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Vegetation structure of Debra-libanos Monastery forest patch of North Oromia Region, Central Ethiopia

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ABSTRACT

Context: Dry Afromontane forests are the most altered and endangered ecosystems. *Objectives:* This study was aimed to assess the status of basal area, and vegetation structure of woody plant species in Debra-libanos Monastery forest patch (DMFP) in Oromia Region. Fifty quadrats were placed on transects along altitudes using a systematic sampling design. *Methods:* Quadrats of 1m^2, 100m^2, and 400m^2 were designed to record seedling, sapling and tree species, respectively. *Results:* 49 woody plant species were recorded in the forest patch. It was found that a total of 33.5 m^2 ha^{-1} basal areas were computed from the forest. Woody species such as *Olea europaea* subsp. cuspidata (15.6 m^{2}ha^{-1}), *Juniperus procera (*10.7 m^{2}ha^{-1}), *Euphorbia abyssinica* (2.6 m^{2}ha^{-1}), and *Allophylus abyssinicus* (1.49 m^{2}ha^{-1}) were relatively higher basal areas in the forest patch. From DBH classes categorized in the forest, the overall distribution of the densities of stems ha^{-1} for selected woody species, DBH-classes mostly recorded in DBH-Class-1 (93 ha^{-1}), then declining towards the end of DBH-Class-9 (20.5 ha^{-1}), but slightly inclining towards the last DBH classes-10 (38 ha^{-1}). The upper story was represented by a height greater than 23.3m which accounts about 19.9% frequency of the woody species whereas the middle story ranges from 11.7 m to 23.3 m (29.8%) and < 11.67 m (50.3%) were constituted by the lower story. *Conclusions:* Unless improved management interventions are made, the sustainability of contribution for livelihood income diversification and ecosystem services obtained from the forest will be suffered.

Keywords: Basal area, church forest, Debra-libanos, Monastery, patch, structure

1. INTRODUCTION

Globally, the most altered and endangered ecosystems are Dry Afromontane forests. Nevertheless, to safeguard these threats of the diverse ecosystems, sites are prioritized and designated for conservation (Tura et al., 2017). Across the world, forests have been fragmented into small patches, and the forest structures have been influenced by this fragmentation and habitat loss (Wassie, 2010). Likewise, forest resources particularly in the central and northern Ethiopia have been denuded in the last several decades and are shrinking mainly towards the south (Dessie and Kleman, 2007) and southwestern (Aynekulu, 2011) parts of the country. In the northern and central highlands, only a few isolated patches can be found in unreachable areas and around the Ethiopian Orthodox Tewahido churches (Wassie, 2007; Bekele, 1994).

Basal area is the common term used to describe the average amount of an area occupied by tree stems. Moreover, it is the total cross-sectional area of all stems in a stand measured at breast height, and expressed as per unit of land area (typically square meter per hectare) (Wikipedia, 2019). But Delang and Li (2013) described forest structure as a complex system considered from the whole rather than any single part. In their study, it is the truth that not to simply add together the various measures, and produce some average quantification of forest structure.

Deforestation of tropical forests for agriculture is one of the major forces shaping the Earth's surface (Lambin and Meyfroidt, 2011). Moreover, unprecedented population growth coupled with traditional practices has posed a tremendous impact on the land resources in the highlands where climatic conditions are more favorable for life and agricultural production. The high concentration of farming population in the highlands is resulting in land shortage, land fragmentation, totally devoid of vegetative cover and erosion of the soil cover and exposure of extensive areas of the substratum (Teshome, 2014).

On the other hand, the antagonism between forestry and grazing has also given rise to a fragmented landscape, with remnant patches of native forests at the top of the hills and grasslands in the valleys (Sanchez-Jardn et al., 2010). Consequently, deforestation and fragmentation influence the microclimate, composition, and vegetation structure of the remaining patches of the tropical forest (Nagy et al., 2015). According to Shiferaw et al. (2018), the effects of deforestation and degradation are also continuing in highlands of Ethiopia particularly within Debrelibanos Monastery forest patch (DMFP) due to intensive grazing and other anthropogenic activities. These are influencing the forest structure and basal area of individual woody species and thus as a whole the forests' basal areas. Moreover, due to land use/cover changes, deforestation and degradation are experiencing in the like the other forest ruminants of Ethiopia. These changes cause dynamics in the species forest structures from time to time. Except few research reports made by Getaneh and Girma (2014), (Demie et al., 2013), and Shiferaw et al. (2018), no detailed scientific knowledge has been carried out particularly around and in the DMFP. Furthermore, no sufficient results were documented previously from the forest in terms of the status of woody species cross-sectional area and forest structure for further conservation and restoration plans in the area. This study, therefore, assesses: (1) the status of the basal area the woody species, and (2) the structure of the forest in the DMFP in the North Showa Zone of Oromia National Regional State.

2. MATERIALS AND METHODS

Description of the study area

This study was conducted in the DMFP, Debrelibanos district, North Showa Zone of the Oromia National Regional State in Ethiopia from April 15-30, 2017. Debrelibanos district is located 110 km north of Addis Ababa. Debrelibanos Monastry is situated between

2341 m and 2500 masl. The area of DMFP was 85 ha (Getaneh and Girma, 2014). The Monastery is located between WGS 38° 50′ 51″ E to 9° 42′ 43″ N or 37P0483272, UTM1073568 (Fig. 1).

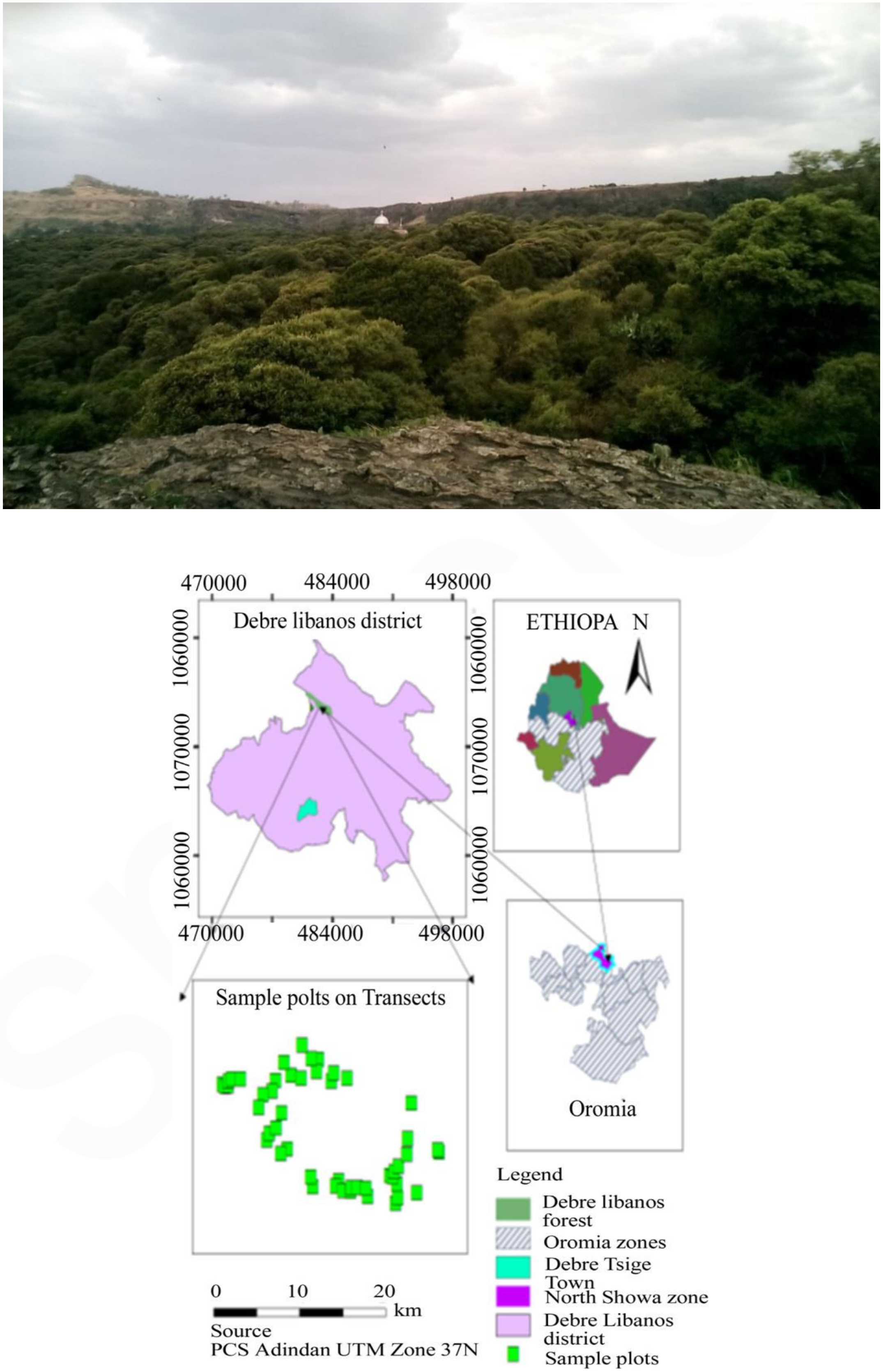


Figure 1 Map of the Study area (Source: Shiferaw et al., 2018)

Since there was no meteorological station for Debrelibanos district, climate data from nearest Fiche meteorological station was taken from National Meteorology Agency of Ethiopia in 2017. Thirty-seven years of climate data were drawn by using Walter climadiagram program in R software version 3.5.2 (R SoftWare Development Team, 2019) and library climatol (Woldu, 2017). The study area is characterized by bimodal rainfall during the long rainy season (June to October) and the shorter rainy season (March to April). The highest monthly rainfall was recorded in July (320.4mm) and the lowest in November and December 8.4mm for each. The average monthly maximum temperature was recorded in June (20.9^{0}C) and monthly average minimum temperature in December (5.7^{0}C). The annual rainfall and temperature were 1097mm and 13.30^{0}C, respectively (Fig. 2).

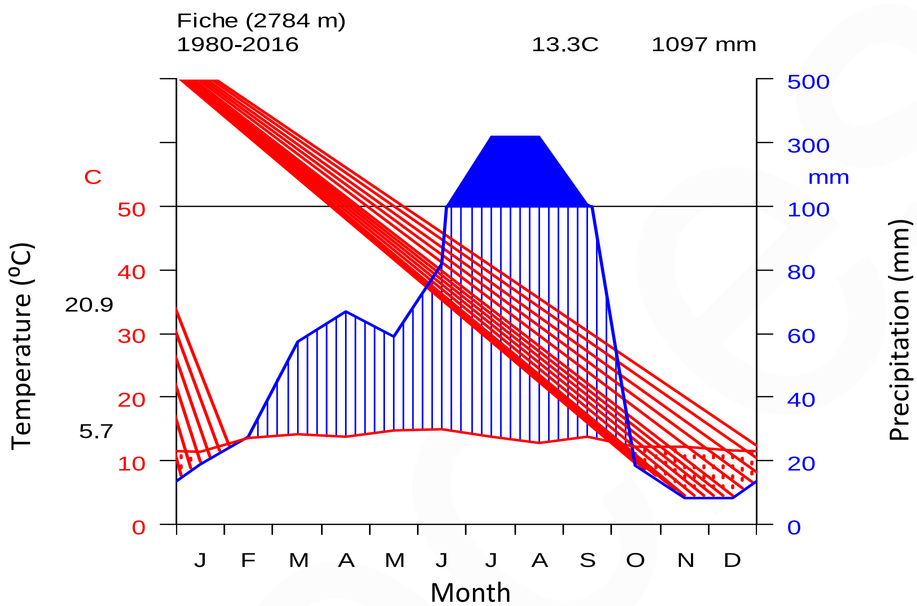


Figure 2 Walter Climadiagram of Fiche, Selalee, near study area (Source: Shiferaw et al., 2018)

The most frequent soil type in the area is black soil which is dominant and constitutes about 56% (16,675 hectares), while the red soil comprises 38% (11,341 hectares) and the rest 6% (1,787 hectares) are a mixture of different soil type. The soil texture is 63% clay, 27% silt and 10% sand (Getaneh and Girma, 2014). The vegetation of the study area is characterized by old remnant afro montane forest in the middle altitudes and grasslands dominant at higher elevations in the highlands. The old Afromontane forest in the middle altitude is owned by Debrelibanos Monastry of Ethiopian Oriental Orthodox Church. The common vegetation in the study area is mostly remnants of trees in agricultural fields, bushes, shrubs, and secondary forests. The common plant species of the study area include *Allophylus abyssinicus* (Hochst.) Radlkofer, *Acacia abyssinica* Hochst., *Acacia lahai* Steud. & Hochst. ex Benth., *Juniperus procera* Hochst. ex Endl., *Olea europaea subsp. cuspidata* L., subsp. cuspidala *(Wall. ex G.Don) Clf., Carissa spinarum* L., *Snowdenia polystachya* (Fresen.) Pilg., *Cynodon dactylon* (L.) Pers., *Dodonaea angustifolia* L. f., *Ficus sur* Forssk., *Euphorbia abyssinica* Gmel., *Leonotis ocymifolia* (Burm. f.) Iwarsson, and *Pavetta abyssinica* Fresen. The human population of Debrelibanos district was estimated to be about 45,179 (CSA, 2007).

Sample design

After reconnaissance survey of the forest area, nine parallel transect lines with 500m interval between lines were laid across the forest running from Southwest to Northeast in all positions of the forest. Sample quadrats of 20 m×20 m (400m^2) were placed systematically on transects with 10m altitude changes. Thus, for tree inventory, 20 m x 20 m size quadrants were considered while for sapling and seedling and herbaceous species, 10 m x10m and 1 m x1 m were subplots laid in each main plot, respectively. A compass bearing was used to allow transects to be parallel with one another. Parallel transects were spaced depending on the size, aspect, topography, vegetation heterogeneity and changes of elevation in the forest.

Data collection

In each plot, all trees and shrubs were measured, identified, counted and cover abundances were estimated using van der Maarel (1979). Diameter at breath height (DBH) for trees or diameters at the stump height (DSH) for shrubs were measured in the plots. Diameter tape and hypsometer were used for diameter and height, respectively.

Individual woody categorizations were made at the height less than 1m and DBH/DSH less than 1cm for seedlings. The height 1-2m and DBH/DSH 1-5cm for saplings, and height greater than 2.0m and DBH/DSH greater than or equals to 5cm for tree/shrub species were used. For saplings and seedlings (height less than 1m), only their numbers were recorded (Joshi *et al*., 2012). If a tree is branched at breast height or below, the diameter was measured separately for the branch and then averaged. Any individual with its above-ground stem growing in a bunch (cluster) for shrubs was counted and measured as a single individual for basal area calculation following fixed-area micro-plot method (Chojnacky and Milton, 2008). If a total shrub plant diameter is desired, the equivalent diameters (DSH) were recommended.

$$\mathrm{DSH} = \sqrt{\textstyle\sum_{i=1}^{n} \mathrm{DSH}i^2} \text{------------------------ (1)}$$

Where, DSH=Diameter at stump Height, stem i stem to n number of stems.

$$B_{\mathrm{A}} = \frac{\pi d^2}{4} \text{ (Lamprecht 1989)----------------- (2)}$$

Π= 3.14

Where d is diameter at breast height, B_{A} is the basal area

$$I_{\mathrm{VI}} = R_1 + R_2 + R_3 \text{ -------------------- (3)}$$

Where I_{VI} is Importance Value Index; R_1 is Relative Density, R_2 is Relative Dominance, and R_3 is Relative Frequency.

Jacquard's similarity coefficient

The Jacquard's similarity index was used to determine the pattern of species turnover among the communities to evaluate the similarity among community types in the forest. It is determined using the following formula (Kent and Coker, 1992).

$$\mathrm{Sj} = \frac{a}{(\mathrm{a+b+c})} \text{ ---------------------------- (4)}$$

In this equation, "a" is the number of species common to both compared clusters, "c" is the number of species present in one of the clusters compared, and "b" is the number of species present in the other cluster.

The regeneration status of the woody plant species within the sampling plot was also investigated. Saplings were sampled using subplots of 10 m x 10 m established in the center of the plot, whereas seedlings using 1 m x 1m were counted per species at the center and four corners of the main plot. The presence or absence of plant species was registered by visual estimation. Basal cover of woody species was estimated and counted in the 20 m x 20 m (van der Maarel, 1979). All plots were geo-referenced using GPS for location (coordinates) and altitudes, and clinometer for slopes.

In each plot, all plant species were identified by their local names, pressed, coded and then grouped as trees, shrubs, herbs and climbers (vines, lianas). Scientific names identification of plant species were carried out both in the field and in the herbarium, and voucher specimens were prepared and placed in the National Herbarium (ETH), Addis Ababa University for further identification. Nomenclatures were followed published volumes from 1 to 8 floras of Ethiopia and Eritrea (Edward et al., 1995; Edward et al., 1997; Edward et al., 2000; Hedberg et al., 1989; Hedberg et al., 2006; Hedberg et al., 2009; Mesfin Tadesse, 2004a; Mesfin Tadesse, 2004b).

Species-area relationship

The species-area curve revealed that the pattern of species richness was increasing with the increasing area for the study area (Fig. 3). The curve clearly showed an initial sharp increase in the number of species with the increasing area and tendency towards flattening. Similar patterns were observed around Lake Zengena Forest, a remnant montane forest patch in northwestern Ethiopia (Tadele et al., 2014).

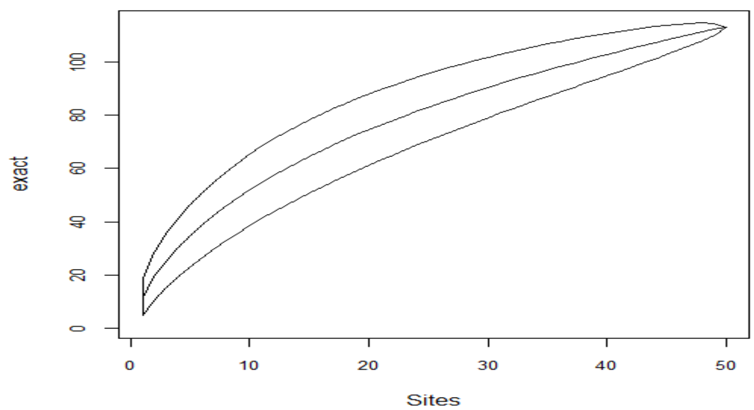


Figure 3 Species accumulation curve

Data Management and presentation

The collected data were checked and analyzed using MS Excel. The plant community types were also analyzed using R software programs to see the best predictor of similarity indices. Then the forest basal areas and structures for each woody species and population of the species were analyzed and presented using histograms and tables.

3. RESULTS AND DISCUSSION

Basal area of the Debrelibanos Monastery forest patch

Computing stand basal area is used to achieve forest management goals and it is very important for the use of prescribed fire or other silvicultural treatments (Elledge and Barlow, 2012). The basal areas (m^2/ha) of *Olea europaea subsp. cuspidata* (15.63 m^2ha^{-1}), *Juniperus procera* (10.67 m^2ha^{-1}), *Euphorbia abyssinica* (2.61 m^2ha^{-1}) and *Allophylus abyssinicus* (1.49 m^2ha^{-1}) were relatively higher basal areas in the forest patch (Table 2). Whereas, *Zehneria scabra* (0.002 m^2ha^{-1}), *Calpurnia aurea* (0.002 m^2ha^{-1}), *Ekebergia capensis* (0.004 m^2ha^{-1}), *Prunus africana* (0.08 m^2ha^{-1}), *Rhus glutinosa* (0.068 m^2ha^{-1}), *Maytenus senegalensis* (0.007 m^2ha^{-1}), and *Rhus natalensis* (0.033 m^2ha^{-1}) were among the woody species which had lower basal areas in the forest (Table 2). The reason for the various in the basal areas of the species might be due to size and number of individual species in the forest. The amount of basal area in a stand is a function of the number of trees and the size of the trees. As such, it is a measure of the overall level of competition for resources between trees in the stand, and it is frequently used to determine whether a stand should be thinned.

The overall basal areas of the present study was 33.46 m^2 ha^{-1} which was comparable with Bekele (1994) in Menagesah Suba forest (36.10 m^2 ha^{-1}), Bekele (1994) in Chilimo forest (30.10 m^2 ha^{-1}), Wassie (2007) in Amstya church forest (32.7 m^2 ha^{-1}), Wassie (2007) in Alember church forest (30 m^2 ha^{-1}), and Bantiwalu (2010) in Sanka Meda forest (34.71 m^2 ha^{-1}).

On the other hand, the overall basal area of DMFP was higher than Wonberoch church forest (13.9 m^2 ha^{-1}) and Enshet Kuskuam church forest (18.5 m^2 ha^{-1}) in North Ethiopia (Wassie, 2007). However, the basal area of the forest was far less than Bekele (1994) in Wef-Washa forest (101.8 m^2 ha^{-1}), Wassie (2007) in Mekedesemariam church forest (80.20 m^2 ha^{-1}), Wassie (2007) in Hiruy church forest (111.5 m^2 ha^{-1}), Quar church forest (100.5 m^2 ha^{-1}) and Gelawdios church forest (52.9 m^2 ha^{-1}) and Tilahun et al (2015) in Menagesha Amba Mariam (84.17 m^2 ha^{-1}).

Table 1 Basal area m^2 ha^{-1}, density stems ha^{-1}, Frequency and I_{VI} of woody species in the DMFP

Species name	BA m^2 ha^{-1}	Ab	Density stems ha^{-1}	R_1	Dom	R_2	F	R_3	I_{VI}
Acacia abyssinica	0.342	82.000	41.000	8.923	0.171	1.022	0.380	6.597	16.542
Acacia lahai	0.265	39.000	19.500	4.244	0.132	0.792	0.240	4.167	9.202
Allophylus abyssinicus	1.488	62.000	31.000	6.747	0.744	4.446	0.240	4.167	15.360
Buddleja polystachya	0.005	2.000	1.000	0.218	0.002	0.015	0.040	0.694	0.927
Calpurnia aurea	0.002	2.000	1.000	0.218	0.001	0.006	0.360	6.250	6.474
Carissa spinarum	0.007	6.000	3.000	0.653	0.004	0.022	0.860	14.931	15.605
Clutia abyssinica	0.019	10.000	5.000	1.088	0.009	0.056	0.360	6.250	7.394

Croton macrostachyus	0.153	11.000	5.500	1.197	0.077	0.458	0.080	1.389	3.044
Ekebergia capensis	0.004	1.000	0.500	0.109	0.002	0.012	0.000	0.000	0.120
Eucalptus globulus	0.006	6.000	3.000	0.653	0.003	0.018	0.020	0.347	1.018
Eucalptus grandis	0.354	11.000	5.500	1.197	0.177	1.057	0.080	1.389	3.642
Euphorbia abyssinica	2.606	56.000	28.000	6.094	1.303	7.789	0.280	4.861	18.744
Ficus sur	0.091	35.000	17.500	3.809	0.045	0.271	0.220	3.819	7.899
Ficus thonningii	1.621	2.000	1.000	0.218	0.810	4.844	0.040	0.694	5.756
Grewia trichocarpa	0.011	8.000	4.000	0.871	0.006	0.034	0.020	0.347	1.251
Juniperus procera	10.668	211.000	105.500	22.960	5.334	31.883	0.820	14.236	69.079
Maytenus senegalensis	0.007	5.000	2.500	0.544	0.004	0.021	0.460	7.986	8.551
Olea europaea subsp. cuspidata subsp. *cuspidata*	15.628	348.000	174.000	37.867	7.814	46.710	0.920	15.972	100.549
Prunus africana	0.080	1.000	0.500	0.109	0.040	0.238	0.060	1.042	1.388
Rhus glutinosa	0.068	3.000	1.500	0.326	0.034	0.203	0.020	0.347	0.876
Rhus natalensis	0.033	16.000	8.000	1.741	0.017	0.099	0.180	3.125	4.965
Zehneria scabra	0.002	2.000	1.000	0.218	0.001	0.006	0.080	1.389	1.612
Total	33.459		459.500	100.000	16.729	100.000	5.760	100.000	300.000

Ab=Abundance, BA= Basal area, R_1=Relative Density, Dom=Dominance, R_2=Relative dominance, F=Frequency, R_3=Relative Frequency, I_{VI}=Importance Value Index

Similarity among plant communities in the Debrelibanos Monastery forest patch

Jacquard's similarity index (S_J) was used to determine the similarity of patterns of species distribution among plant communities. As it has been observed from the computed Jacquard's similarity coefficient, the distribution of species showed significantly dissimilar among the communities. The overall similarity values in species composition between the communities ranged from 0.21 to 0.33. More similarity (S_J = 0.33) was observed between community type I and III and less similarity (S_J= 0.21) was observed between community type II and community type IV (Table 2). This indicated that the dissimilarity accounted for 77% for the most similar communities (a community I and III) and 79% for those that shared least similarities (community II and IV). Values in bold refer to Jacquard's dissimilarity coefficients.

The relatively higher similarity between community type I and III were probably due to the similar environmental conditions. This is confirmed by Javad et al (2017) which stated that ecological species groups the plants that share similar affinities to environmental conditions and tend to occupy the same ecological niches across the landscape. As it has also been indicated in the works of Wana and Woldu (2005) environmental factors such as altitude, aspect, slope, soil physical and chemical properties have sound effects on patterns of species in communities. For all plant communities recognized in the DMFP, the computed Jacquard's similarity coefficient values were below 0.5, indicating the existence of low similarities among them and implied that all the communities were important in terms of floristic diversity and need attention from a conservation point of view.

Table 2 Jacquard's similarity coefficient for communities

	Community I	Community II	Community III	Community IV
Community I		0.28	0.33	0.25
Community II	0.72		0.28	0.21
Community III	0.77	0.72		0.28
Community IV	0.75	0.79	0.72	

Population structure of the Debrelibanos Monastery forest patch

Density class of woody species

The densities of woody species (≥5cm DBH) were analyzed and presented into ten DBH-classes (Fig. 4). The results showed that the existence of variations in density across diameter classes of woody species in the forest (Appendix 1). From the total density of Class-1 (93 ha^{-1}), *the* density of *Acacia abyssinica* (26.5 ha^{-1}), *Olea europaea subsp. cuspidata* (16 ha^{-1}), *Allophylus abyssinicus* (9.5

stems ha^{-1}), *Rhus natalensis* (8 ha^{-1}), *Acacia lahai* (7.5 ha^{-1}), whereas the rest density (25.5 ha^{-1}) of the class was constituted by ten woody species such as *Calpurnia aurea, Clutia abyssinica*, *Eucalptus globulus*, *Juniperus procera, Carissa spinarum, Euphorbia abyssinica, Ficus sur, Grewia trichocarpa, Maytenus senegalensis* and *Zehneria scabra,* in the forest (Appendix 1). From the total density of Class-2 (61.5 ha^{-1}), the density of *Juniperus procera* (14.5 ha^{-1}), *Acacia abyssinica* whereas *Olea europaea subsp. cuspidata* 14 ha^{-1} each, *Acacia lahai* (9.5 ha^{-1}) and the rest 9.5 h^{-1} density were constituted by *Allophylus abyssinicus, Ekebergia capensis, Euphorbia abyssinica*, *and Ficus sur* species of the class in the forest (Appendix 1).

Olea europaea subsp. cuspidata (18.5 ha^{-1}), *Allophylus abyssinicus* (10 ha^{-1}), *Euphorbia abyssinica* (6.5 ha^{-1}), *Juniperus procera* (6 ha^{-1}), *Croton macrostachyus* and *Ficus sur* 5.5 ha^{-1} each, whereas the rest 4.5 ha^{-1} density were shared by *Acacia abyssinica, Acacia lahai and Eucalptus grandis* species from the total density of Class-3 (56.5 ha^{-1}) in the forest. From the total density of Class-4 (46.5 ha^{-1}), *Juniperus procera* (23 ha^{-1}) and *Olea europaea subsp. cuspidata* (13 ha^{-1}) constituted most density in the class. Other woody species such as *Allophylus abyssinicus*, *Eucalptus grandis*, *Euphorbia abyssinica*, and *Rhus glutinosa* constituted densities 10.5 stems ha^{-1} in the class. From the total density of Class-5 (44 ha^{-1}), 90.9% (40 ha^{-1}) density was *Olea europaea subsp. cuspidata and* the rest 9.09% (4 ha^{-1}) was constituted by *Euphorbia abyssinica* and *Juniperus procera* in the class (Appendix 1).

From the total density of Class-6 (32.5 ha^{-1}), *Olea europaea subsp. cuspidata (*20.5 ha^{-1}) was constituted the highest density followed by *Juniperus procera* (10 ha^{-1}), whereas the rest 2 ha^{-1} density of the class was shared by *Eucalptus grandis* and *Ficus thonningii* in the forest (Appendix 1). In DBH Class-7 (33 ha^{-1}), only three woody species namely *Juniperus procera* (14 ha^{-1}*), Olea europaea subsp. cuspidata (*18 ha^{-1}), and *Ficus sur* (1 ha^{-1}) were recorded in the forest (Appendix 1). From total density in Class-8 (33 ha^{-1}), *Allophylus abyssinicus* (6.5 ha^{-1}), *Juniperus procera* (10.5 ha^{-1}) and *Olea europaea subsp. cuspidata* (10 ha^{-1}) and the rest 6 ha^{-1} densities of the class were shared by *Eucalptus grandis, Euphorbia abyssinica* and *Ficus sur* in the forest (Appendix 1). From total density in Class-9 (20.5 ha^{-1}), *Euphorbia abyssinica* was constituted the highest density (8 ha^{-1}) followed by *Juniperus procera* (6.5 ha^{-1}), *Olea europaea subsp. cuspidata* (4.5 ha^{-1}) and *Ficus sur* (1.5 ha^{-1}) in the forest (Appendix 1). 38 stems ha^{-1} was the density of Class-10 which showed that *Olea europaea subsp. cuspidata* (19.5 ha^{-1}) constituted the highest density followed by *Juniperus procera* (14.5 ha^{-1}), *Euphorbia abyssinica* (3.5 ha^{-1}) and *Ficus sur* (0.5 ha^{-1}) in the forest (Appendix 1).

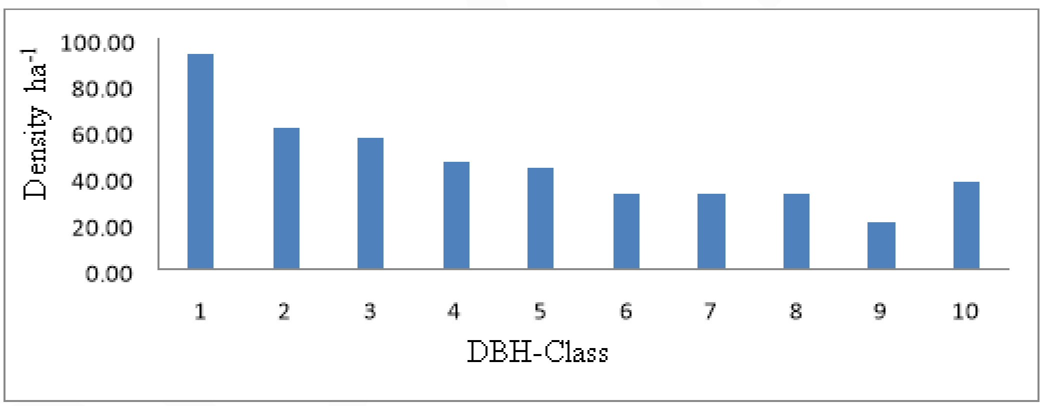


Figure 4 The density of woody species by DBH-Class distribution in DMFP

As shown in Figure 5, the overall distribution of densities of stems ha^{-1} of selected woody species in DBH-Classes was mostly recorded in DBH-Class-1 (93 ha^{-1}) than declining towards the end of DBH-Class-9 (20.5 ha^{-1}), but slightly inclining towards the last DBH class-10 (38 ha^{-1}) in the forest.

DBH-Class of woody species in the Debrelibanos Monastery forest patch

The DBH was classified into four DBH-classes. The results showed the existence of variations in diameter classes of woody species in the forest (Figure 6a-i). Population pattern of *Acacia lahai, Acacia abyssinica, Euphorbia abyssinica*, and *Olea europaea subsp. cuspidata* showed that their population distribution in the forest was declining in the number of individuals from DBH Class-1 to Class-4 (Figure 6a, b, e & g). Such patterns skewed to a reversed J-shape distribution in the forest which was considered to have the favorable status of regenerations and recruitments and hence there were stable and healthy populations (Gebrehiwot, 2003). There were also some losses of DBH Class observed in *Euphorbia abyssinica* population in the forest (Figure 6e). This might be due to cutting of the species in the forest patch.

Prunus africana, Allophylus abyssinicus, Croton macrostachyus, and *Rhus natalensis* showed different patterns of population distributions (see Shiferaw et al., 2018). The population showed none of the three shapes (Type I, II& III). Due to effects of long term and gradual selective cutting and livestock grazing in the forest, population growths in most of DBH classes were discontinued from population distribution in the forest (Figure 6c, d, h & I). However, the population pattern of *Allophylus abyssinicus* was relatively better than the aforementioned species *except* for some DBH-Classes (2, 6, 7 &8) were lost from population distributions (Figure 6c). The reason might be due to the long-term selective cutting of the species from the forest patch. These implied that the population of these species was endangered in the forest. Population distribution of *Juniperus procera* showed a different pattern which was different from the three population distribution types I, II and III used by Gebrehiwot (2003). But, in Figure 6f, the population *Juniperus procera* showed bell-shaped distribution or irregular distribution in the forest in which its regeneration capacity was hampered (Worku et al., 2012).

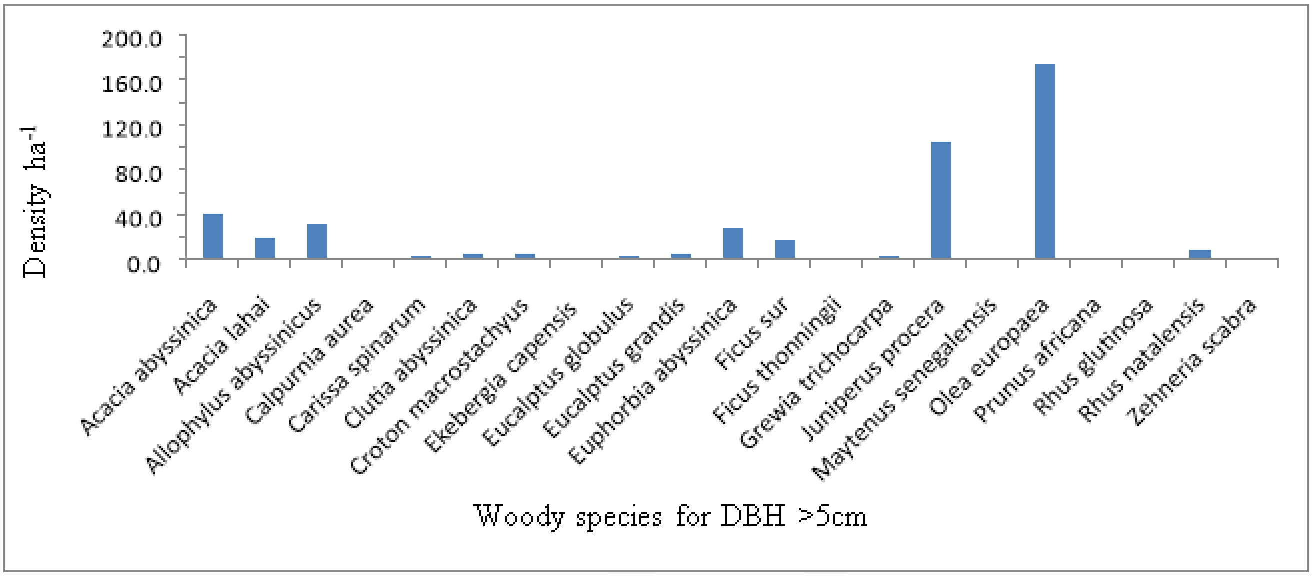
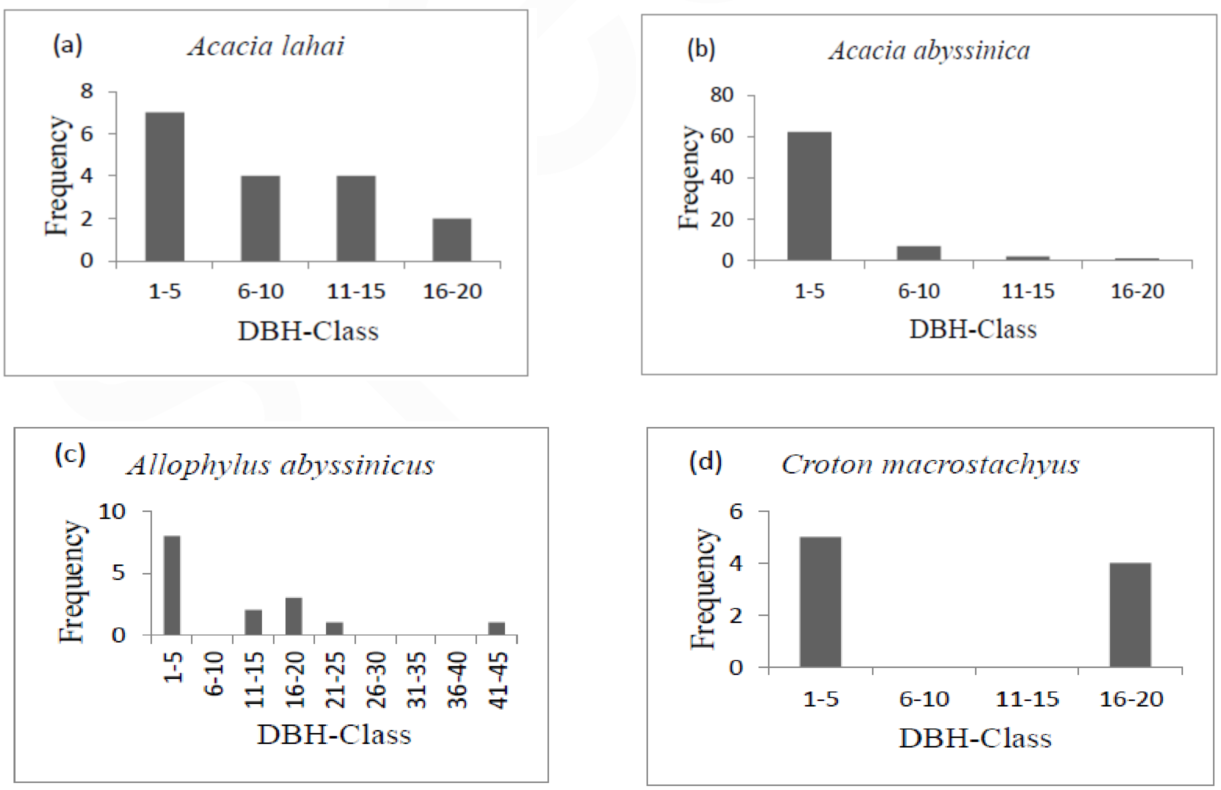


Figure 5 The overall density of woody species >5cm in DMFP



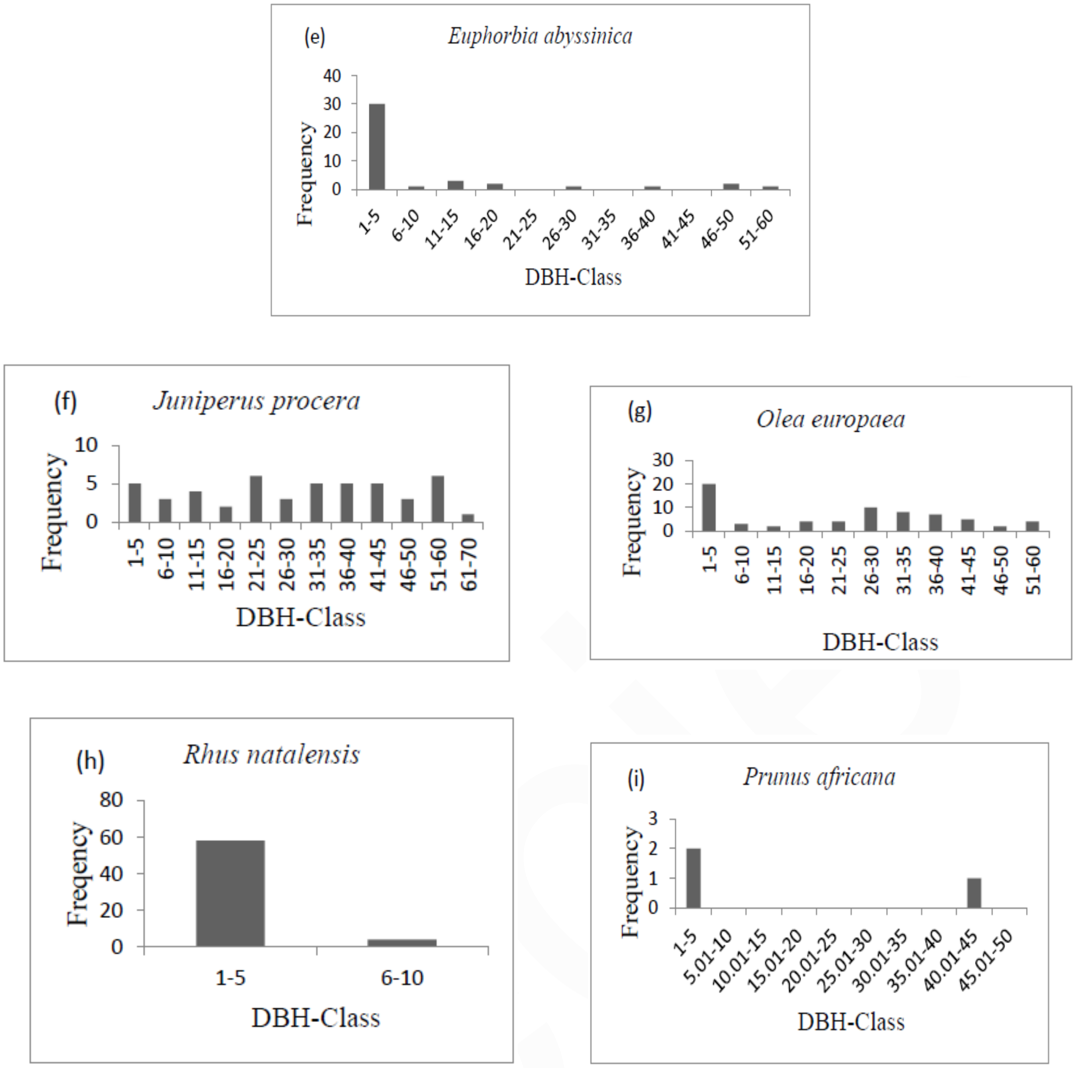


Figure 6 a-i. DBH-Class of woody species in DMFP

Height Class of woody species in the Debrelibanos Monastery forest patch

The population patterns of ten woody species in the forest were also presented in height classes (Fig.7a-j). The results showed that distribution of *Acacia abyssinica, Acacia lahai, Croton macrostachyus* and *Rhus natalensis* were categorized in similar patterns of population distributions in the forest. Except some lower DBH Classes, the four species had lost the higher DBH classes (Fig.7a, b, d & i). These might be due to the long term and gradual selective cutting of species in the forest.

The species population distributions of *Allophylus abyssinicus, Ficus thonningii* and *Prunus africana were* shown in Figs 7c, e & h. In these species population, because of some reasons population patterns in middle and higher height classes were lost. These indicated that the species had no mother plants for future healthy regeneration of the species in the forest. In the *Olea europaea subsp. cuspidata, Ficus sur, and Juniperus procera* population, the results showed that distribution of their population had an inverted J-shape distribution in the forest which were considered to have a favorable status of regeneration and recruitment and hence stable and healthy population (Fig.7g, f & j).

The results also showed that in some height classes, their numbers were declined. For instance, in height class-3 from the population of *Juniperus procera* and height class-2 & 4 from the population of *Ficus sur* some stems were cut in the forest. This might be due to a cut of trees from these height classes in the forest (Fig.7f & j). The variation in height and DBH distribution can be due to the previous exposure of the forest to long-term and gradual human activities such as cutting and livestock grazing in the forest. The presence of some large-sized trees and prevalence of small to medium-sized individuals in the forest might also be due to the barrier in seed rain and seed dispersal and due to lack of seed dispersal corridors of forests in the region (Wassie, 2007) and the forest is in a late stage of secondary development (Bekele, 1993).

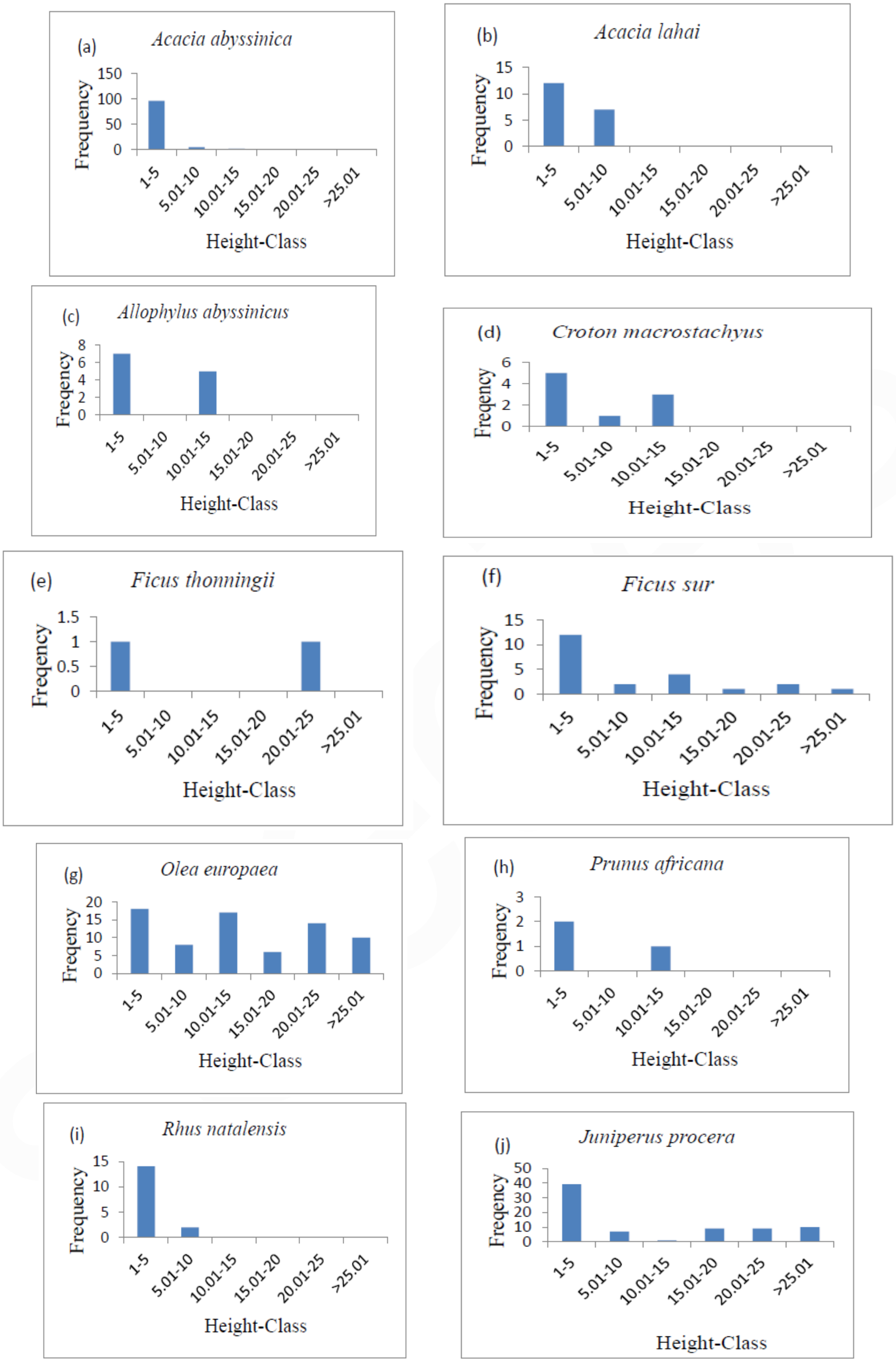


Figure 7a-j. Height-Class distribution of woody species in the DMFP

Vertical stratification of the Debrelibanos Monastery forest patch

According to Lamprecht (1989), three simplified vertical structures are distinguished in tropical montane forests: upper, middle and lower story. Accordingly, the tree/shrub structures in the DMFP were categorized into three vertical stories: upper story (tree height>2/3 of dominant height), middle story (tree height between 1/3 and 2/3 of dominant height) and lower story (tree height <

1/3). The dominant height in the forest patch was *Juniperus procera* with the height of 35m. As the result, the upper story was represented by a height greater than 23.33m which accounts about 19.91% frequency of the woody species whereas the middle story ranges from 11.67-23.33 (29.83%), and the lower story less than 11.67m (50.26%) in the forest vertical layer (Table 3).

Table 3 Frequency, percentage of individual woody species and richness in lower, middle and upper strata of DMFP

Tree story	Frequency	Percent (%)	Species richness
a	578	50.26	49
b	343	29.83	14
c	229	19.91	9

Notice: a=lower story (<11.67m), b=middle story (11.67-23.33m), c=upper story (>23.33m)

The three vertical structures can also be described in such ways that 9 (12.50%) species richness were recorded in the upper story whereas 14 (19.44%) species in middle story, and 49 (68.06%) in lower strata of the forest. The study showed that the majority of the individual woody species frequencies (49) of the study area were in lower height class (Table 3).

Acacia abyssinica, Acacia lahai, Acokanthera schimperi, Clutia abyssinica, Croton dichogamus, Phytolacca dodecandra, Pavetta abyssinica and *Rhus glutinosa* woody species which can be listed among the emergent 49 woody species that contributed the lower canopy of the forest (Appendix 2). *Zehneria scabra, Croton macrostachyus, Allophylus abyssinicus, Juniperus procera, Prunus africana were* among emergent woody species which can also be listed in the middle story whereas *Allophylus abyssinicus, Carissa spinarum, Eucalptus grandis, Euphorbia abyssinica, Ficus thonningii, Ficus sur, Juniperus procera, Maytenus senegalensis,* and *Olea europaea subsp. cuspidata were* the 9 emergent woody species in the upper story of the forest (Appendix 2).

4. CONCLUSIONS AND RECOMMENDATIONS

In the present study, results showed that DMFP harbored 113 plant species. Among the species recorded, herbs contributed the highest followed by shrubs and trees in the forest. From these species, more than about 49 woody species were recorded in the forest. This indicated that the regeneration of woody species was more vulnerable to human activities in the form of gradual cutting and livestock grazing. As a result, herbs and shrubs species have got the opportunity for dominating the lower strata of the forest.

Concerning the basal area of the forest, the basal area of the DMFP was also lower than some dry Afromontane forests in Ethiopia. This indicated that the size of diameter at breast height and number of individual of woody species were lower in the forest. This implied that the forest was under severe disturbances by human activities in the forest.

The results showed that variations in diameter and height classes of woody species were observed in the forest. For instance, the patterns of the population distribution of *Acacia lahai, Acacia abyssinica, Euphorbia abyssinica*, and *Olea europaea subsp. cuspidata showed* skewed to a reversed J-shape distribution in the forest. This revealed that their population was in good regeneration potential in the forest. Whereas, *Prunus africana, Allophylus abyssinicus, Croton macrostachyus* and *Rhus natalensis* showed that their normal natural regenerations were hampered or irregular at some diameter or height classes. Population pattern of *Juniperus procera* also showed irregular distribution which showed hampered and it captured the upper forest layer in the forest. The study showed that the majority of the individual woody species frequencies of the study area were in lower height class. This had implications of selective logging, and grazing intensity that inhibits the growth of species into upper diameter classes (middle and upper tree layers). The presence of some large trees and prevalence of small to medium-sized individuals in this forest showed that the forest was exposed to long-term and gradual human activities (grazing, cutting) and problems in the barrier of seed rain and dispersal in the forest. In general, the dynamics of forest conditions in the DMFP needs detail studies in the future, as it harbors the significant number of endemic species.

However, from the foregoing discussion, it can be seen that the forest requires better management so that its resources could be effectively utilized on sustainable bases. Therefore, the following recommendations are made to meet these requirements: Create awareness on the various uses of Non Timer Forest Products (NTFPs) to utilize from the forest so that local communities will be harmonized and devoted for forest management, grazing land management in the surrounding sites (Kebeles) should be encouraged so that pressure of grazing in the forest can be reduced, extension program including forest management (tree planting) should be extended so as to reduce pressure on forest resources and awareness creation for local communities in utilization of the forest, planned forest management techniques such as enrichment planting especially with indigenous plant species in the forest should be encouraged. Researches such as the status of soil seed banks, initiatives of the local communities towards forest management and plantations, the status of the annual plantations by the regional government with community needs, existing forest management practices and plantations, restoration of bushlands by areas closure, the contribution of the *Eucalyptus globulus* Labill. And the *Eucalyptus* species for reduction of deforestation pressure on existing forest fragments and vegetations, and carbon sequestration potential of the forest should also be investigated in the future.

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Appendices

Appendix 1 Density stems ha^{-1} distribution of woody species by DBH-Class the DMFP

Species name	Class1	Class2	Class3	Class4	Class5	Class6	Class7	Class8	Class9	Class10	Density stems ha^{-1}
Acacia abyssinica	26.5	14.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.0
Acacia lahai	7.5	9.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.5
Allophylus abyssinicus	9.5	2.5	10.0	2.5	0.0	0.0	0.0	6.5	0.0	0.0	31.0
Calpurnia aurea	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Carissa spinarum	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Clutia abyssinica	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Croton macrostachyus	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
Ekebergia capensis	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Eucalptus globulus	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Eucalptus grandis	0.0	0.0	1.5	2.0	0.0	1.0	0.0	1.0	0.0	0.0	5.5
Euphorbia abyssinica	1.0	2.0	6.5	4.5	1.5	0.0	0.0	4.0	8.0	0.5	28.0
Ficus sur	1.0	4.5	5.5	0.0	0.0	0.0	1.0	0.5	1.5	3.5	17.5
Ficus thonningii	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0
Grewia trichocarpa	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
Juniperus procera	4.0	14.5	6.0	23.0	2.5	10.0	14.0	10.5	6.5	14.5	105.5
Maytenus senegalensis	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5
Olea europaea subsp. cuspidata	16.0	14.0	18.5	13.0	40.0	20.5	18.0	10.0	4.5	19.5	174.0
Prunus africana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5
Rhus glutinosa	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Rhus natalensis	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0
Zehneria scabra	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total	93.0	61.5	56.5	46.5	44.0	32.5	33.0	33.0	20.5	38.0	459.5

Class-1=5-10, Class-2=10.01-15, Class-3=15.01-20, Class-4=20.01-25, Class-5=25.01-30, Class-6=30.01-35, Class-7=35.01-40, Class-8=40.01-45, Class-9=45.01-50 and Class-10=>50cm

Appendix 2 Woody species in vertical structure of the DMFP

Lower story	Middle story	Upper story
Acacia abyssinica	*Acacia abyssinica*	*Allophylus abyssinicus*
Acacia lahai	*Acacia lahai*	*Carissa spinarum*
Acokanthera schimperi	*Allophylus abyssinicus*	*Eucalptus grandis*
Albizia schimperiana	*Croton macrostachyus*	*Euphorbia abyssinica*
Allophylus abyssinicus	*Eucalptus globulus*	*Ficus thonningii*
Brucea antidysenterica	*Eucalptus grandis*	*Ficus sur*
Buddleja polystachya	*Euphorbia abyssinica*	*Juniperus procera*

Calpurnia aurea
Carissa spinarum
Clutia abyssinica
Croton dichogamus
Croton macrostachyus
Dodonaea angustifolia
Ekebergia capensis
Entada abyssinica
Eucalptus globulus
Eucalptus grandis
Euclea racemosa
Euphorbia abyssinica
Ficus sur
Ficus thonningii
Grewia bicolor
Grewia ferruginea
Grewia trichocarpa
Hypericum gnidiifolium
Ilex mitis
Juniperus procera
Justicia schimperiana
Leonotis ocymifolia
Maytenus arbutirolia
Maytenus senegalensis
Myrsine africana
Olea europaea subsp. cuspidata
Osyris quadripartita
Pavetta abyssinica
Phytolacca dodecandra
Rhus glutinosa
Rhus natalensis
Rici.comm
Rosa abyssincia
Rytigynia neglecta
Sparmannia ricinocarpa
Teclea nobilis
Vepris dainellii
Vernonia amygdalina
Vernonia bipontini
Vernonia hochstetteri
Zanthoxylum chalybeum
Zehneria scabra

Ficus sur
Grewia trichocarpa
Juniperus procera
Olea europaea subsp. cuspidata
Prunus africana
Rhus glutinosa
Zehneria scabra

Maytenus senegalensis
Olea europaea subsp. cuspidata

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