

The study revealed that the study area harbored rich floristic composition and diversity. Accordingly, the number of woody species recorded in this study is higher than similar studies conducted in the Dry evergreen Afromontane Forests of Ethiopia such as Zege Peninsula Forest (Aleign et al., 2007), forests of central plateau of Shewa (Bekele, 1993), Adelle and Boditi Forests (Yineger et al., 2008), Amba Mariam Forest (Tilahun et al., 2011), Tara Gedam and Abebaye Forests (Zegeye et al., 2011), Zengena Forest (Tadele et al., 2013) and Kuandisha Forest (Berhanu et al., 2017). This could be partially attributed to the ecological diversity of the present study area, which covers wide altitudinal ranges. It has been long known that altitude plays paramount role in plant distribution and richness/diversity and the underlying direct causes such as climate, air pressure and soil properties are directly related to altitude (Brown and Lomolino, 1998; Barry, 2008). However, the present study area is not as much of some of similar study areas such as central plateau of Shewa (Jibat forest) in terms of altitudinal coverage (Bekele, 1993). Thus, the most important justification for such variations could be climate variability (Schmitt et al., 2010) and forest disturbance (Økland, 1990). The present study area is found in the intermediate zone between moist and dry climates and harbors a diverse assemblage of both the dry and moist evergreen Afromontane Forest species and has been classified as a new vegetation type (Berhanu et al., 2018). Although disturbance is present in some of the forest patches in the present study area, the forests are relatively well protected, which contributed in conserving many of economically and ecologically useful canopy species. On the other hand, in terms of herbaceous species, a smaller number of species were recorded than other study areas (Yineger et al., 2008; Tilahun et al., 2011). The low number of herbaceous species richness may be attributed to the closed canopy cover of the forest patches in the study area. According to Friis (1986) and Murphy and Lugo (1986), herbaceous species cover is usually inversely proportional to canopy cover. That is closed canopy sites of forests have poor herbaceous cover and vice versa depending the amount of light penetration.

The order of families in terms of species richness is in accordance with other studies in that Asteraceae is reported to be the richest family in northwestern and central Ethiopian forests (Yineger et al., 2008; Tilahun et al., 2011; Lulekal, 2014) and in this study. On the other hand, Berhanu et al. (2017) documented that the family Fabaceae was the richest family followed by Euphorbiaceae and Asteraceae in Kuandisha dry evergreen Afromontane Forest fragment. Fabaceae is also known to be the richest family in Ethiopia followed by Poaceae, Asteraceae and Euphorbiaceae (Kelbessa and Demissew, 2014).

The least Shannon diversity index in Ambiqi forest could have mainly resulted from severe disturbance such as selective logging and grazing (Maguran, 2004). The high diversity index in other forest patches may be attributed to the relatively less disturbance and high evenness values. The correlation between Shannon diversity index and evenness values was positive and strong ($r = 0.9$; $P < 0.05$) in the study area. Species diversity increases when the populations have more even abundances and vice versa (Maguran, 2004; Lean and Maclaurin, 2016). In other words, many of the species were rare and the distributions of individuals of the species were even ($J \geq 0.7$). Shannon diversity index is sensitive to the presence of rare species and high evenness values (Maguran, 2004; Schmitt et al., 2010). Consequently, the diversity index was higher than other forests in the DAF (Dry evergreen Afromontane Forest) such as Tara Gedam and Abebaye forests (Zegeye et al., 2011), Amba Mariam forest (Tilahun et al., 2011) and Zengena forest (Tadele et al., 2013). The beta diversity index was also high ($\beta = 5.6$), which was strongly and positively correlated with richness of forest patches ($r = 0.7$, $P < 0.05$). According to Maguran (2004), a beta diversity index greater than five can be considered as high value and this indicates a high turnover in and among the forest patches.

Structure of forests and woody species

Frequency and density

A significant portion of the species were rare in the study area. The most frequent species were pioneer species such as *Croton macrostachyus* and *Bersama abyssinica* (Bekele, 1993) and the common weed *Achyranthes aspera* (Townsend, 2000), which are also common in the disturbed forests and forest edges of the DAF and MAF (Moist evergreen Afromontane forest) (Townsend, 2000; Friis et al., 2010). *Vepris dainellii* is an endemic species, which was common in most (61%) of the sampling plots. According to Gilbert (1989), the species occurs in the understory of moist montane forests, often with *Podocarpus falcatus* or *Pouteria adolfi-frederici*, less often at forest margin or in secondary growth. Bekele (1993) reported similar results about the species in Jibat forest. The other most frequent species, namely *B. abyssinica* and *Maytenus arbutifolia* are common species in disturbed and secondary forests with early developmental stage in the DAF and MAF and they are usually strongly associated with overgrazing (Tesfaye and Berhanu, 2006; Berhanu et al., 2017).

Canopy trees such as *Albizia schimperiana* and *A. gummifera* are also dominant species in the Afromontane Forests between altitudes 1600 and 2600 m and they are widely distributed in eastern Tropical Africa (Thulin, 1989; Friis et al., 2010). *A. gummifera* and *C. macrostachyus* have also been reported to be the most frequent species in Tara Gedam and Abebaye forests, respectively (Zegeye et al., 2011). On the other hand, the liana species *Landolphia buchananii*, which was also highly frequent in the study area, is mainly of a lowland species in gallery forests, woodlands, often on or near rocks between 1300 and 1550 m (Leeuwenberg, 2003). Hence, its high presence above 1550 m (up to 2100 m) in the study area is unusual. The species has also been reported to be the second most dominant species next to *Coffea arabica* in moist evergreen Afromontane forests of southwestern Ethiopia (Senbeta, 2006). Thus, its high presence in the study area may be attributed to the transitional climate from moist to dry climates. Generally, except few variations, many of the most frequent species in the study area were also the most frequent in each forest patch.

The overall density of woody species with DBH ≥ 2.5 cm was considerably lower than other forests such as Zege Peninsula, Tara Gedam and Kuandisha forests in the DAF (Alelign et al., 2007; Zegeye et al., 2011; Berhanu et al., 2017) and moist evergreen Afromontane forests of southwestern Ethiopia (Senbeta, 2006). The composition of the top most abundant species was also different from such forests except *Rytigynia neglecta*, *Croton macrostachyus, Maytenus arbutifolia* and *Bersama abyssinica* that are gap fillers and pioneer woody species in disturbed sites, secondary forests and forest edges (Bekele, 1993; Dalle and Fetene, 2004; Bekele, 2007; Berhanu et al., 2017). Some climax tree species such as *Albizia gummifera* and *Millettia ferruginea* were also reported as having the highest density in Tara Gedam and Zege Peninsula forests, respectively (Alelign et al., 2007; Zegeye et al., 2011).

Generally, about 7% of the species accounted for 53% of the total stem density and also had the largest density of seedlings. This has partly to do with disturbance as species such as *Maytenus arbutifolia* and *Justicia schimperiana* favor disturbance and sudden openings of forests for their germination, growth and establishment (Dalle and Fetene, 2004; Tesfaye and Berhanu, 2006; Berhanu et al., 2017). In contrast, seedlings of *Albizia gummifera* and *A. schimperiana* were abundant in openings near mother trees where the sites were relatively undisturbed. According to Muhanguzi et al. (2002), *A. gummifera* has a very high rate of seed germination under shade or light conditions, which is an escape mechanism from mortality factors.

The absence of seedlings of some of the canopy trees such as *Juniperus procera* and *Syzygium guineense* is highly attributed to disturbance (trampling and seedling removal), seed predation, habitat unsuitability and life history strategy. Disturbance and seed predation have been noted to play their own role in reducing the seedling population of woody species (Teketay, 2005b; Wassie et al., 2009). Consequently, no seedlings of *Juniperus procera* were encountered in the study area (Khatasa forest) during the study period, which is in contrast to the reports from the local people. Similarly, no or poor regeneration of *J. procera* under natural conditions have been reported elsewhere in Ethiopia (Sharew, 1982; Aynekulu et al., 2009) and Saudi Arabia (El-Juhany et al., 2008). Consequently, it has been noted that *J. procera* will not regenerate in its own shade and its presence as a forest tree is largely dependent on fire, either natural or man-made, which removes the deep layer of humus and exposes the soil mineral for seed germination, seedling growth and survival (Sharew, 1982; White, 1983; Orwa et al., 2009).

Basal area and dominance

The total basal area of woody species is generally in the range provided for tropical and subtropical dry and wet forests of the world (Murphy and Lugo, 1986). Moreover, the range of the total basal area of woody species in the forest patches of the study area was comparable to that of Moist evergreen Afromontane Forests of southwestern Ethiopia (Senbeta, 2006) and Dry evergreen Afromontane Forests of central

Ethiopia (Lulekal, 2014). The lower and higher DBH classes contributed most to the total basal area, which was also supported by other studies (Bekele, 1993; Senbeta, 2006; Tadele et al., 2013; Lulekal, 2014; Berhanu et al., 2017).

The basal area and dominance value of woody species was higher than some forests such as Zengena Forest (Tadele et al., 2013), Kuandisha Forest (Berhanu et al., 2017), Hugumburda Forest (Aynekulu, 2011) and Adele and Boditi Forests (Yineger et al., 2008). On the other hand, the basal area of woody species reported from Tara Gedam is higher than the present study area (Zegeye et al., 2011). According to Wassie et al. (2005), churches and monasteries harbor many of the forests with the oldest and large-sized individuals of trees in north Gondar.

Importance value index

The importance value index (IVI) of woody species in the study area was generally lower compared to other forests in the DAF (Zegeye et al., 2011; Tadele et al., 2013; Lulekal, 2014; Berhanu et al., 2017). The variability of IVI values of species among the forest patches is partly attributed to the conservation status of some of the highly dominant species in those forests. *Albizia schimperiana* and *A. gummifera*, for example, which are highly valued for their shade for livestock and humans and protected by the community, were the most abundant and dominant species having the highest IVI values in Ambiqi, Kidamaja and Bradi forest patches. Habitat suitability also plays its own part. For instance, *Carissa spinarum* and *Croton macrostachyus* were the most important species in the highly disturbed Ambiqi forest, which are usually indicators of degraded or seriously disturbed forests (Bekele, 1993; Friis et al., 2010; Berhanu et al., 2017). On the other hand, some of the least important species in the forests of the study area such as *Syzygium guineense* and *Salix subserrata* are usually important species in the Riverine vegetation, beside streams and lake shores; occasionally also transgressing into humid secondary evergreen bushland and woodland (Meikle, 1989; Friis, 1995; Friis et al., 2010). Moreover, least important species in the study area such as *Steganotaenia araliacea* and *Stereospermum kunthianum* are usually found in open woodlands and savanna elsewhere (Hedberg and Hedberg, 2003; Bidgood, 2006) and their least IVI values in the study area may be attributed to unsuitable habitats. On the other hand, *Rhus glutinosa* subsp. *glutinosa* had been excessively exploited for its high-quality wood for traditional house construction as it is resistant to termites and its use for firewood, farm tools and tool handles in the study area and elsewhere (Bekele, 2007). Thus, its status in the study area is very poor having the least IVI value with rare presence as a result of overexploitation.

Population structure of forests and woody species

The population structural patterns of all forests of the study area and individual forest patches generally indicated a healthy status of those forests; which was Inverted-J shaped. Similar findings have been reported elsewhere in Ethiopia (Senbeta, 2006; Beche, 2011; Tadele et al., 2013; Berhanu et al., 2017). However, that was contrary to the fact that is clearly seen from patterns of population structures of each tree species. Consequently, an investigation of the population structure of many of the tree species revealed that they lacked individuals at various DBH and height classes. Moreover, a highly skewed Inverted-J shaped population pattern may to some extent indicate abnormal distribution of population densities in the forests undergoing secondary development after forest clearance or disturbance such as selective logging of individuals having higher DBH classes (Friis, 1986; Bekele, 1993). And under such circumstances, it is usually difficult to generalize based on the shape of the population pattern of the whole forest alone as indicator of forest health. Consequently, the Inverted-J shaped distribution pattern of forest patches should be interpreted with caution (Westphal et al., 2006; Ducey, 2010). The pertinent reason, which was observed from population patterns of forest patches, was the “compensatory effect”; where populations of one species compensate for the missing populations of another species in various DBH and height classes. Hence, the population pattern of each tree species was found to be comparatively useful for forest health indicator in the study area as population absences and presences for each tree species were clearly detected in various DBH and height classes.

Different population patterns of tree species are usually caused by various factors such as selective cutting, disturbance, shade-intolerance and life history strategy (Teketay, 2005a; Bin et al., 2012). The five population patterns revealed in this study are attributed to those factors. The first pattern, which is Inverted-J shaped is usually an indicator of healthy population status of a species (Teketay, 2005a; Senbeta, 2006; Alelign et al., 2007; Tadele et al., 2013; Berhanu et al., 2017) even though the density of individuals in various DBH or height classes slightly varied among studied forest patches. The second pattern, which is unimodal or bell-shaped, is highly attributed to poor regeneration and selective removal of individuals with lower and higher DBH classes; while populations in the middle classes are left. This pattern has rarely been reported in the DAF (Tadele et al., 2013; Lulekal, 2014) and MAF (Senbeta, 2006; Kelbessa and Soromessa, 2008).

The third pattern, which was a J shaped distribution, is an indicator of a highly disturbed forest with poor reproduction and selective removal of individuals with lower DBH classes (Bekele, 1993; Senbeta, 2006). That is intermediate and mature individuals are usually left in the population whereas lower DBH classes are removed for various uses such as firewood, construction and farm implements (Bekele, 1993). The fourth pattern with Broken Inverted-J shaped structure lacked individuals in intermediate or higher DBH classes. This pattern is caused by selective removal of mature individuals for construction purposes (Senbeta, 2006; Alelign et al., 2007).

The fifth pattern lacked all of the individuals except the highest DBH class (>42.5 cm). This pattern is an indicator of lack of regeneration and establishment of populations of a species after a major disturbance such as clear-cutting for agriculture, grazing land or settlement, leaving few mature individuals as shade trees (Friis, 1986) or a life history strategy where mother trees negatively influence the germination of seeds and establishment of seedlings under their canopies (White, 1983; Bin et al., 2012). This pattern has rarely been reported for tree species, namely *Juniperus procera* and *Erythrina brucei* in the highly disturbed forests of the DAF (Bekele, 1993; Tadele et al., 2013).

CONCLUSION AND RECOMMENDATION

The hypothesis was rejected in that species richness, density and basal area of the six forest patches of the study area were not significantly different. However, a number of plant species in the study area were found to be at conservation risk. Despite this fact, the population structure patterns of the forests of the study area and each forest patch revealed that the study area and the forest patches were in healthy status. Five population density patterns were evident for 28 tree species investigated, namely Inverted-J shaped, J shaped, Broken Inverted-J shaped, unimodal/bell-shaped and a fifth pattern where only mature individuals were represented. The majority of species had IVI values below one in each forest patch and in the study area in general. Moreover, the population structure of tree species, except naturally rare plants, confirmed the absence of individuals in various DBH classes that contributed to the least IVI values.

Using population structure patterns in various DBH and height classes to show the status of forests and individual tree species has been largely employed in Ethiopia and elsewhere. However, the use of such patterns particularly for forest patches was not that useful as realized in this study because of "compensatory" effects of individuals of different species in various DBH or height classes. Thus, it is highly recommended to use population structure patterns of each tree species and interpret the results with caution as some tree species may show different patterns because of life strategy or other natural factors. Degraded and threatened forests and species require maintenance and restoration activities, enrichment planting in suitable areas and protection of sites. Special emphasis should also be given for the conservation of species with low IVI values.

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