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ORIGINAL PAPER

Woody plant species diversity and composition in and around Debre Libanos church forests of North Shoa Zone of Oromiya, Ethiopia

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Abstract Dry afromontane forests are among the most poorly managed and endangered ecosystems. Therefore, we assessed the composition, diversity, and conservation status of woody plant species of the Debre Libanos church forests and surrounding forest lands in Oromiya Regional National State, central Ethiopia in 62 nested circular sample plots spaced 200 m apart along two transect lines. Large circular plots 314 m^2 were used to sample trees with DBH of at least 10 cm, and subplots of 28.26 m^2 were laid in each main plot were used to assess saplings and shrubs; a small subplot of 3.14 m^2 was used to assess seedlings. In total, 70 woody plant species belonging to 62 genera and 43 families were recorded. Of these, 59, 28 and 32 were in the church, government and private forest types, respectively. The most dominant families were *Fabaceae* and *Verbenaceae*, each represented by five species. In the forests considered, trees accounted for 61%, and shrubs with diameter at breast height (DBH) of 1–10 cm accounted for ca. 33%. Among growth forms of woody species, shrubs and seedlings, followed by trees constituted much of the density of woody species in all the three ownership types of forests. The church forest had the most species (59) and highest Shannon (3.12) and Simpson (0.92) species diversity indices, and the government and private forests had a nearly similar total number of species and Shannon and Simpson species diversity indices. Most of the species with higher importance value indices (IVI) were indigenous in origin within the church forest (*Juniperus procera* = 82), government forest (*J. procera* = 66) and private forest (*Acacia abyssinica* = 84). The composition, diversity, and population structure of woody species in the church forest were significantly higher than in the other forest lands. However, interventions of the government and private sectors to conserve forest systems in the areas, particularly the government-owned forest and specific species such as *Olea europaea* need active enrichment plantings due to their limited natural regeneration. Without improved management interventions, livelihood income diversification and ecosystem services obtained from the forest will not be sustainable.

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Introduction

Internationally, the most disrupted, endangered ecosystems are dry afromontane forests (Gebeyehu et al. 2019; Tesfaye et al. 2019). Likewise, a significant amount of dry afromontane forest coverage, particularly in the central and northern parts of Ethiopia, has been lost in the last several decades. Only a few small fragmented patches of dry afromontane forests remain in remote areas and around Ethiopian Orthodox Tewahido churches, and the resultant habitat loss threatens biodiversity, including that of woody plant species and forest composition and structures (Aerts et al. 2016; Tesfaye et al. 2019).

The major causes of forest loss in Ethiopia include conversions to agricultural land and urbanization, illegal logging, fuel wood collecting, cattle grazing and coffee forest management for coffee production (Hundera et al. 2013; Geeraert et al. 2019). Furthermore, poorly defined property rights and demographic pressure have been identified as the underlying drivers of deforestation in Ethiopia (Lemenih and Kassa 2014; Bareke 2018; Tura 2018). Poorly defined property rights, for instance, influence local people's capability to retain and plant trees and shrubs in forests, in farmland, grazing land and home gardens (Shumi et al. 2018). Moreover, rapid population growth and inappropriate natural resource management practices have tremendously impacted forest resources in the highlands of Ethiopia, where climatic conditions are also favorable for agricultural production and human settlements (Tura 2018; Duguma et al. 2019). On the other hand, land scarcity and land-use competition, e.g., between forestry and grazing land-use, have also aggravated landscape fragmentation, where remnant, native forest patches are only found at the top of hills (Stanturf et al. 2017). Aside from forest fragmentation, the complete loss of vegetation cover, decrease in biodiversity, and severe erosion are also major problems in the highlands of Ethiopia (Teshome 2014; Aerts et al. 2016).

Today, remnant dry afromontane forest patches are common around churchyards, in monasteries, church compounds and other religious burial grounds in central and northern part of Ethiopia (Aerts et al. 2016; Bongers et al. 2006). In much of the landscape of northern Ethiopia, the lush vegetation on the hillsides surrounding a church or a monastery presents a sharp contrast to the surrounding bare ridges and mountain slopes (Aerts et al. 2016). In this regard, unlike other institutions, the Ethiopian Orthodox parish church places great value on the preservation of natural forests as indicated by the presence of dense and attractive forests that are conserved by monasteries and churches (Mulat 2013; Aerts et al. 2016). The church forests have been managed for centuries by priests and communities around church buildings (Cardelús et al. 2012). Therefore, understanding the conservation value, particularly for woody plant species diversity and composition, of such efforts in relation to other forest management practices, e.g., of government and private forests is crucial for devising appropriate conservation strategies. Yet, relatively few studies have investigated the conservation value of the church forest as compared to other forest land-uses (Seyoum and Zerihun 2014; Demie 2015; Shiferaw et al. 2019), and the studies were superficial and lack detailed scientific information on the conservation value of church forests, e.g., the Debre Libanos Monastery forest patch. Drawing on the rationale outlined above, we investigated woody plant species composition, diversity and population structure in the Debre Libanos church, private and government forests.

Materials and methods

Study area

This study was carried out in Debre Libanos and Girar Jarso district. Debre Libanos forest is located in North Shoa Zone of the Oromiya regional state in central Ethiopia (Fig. 1). It is situated at about 106 km from Addis Ababa and 14 km from Fiche town, the capital of North Shoa Zone, namely the Debre Libanos Monastery. Geographically, the area is located between 38°82′–38°85′ E longitude and 9°71′–9°73′ N latitude at 2311–2538 m a.s.l. The climatic data recorded at meteorological stations within the Debre Libanos forest, the annual average maximum and minimum temperature of the study area is 23 °C and 15 °C, respectively, and the annual average rainfall is 1000 mm (Seyoum and Zerihun 2014). And the total area of the study was about 178.03 ha church land, 26.26 ha government and 18.58 ha private forest land (based on GPS results in a survey). The natural forest of Debre Libanos encompasses two districts and 27 peasant associations, such as Debere Libnos and Girar Jarso Districts. The government and private natural forests are found within the boundary of the Girar Jarso District. However, the church forest is located in the Debre Libanos district. The three natural forests are within the Debre Libanos Forest. The forest is dominated by afromontane forest tree species *Olea europaea* and *Juniperus procera* (personal observation by Hingabu Hordofa).

Vegetation survey

A systematic sampling design was used to locate sample plots in each forest-ownership system (Mary et al. 2011). The sampling unit was composed of three concentric circular

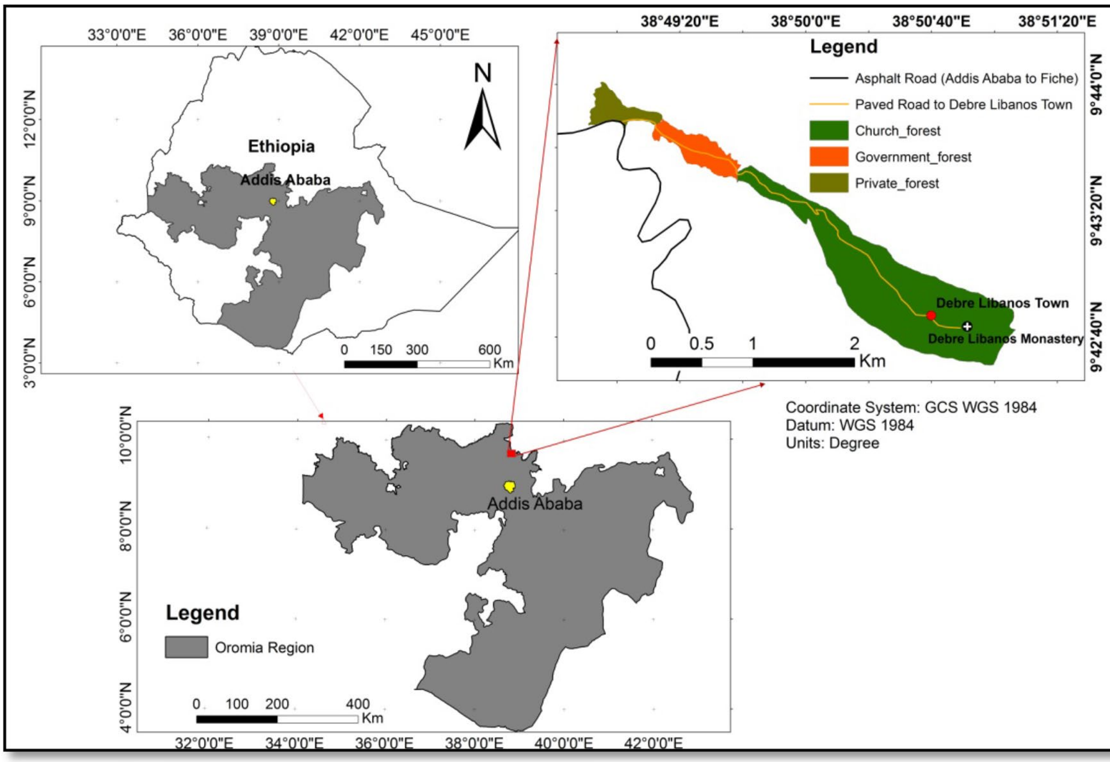

Fig. 1 Maps of the study area in Ethiopia

plots each having 1-m (3.14 m^2), 3-m (28.26 m^2) and 10-m (314 m^2) radius. The first transect line and the first plots were selected randomly. The circular plots were then laid out along a horizontal gradient every 200 m, while subsequent transect lines were spaced every 190 m. In total, 62 circular plots were established; 34 plots in the church forest, 15 in the government, and 13 in the private forests. As a result of the variation of the study sites, the number of samples in plots at each site differed. In each forest, two-stage sampling technique was employed for statistical purposes (confidence interval = 95%) due to sample size (Mary et al. 2011). Accordingly, a total of 11 initial plots were established to meet the total required number of plots for the study sites determined according to the International Forestry Resources and Institutions Research. Thereafter, the trees in each plot were counted in each forest system (Mary et al. 2011).

Vegetation data were collected within the circular plots following the guidelines of the International Forestry Resources and Institutions Research (IFRI) (Mary et al. 2011). Accordingly, trees, defined as woody plants with a DBH of at least 10 cm, were recorded within 10-m-radius circular plots, while saplings, defined as woody plants with DBH < 10 cm were recorded within 3-m radius circular subplots. The diameter of woody shrubs and lianas was measured at the thickest point along their length was also recorded within 3-m radius circular subplots. Seedlings, defined as woody plants with DBH < 2.5 cm and height < 1 m (Mary et al. 2011) were recorded within a 1-m radius circular subplot.

A tree caliper was used to measure the DBH of trees and saplings and the maximum stem diameter of shrubs and lianas. Diameter tape was used at the rare times that a tree trunk exceeded 50 cm DBH. Hypsometer was used to measure the height of trees, saplings, and shrubs. Seedlings of each woody species were counted. Plants were identified in the field and in the herbarium. Voucher specimens were prepared for all plant species not identified in the field and deposited at the National Herbarium in Addis Ababa University, Ethiopia for subsequent identifications (Chekole et al. 2015). The geographical location of each plot was taken from the center in degrees using Garmin (Olathe, KS, USA) 72 GPS receivers. Likewise, the elevation of each plot was measured using the GPS receiver, and the aspect of each plot was recorded.

Floristic diversity

The woody plant species richness was determined in a given plot as the Shannon diversity index. The Shannon evenness index was determined to evaluate the evenness of the distribution of species in each forest system. The Shannon diversity index (H') was calculated using Eq. (1) (Malik and Husain 2006; Krebs 1985).

$$H' = -\sum_{i=1}^{S} p_i\left(\ln p_i\right), \tag{1}$$

where p_i = the proportion of individuals of the ith species, and the number of species is $i = 1, 2, 3\ldots s$.

The Shannon evenness (J) was calculated using Eq. (2) (Krebs 1985).

$$\boldsymbol{J} = \frac{\boldsymbol{H'}}{\boldsymbol{H'}_{\max}} = \frac{\sum_{i=1}^{S} p_i\left(\ln p_i\right)}{\ln S}. \tag{2}$$

The other popular diversity index used in this study was Simpson's diversity index (D), calculated using following equation

$$D = 1 - \left[\frac{\sum n_i\left(n_i - 1\right)}{N\left(n_i - 1\right)}\right], \tag{3}$$

where n_i = no. of individuals of species i, N = total number of species in the community.

Population structure

Population structure was computed for selected woody plant species. For studying the population structure in the different forest systems, the diameter and height of all or individual woody plants were categorized into arbitrary diameter and height classes. Accordingly, the woody species were grouped into the five DBH classes Feyera (2006) with 1 = 2.5–5 cm; 2 = >5–11 cm; 3 = >11–23 cm; 4 = >23–47 cm and 5 = >47 cm) and seven height classes with 1 = 1–5 m; 2 = >5–10 m; 3 = >10–15 m, 4 = >15–20 m; 5 = >20–25 m; 6 = >25–30 m; 7 = >30 m.

Density The number of seedlings, saplings, shrubs and trees per hectare was calculated by summing up all stems across all sample plots and dividing by the total hectares. The ratio of the density of individuals having DBH of 2.5 cm < DBH < 10 cm to that of the individuals having DBH > 10 cm was computed as a measure of the distribution of the size classes (Nowak et al. 2014).

Statistical analysis Descriptive statistics were used to compute the mean values (mean ± SEM). A one-way ANOVA with unequal replications was used to test for significant variation among means. When variations among means were found to be significant; the Fisher least significant difference (LSD) test was performed to test for a significance difference between any two means.

DBH and height size class distribution DBH size and height class distribution was computed for selected tree species. For this, the DBH and height of all or individual woody plants were categorized into arbitrary DBH and height classes were described above.

Importance value index (IVI) The IVI is used to compare the ecological significance of species; a high IVI value indicates that the species' sociological structure in the community is high (Gebeyehu et al. 2019). The species with the greatest IVI are the most dominant in the community (Teshager 2018; Yineger et al. 2011). Equations (4)–(8) were used to determine the IVI.

$$R_{\mathrm{f}} = \left(F_{\mathrm{s}}/T_{\mathrm{f}}\right) \times 100, \tag{4}$$

where R_{f} is relative frequency, F_{s} is frequency of the species, and T_{f} is total frequency of all species.

$$D_{\mathrm{s}} = \left(N_{\mathrm{s}}/A_{\mathrm{s}}\right) \times 100, \tag{5}$$

where D_{s} is the density of a species, N_{s} is the number of individuals of that species, and A_{s} is area sampled.

$$R_{\mathrm{d}} = \left(D_{\mathrm{s}}/T_{\mathrm{s}}\right) \times 100, \tag{6}$$

where R_{d} is relative density, D_{s} is density of the species, and T_{s} is total density of all species.

$$R_{\mathrm{do}} = \left(\mathrm{DO_s}/T_{\mathrm{d}}\right) \times 100, \tag{7}$$

where R_{do} is relative dominance, $\mathrm{DO_s}$ is dominance of the species, and T_{do} is total of dominance of all species.

$$\mathrm{IVI} = R_{\mathrm{f}} + R_{\mathrm{d}} + R_{\mathrm{do}}, \tag{8}$$

where R_{f} is relative frequency, R_{d} is relative density, and R_{do} is relative dominance.

Data analysis

Once the biophysical data representing the different forest systems were collected, vegetation data were encoded using Excel. Statistical analyses were carried out using SPSS version 20.0 and Excel software (Microsoft, Redmond, WA, USA). Data from each forest were analyzed based on selected variables and an analytical tool package version 2.5-6 employed by vegetation ecologists (Kassa et al. 2016; Oksanen et al. 2019). Accordingly, diversity and similarity indices, density, population structures and IVIs were

Table 1 Number of family, genera, and species encountered in different forest systems

Taxa	All forest systems	Church forest	Government forest	Private forest
No. of families	43	37	21	22
No. of genera	62	49	26	28
No. of species	70	59	28	32
Genera to family ratio	1.44	1.32	1.13	1.27

analyzed, and some woody species encountered within the studied forest systems.

Results

Floristic composition

A total of 70 species, representing 62 genera and 43 families were recorded in all plots (Table 1). Regarding species distribution, a total of 59 tree species were found in the church, 32 species in private and 28 species in government forests (Tables 1 and 2). The identified woody plant species represented different life forms. Of these, trees accounted for 43 species (61%), the most dominant growth form, followed by the shrubs and lianas comprising of 23 species (33%), and 4 species (6%), respectively (Table S1).

The church forest harbored 34 (57%) tree species, 21 (36%) shrub species, and four (7%) liana species. The government forest comprised mainly tree species, accounting for 18 (64%) of all the woody species recorded in it, shrubs comprised eight species (29%), and lianas only two (7%) (Table 2).

At the family level, *Fabaceae* and *Verbenaceae* were the most diverse families, each represented by five species, followed by *Euphorbiaceae* and *Anacardiaceae* each represented by four species (Table S1). In the church forest, *Anacardiaceae* and *Verbenaceae* were the most diverse families, each represented by four species; followed by *Euphorbiaceae* and *Acanthaceae* each represented by three species (Table S1). In the government forest, the most dominant families were *Fabaceae*, *Euphorbiaceae*, and *Verbenaceae*, each represented by three species followed by *Apocynaceae* and *Moraceae* each represented by two species (Table S1). In the private forest, *Fabaceae* was the dominant family that represented by four species and followed by *Euphorbiaceae* and *Verbenaceae* each represented by three and two species respectively (Table S1).

Of the 70 total species, 19 (27%) were common to all three forests under different management regimes; 24 (34%) species were common to church and government forests, 23 (33%) were common to church and private forests; and 20 (29%) were common to government and private forests. The church forest was relatively the most diverse forest (Table 3). The church forest had the most species and the highest Shannon and Simpson species diversity indices, while the government and private forests had a nearly similar total number of species and Shannon and Simpson species indices diversity indices (Table 3). The Shannon species diversity evenness was slightly lower in the church forest as compared to the government and private forests (Table 3).

Population structure of woody species

Among the woody species encountered in the entire study area, *Acacia abyssinica*, *J. procera*, *Calpurnia aurea*, *Carissa spinarum*, and *Maytenus senegalensis* had relatively the highest relative density and also the highest relative density in the church forest. Similarly, *A. abyssinica*, *J. procera*, and *M. senegalensis* had the highest relative density in the government forest. *A. abyssinica*, *M. senegalensis*, and

Table 3 Species diversity indices woody plant species in church, government and private forests of Debre Libanos

Forest type	Total no. of species	Shannon diversity (H')	Shannon evenness (E)	Simpson diversity (D)
Church	59	3.135	0.768	0.917
Government	28	2.741	0.822	0.910
Private	32	2.775	0.801	0.890

Table 2 Growth form composition of the different forest systems

Growth form	All forest systems		Church forest		Government forest		Private forest	
	No. of species	Percent	No. of species	Percent	No. of species	Percent	No. of species	Percent
Trees	43	61	34	57	18	64	20	63
Shrubs	23	33	21	36	8	29	10	31
Liana*	4*	6	4	7	2	7	2	6
Total	70	100	59	100	28	100	32	100

*All lianas were woody and found in all forests

C. spinarum had the highest relative density in the private forest.

In terms of growth forms of woody species, shrubs and lianas, followed by trees, constituted much of the density of woody species in all the three forest types. The highest density of shrubs and trees was recorded in the church forest, followed by the government forest; the private forest had the lowest densities of all the growth forms. The mean density per plot (314 m^2 area) of shrubs and trees in the church forest was significantly higher than that of the government and private forests.

DBH and height size class distribution

The visual evaluation of the DBH size distribution of the selected tree species in the church forest revealed four main patterns of population structure (Fig. 2). These are almost near to J-shape (*C. aurea*), an inverted J-shape (*C. spinarum*), almost a U-shape (*J. procera*) and a broken inverted J-shape (*O. europaea*).

The evaluation of the population structure of woody species within government forest revealed two population structures (Fig. 3): inverted U-shape (*A. abyssinica*) and a J-shape (*Croton macrostachyus*).

Woody species population structures within the private forest revealed the two main patterns of population

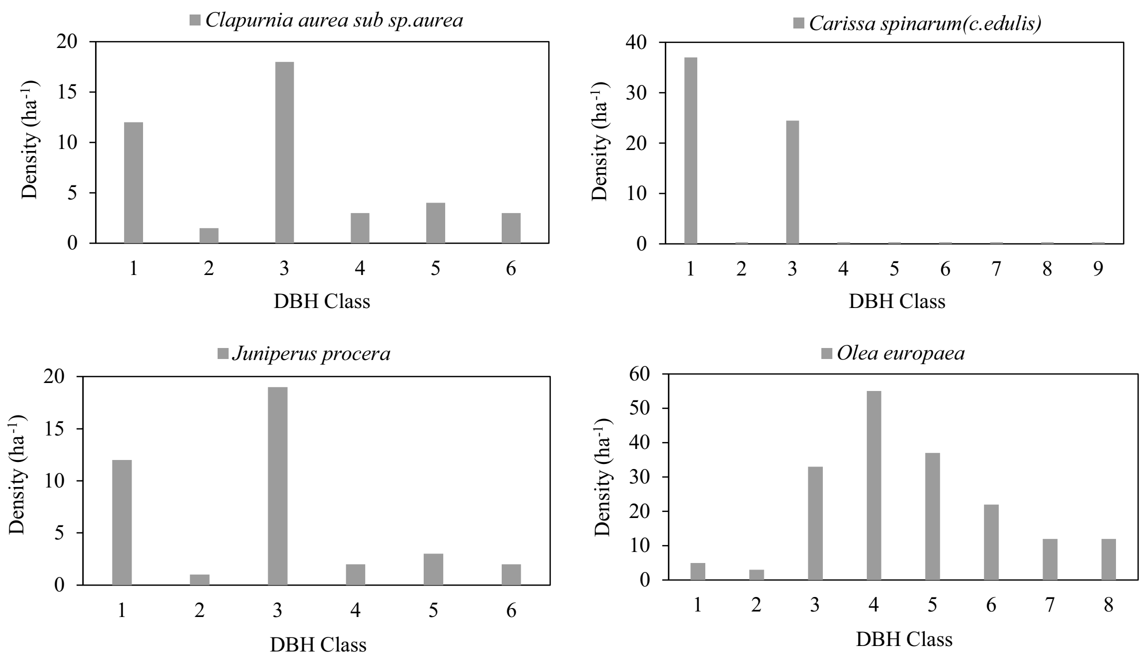

Fig. 2 Diameter class distribution of selected tree species in the church forest of Debre Libanos. DBH classes: 1 = 1–5 cm; 2 = >5–10 cm; 3 = >10–15 cm; 4 = >15–20 cm, 5 = >20–25 cm, 6 = >25–30 cm and 7 = >30 cm

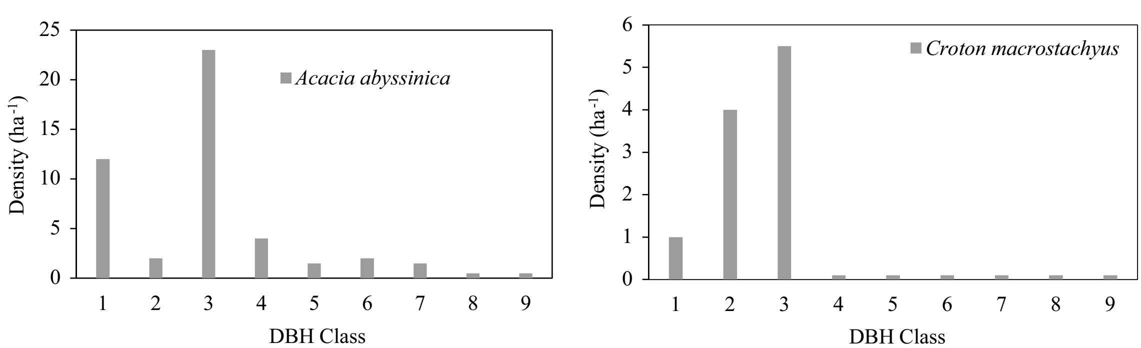

Fig. 3 Diameter class distribution of selected tree species in the government forest of Debre Libanos. DBH classes: 1 = 1–5 cm; 2 = >5–10 cm; 3 = >10–15 cm; 4 = >15–20 cm, 5 = >20–25 cm, 6 = >25–30 cm and 7 = >30 cm

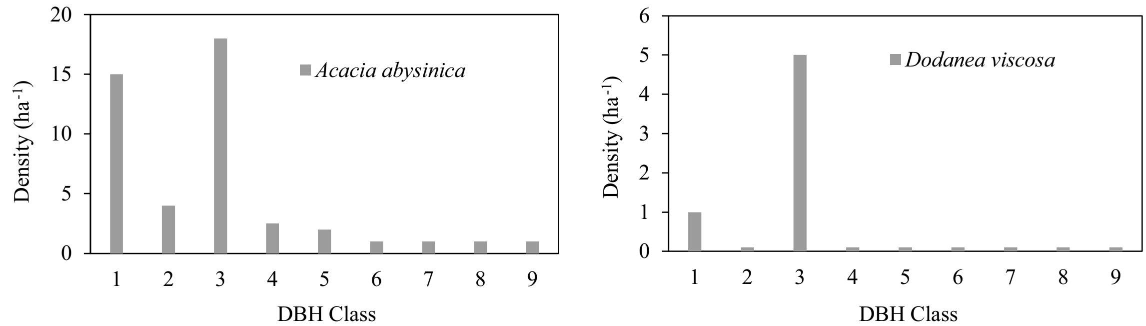

Fig. 4 Diameter class distribution of selected tree species in the private forest of Debre Libanos. DBH classes: 1 = 1–5 cm; 2 = >5–10 cm; 3 = >10–15 cm; 4 = >15–20 cm, 5 = >20–25 cm, 6 = >25–30 cm and 7 = >30 cm

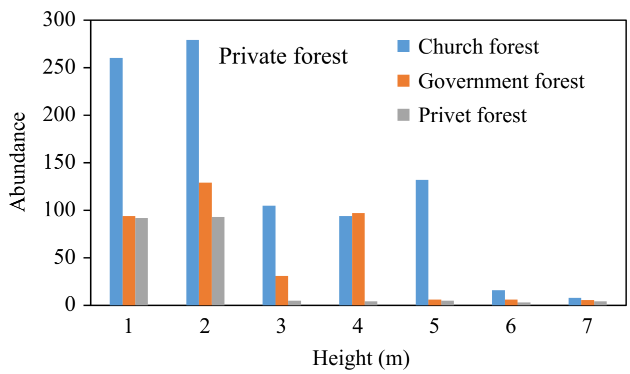

Fig. 5 Height class distribution of all woody plants within church, government and private forests of Debre Libanos. Height classes: 1 = 1–5 cm; 2 = >5–10 cm; 3 = >10–15 cm; 4 = >15–20 cm, 5 = >20–25 cm, 6 = >25–30 cm and 7 = >30 cm

structures described for the private forest. For instance, *A. abyssinica* revealed a U-shape with the first DBH, and the third class was high; *Dodonea viscosa* had more J-shape with the first three DBH classes (Fig. 4).

Analysis of the height class distribution patterns of the woody species under the different management systems revealed that the highest proportion of individuals was relatively concentrated in the lower height classes, and the lowest proportion of individuals was in the highest height classes (Fig. 5). For instance, about 34%, 37%, and 51% of the individuals in the church, government and private forests, respectively, was represented in the >5–10 m height class , whereas only 1% of the individuals in the church, less than 1% in the government, and none in the private forests was greater than 30 m tall (Fig. 5).

Importance value index (IVI) of woody species

The IVIs for the woody plant species within the church, government and private forests are provided in Table 4, and more details are presented in Table S2. It showed that *J. procera* and *O. europaea* had IVI of 81.45% and 38.63%, respectively, while *A. abyssinica* and *C. spinarum* had nearly equal IVI. *Clutia abyssinica* had the smallest IVI. Few tree species had the highest IVI and accounted for much of the overall IVI of their respective forest type. For instance, 71% of the IV of the woody species in the church forest was accounted for by 10 species: *A. abyssinica*, *C. aurea* sub sp. *aurea*, *C. spinarum*, *C. macrostachyus*, *C. abyssinica*, *Ficus sur*, *J. procera*, *M. senegalensis*, *O. europaea*, and *Osyris compressa*. The rest 49 species (29%) contributed overall IVI (Table 4).

The greatest IVIs for woody species in the government forest were for *J. procera*, *A. abyssinica* and *M. senegalensis* (66.05, 54.19 and 28.76, respectively). The species with the lowest IVI in the government forest was *D. viscosa* (9.98). In general, the IVI for most of the 10 most common woody species in the government forest was higher than in the church forest. Next to *A. abyssinica* and *J. procera*, eight species (*C. spinarum*, *C. macrostachyus*, *D. viscosa*, *Euclea racemosa*, *M. senegalensis*, *Ocimum lamifolium*, *O. compressa* and *Rhus glutinosa*) combined to contribute the most to the IVI of the government forest, accounting for about 83% of the IV (Table 4). The other 18 species (17%) contributed to the overall IVI of woody species.

Discussion

Tree diversity commonly varies among land-uses as a result of human activities as it did among the church, government and private forests in the present study. When the diversity and composition of the woody species were assessed, the species diversity for the total study area of Debre Libanos was higher than in similar dry afromontane forest ecosystems in Ethiopia; Chilimo forest had 66 woody plant species (Tesfaye et al. 2019) and Yerer Mountain Forest had 31 species (Yahya et al. 2019). The reason for the variation or better diversity found in Debre Libanos is due to differences

Table 4 Summary of the importance value index (IVI) and associated data for 10 most common woody species in the church, government and private forests

Forest type	Species	RF (%)	RDO (%)	RD (%)	IVI	Growth form
Church	*Calpurnia aurea*	5.00	6.80	0.38	12.18	T
	Carissa spinarum	6.76	9.86	0.37	16.99	T
	Croton macrostachyus	4.12	5.61	0.36	10.09	T
	Clutia abyssinica	4.12	2.38	0.01	6.51	P
	Ficus sur	1.76	2.55	3.03	7.35	T
	Juniperus procera	8.24	10.03	63.18	81.45	T
	Maytenus senegalensis	7.06	6.29	0.42	13.77	T
	Olea europaea	7.94	3.40	27.29	38.63	T
	Osyris compressa	4.12	3.91	0.19	8.22	T
	Other species (49)	44.96	39.91	4.21	88.26	
	Total	100	100	100	300	
Government	*Acacia abyssinica*	11.93	19.81	22.45	54.19	T
	Carissa spinarum	6.42	3.69	2.33	12.43	T
	Croton macrostachyus	5.51	5.07	3.03	13.59	T
	Dodonea viscosa	4.59	3.69	1.71	9.98	T
	Euclea racemosa	6.42	5.53	2.37	14.32	T
	Juniperus procera	9.17	13.83	43.05	66.05	T
	Maytenus senegalensis	9.17	13.37	6.22	28.76	T
	Ocimum lamifolium	8.26	7.83	0.35	16.44	B
	Osyris compressa	6.42	5.07	1.80	13.29	T
	Rhus glutinosa	7.34	7.83	4.41	19.57	T
	Other species (18)	24.77	14.28	12.285	51.34	
	Total	100	100	100	300	
Private	*Calpurnia aurea*	2.08	4.00	0.56	6.64	T
	Acacia abyssinica	15.63	29.33	38.79	83.75	T
	Carissa spinarum	8.33	8.00	9.639	25.97	T
	Dodonea viscosa	6.25	4.67	6.23	17	T
	Euclea racemosa	4.17	2.67	3.15	9.98	T
	Lantana trifolia	4.17	2.67	0.26	7.09	T
	Maytenus senegalensis	10.43	11.33	10.73	32.48	S
	Ocimum lamifolium	7.29	6.67	0.64	14.60	T
	Osyris compressa	6.25	4.667	5.27	16.18	T
	Rhus glutinosa	5.21	3.33	4.18	12.71	S
	Other species (22)	34.38	25.33	20.55	73.46	
	Total	100	100	100	300	

Notes RF, relative frequency; RDO, relative dominance; RD, relative density; T, tree; B, shrub; P, sapling; S, seedling

in management regime and conservation values (Aerts et al. 2016; Demie 2015; Shiferaw et al. 2019). Here, we found that the church, government and private forests under different management regimes had different conservation values for woody plant species conservation.

The woody plant species diversity in the church forest was higher than in the government forest, which higher than in the private, perhaps because the church forest was protected longer than the government and private forests (Aerts et al. 2016; Demie 2015). The church administration has also contributed significantly to conserving various native species within the church forest, and species such as *J. procera*, *Olea europaea*, and *C. spinarum* were introduced to the church forest by the monastery administration (Shiferaw et al. 2019). As a result, the dominance of some families or tree species that have a spiritual linkage with the community around and within the church forests may be due to deliberate retention or planting of such species within the church compound (Demie 2015; Shiferaw et al. 2019). Moreover, the local government helped conserve its forest so that some species still survive in the face of human-induced challenges. Some of the plant families with higher populations such as *Rosaceae* were found only in the government forest, while *Asteraceae*, *Solanaceae*, *Arecaceae*, *Proteaceae*, and *Hypericaceae* were recorded in private forest, and the rest of the families were found within the church forest. The relatively lower Shannon diversity values of the government and the private forests are due to the greater abundance of individuals of *M. senegalensis* and *A. abyssinica*. Improved status of the population structure of tree species seems to afford promising regeneration potential. Here, the most prominent species such as *A. abyssinica*, *C. spinarum*, *J. procera*, *C. macrostachyus*, *D. viscosa* displayed inverted J-shape and a normal population structure, which helps maintain biodiversity.

The Shannon diversity index ($H'=3.135$; $E=0.768$) of the church forest suggests good regeneration and better recruitment of seedlings and saplings into trees, clearly indicating the need to maintain forests for optimal growth of woody plants, with lower diversity of woody species in comparison with one of the similar study by Alelign et al. (2007) in the Zagie Church forest ($H'=3.74$; $E=0.84$) in northern Ethiopia. The variation in management adopted within the study site influenced the density and IVI of woody species. The higher density of woody species within the church forest compared with the other two in the present study could be due to the fact that the forest is set aside almost entirely for conservation purposes, except for the intensive sustainable use of *C. spinarum*, and otherwise has had almost no human interference for a long time. The density of woody species in the Zegie (3318 ha^{-1}) forest reported by Bongers et al. (2006) is lower than in the Debre Libanos forest. The impact of forest management on the density of woody plants within the government and private forest can be assessed by comparing their densities against the density of woody species within the church forest. However, the mean density per plot of saplings and shrubs among these three forest systems did not vary significantly because the under-protection of woody plants in the sapling layer is compensated by a higher density of small trees within the church and private forests. Furthermore, intensive use of *C. spinarum* for monastery fuel wood in the church forest impacted the density of trees with DBH > 10 cm.

The results of the present study depicted that the density of woody species in the church forest (18,508 ha^{-1}) is less than the density in the Yerer Mountain Forest (8001 ha^{-1}); Yahya et al. 2019), but by far greater than in the Zegie Peninsula (3318 ha^{-1}) (Bongers et al. 2006), Harenna (8937 ha^{-1}) and Maji forest (7273 ha^{-1}) (Feyera 2006). This variation might be due to methodological differences in the vegetation survey or to better protection of the forest system.

According to the comparisons made on the IVI of species for all forest types in the present study, few species were found with higher values, which imply they are the most important species in the study area. For instance, 71% of a species in the church, 83% in the government and 76% of the private forests contributed to the IVI of their respective forest systems. In church and government forests, *J. procera* is by far the most important tree species because of management by nature and by monastery community planting and maintaining the plants within the forests. On the other hand, shrubs were much more important within the church forest, as compared to the government and private forests in which they were deliberately harvested to promote growth of *C. spinarum*. However, the high IVI of a few small trees in the forest ecosystems was due to the abundance of their seedlings within the forests.

In all the forest ecosystems, the aggregate pattern of forest structure indicates a high number of individuals in the lower size classes with far fewer individuals in the higher classes. An almost similar inverted J-shape was reported for the Zegie Peninsula (Alelign et al. 2007). Thus, such a population structure gives the forest stands a more or less inverted J-shape, indicative of good reproduction and recruitment potential. However, the population structures of individual woody species depict different patterns. For instance, *C. spinarum* is among the species in the church forest that have an inverted J-shape. *J. procera* and *O. europaea* in the church forest and *A. abyssinica* in the government forest depict a broken J-shape population, which shows hampered regeneration and good recruitment. The J-shape population structure of *C. macrostachyus* in the government forest and *D. viscosa* in the private forest shows the effect of selective removal of medium-sized trees.

Conclusion

The forest systems in the study area are affected by different drivers such as human activities and management applications by the respective owners. The forest systems differ in the potential to support the diversity of woody species. Although none of the forest systems are enclosed, the church forest is properly demarcated and is not easily accessed due to its natural steep slope. Thus, religious sites, including Church forests in Ethiopia have been playing incredible roles in biodiversity conservation, in addition to environmental, cultural and social benefits. However, fuel-wood collection, illegal tree cutting for burial preparation and deforestation by local residents are threatening the church forest. Thus, Debre Libanos, a religious area that consists of relatively diversified tree species and associated animals urgently needs a management plan.

Furthermore, the present study revealed that the diversity of tree species in the government and private forests around Debre Libanos forest is decreasing due to human induced activities within and around the forests. On the other hand, the seedling and the sampling composition of the church and private forests was better than in the government forest where charcoal production and free grazing are so severe. Thus, the church forest has relatively higher regeneration likely due to church management activities by the church administration.

The dominance of older native trees species in the church forest is due to the conservation of indigenous tree species by the church, and these trees are the most important in that forest based on the IVI results. However, from the foregoing discussion, the forest requires better management so that its resources can be sustainably utilized. For the sustaining the forests in the study area, we recommend:

- Church, government and private forest should be included in the development of a strategic plan for regional forest management.
- The intervention of the government to manage the church forest in collaboration with the church administration is important to ensure sustainability of the church forest.
- The church forest should be considered as important biodiversity hot spots warranting conservation to gain due attention to developing a long-term management plan.

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