Chapter 10
Woody Vegetation Composition and Structure of Church Forests in Southeast of Lake Tana, Northwest Ethiopia

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Abstract Understanding woody plant species composition and structure is fundamental to design and optimize the needed conservation measures for Ethiopian church forests. The aim of this study was to describe the composition, structure, and regeneration status of woody species in church forests in southeast of Lake Tana, Ethiopia. Data were collected from twenty-four church forests. Four plots (20 m × 20 m) were established in each church forest. Plots were located in four cardinal directions (north, east, west, and south) at different distances from the forest center. Four subplots (5 m × 5 m) were established in each plot to assess seedlings and canopy cover. In each plot, all woody plants were identified and counted, and diameter at breast height (DBH) was measured. Species and family importance values were computed to characterize the species composition. Additionally, population structural

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features were analyzed through the variation of tree size classes. Species richness (SR), Pilou evenness (J'), and Shannon–Wiener index (H') were used to determine species diversity. A total of 115 woody species representing 53 families and 97 genera were found. Of these, 62% were trees, 36% shrubs, 1.89% climber, and 0.06% reed species. Species richness differed among forests, ranging between 16 and 38 species. Fabaceae, Sapotaceae, and Rubiaceae were the dominant families with a high family importance values of 41, 28, and 22, respectively. The church forests have relatively high indices of species diversity ($SR = 26 \pm 1.25$), ($J' = 0.75 \pm 0.02$), and ($H' = 2.42 \pm 0.07$), indicating that they play a major role in the conservation of woody species. However, a relatively high densities of *Eucalyptus* spp. ranging from 13 to 1925 individuals ha^{-1} were recorded, and these exotic tree species, thus, form a potential threat to the conservation of native species. The diameter class distribution of some selected keystone and dominant species formed four main shape types, of which the irregular-shaped pattern was most predominant, which suggests missing cohorts and regeneration problems for most species. Higher densities of *Eucalyptus* plantations were recorded in more recently established than old church forests. Therefore, effective measures should be taken to address the major pressures, such as plantation of exotic species that negatively affect the species composition and vegetation structure of these church forests, which, in turn, affect their ecosystem functions and services.

Keywords Biodiversity · Conservation · Fragmentation · Native species · Exotic species · Sacred grove

10.1 Introduction

Forests play a significant role in providing multiple ecosystem services, such as climate change mitigation. However, due to anthropogenic and natural factors, forest cover has drastically declined worldwide (Contreras-Hermosilla 2000). Similarly, Ethiopia has suffered drastic historical deforestation. Logan (1946) reported that only 5% of the Ethiopian highlands were forested in 1946, suggesting that deforestation started a long time ago. The forest cover, particularly in the highlands of northern Ethiopia, has continued to decline (Darbyshire et al. 2003; Nyssen et al. 2004). For example, in Lake Tana Basin, during the mid-twentieth century, about 20% of the area was covered with woody vegetation, while only about 10% remained by 2014–16 (Frankl et al. 2019). The rapid human population growth is the main driving force that is responsible for the loss of forests (Bishaw 2001). Agricultural expansion, urbanization, free grazing, and unsustainable development activities are the major pressures that intensify deforestation and forest degradation (Hailu et al. 2015). Consequently, the forest coverage is fragmented to small patches, particularly in the central and northern highlands of Ethiopia. In most parts of the northern highlands, patchy remnants of natural forests are found almost only surrounding churches (Gashaw et al. 2015).

Ethiopian church forests provide essential ecosystem services and support diverse plant and animal species, including endangered indigenous tree species (Aerts et al. 2006; Bongers et al. 2006; Reynolds et al. 2017; Morgan et al. 2018). Furthermore, church forests serve as a habitat for many insects and animals, such as birds and mammals (Wassie et al. 2005a, b; Scull et al. 2017). Several studies (Nyssen et al. 2004; Aerts et al. 2006, 2016; Wassie et al. 2009a, b; Wassie et al. 2010; Aynekulu et al. 2011; Woldemedhin and Teketay 2016; Abiyot et al. 2017; Morgan et al. 2018) have investigated the species composition and tree community structure of Ethiopian church forests, their role for biodiversity conservation, and the associated conservation challenges. For example, in Amhara region, Woldemedhin and Teketay (2016) documented 56 woody species from nine church forests in West Gojjam, while Morgan et al. (2018) and Wassie et al. (2010) reported 47 from 11 church forests and 168 woody species from 28 church forests in the northern part of the region, respectively. The recorded species were mainly indigenous trees, indicating the high conservation value of Ethiopian church forests. Reynolds et al. (2015) reported that there are more than 8000 church forests across the Amhara National Regional State (NRS); however, if also small church forests are included, the current number of church forests in the NRS could be much higher than this report. Therefore, there is no doubt that church forests in the NRS are playing a significant role in woody species conservation.

Many indigenous trees and shrubs, which are exterminated in some localities, are still found in the compounds of churches (Wassie et al. 2005a). Protection of a large network of small church forests can be more effective for biodiversity conservation compared with the conservation of a few large patches of an equivalent area (Bhagwat and Rutte 2006; Dudley et al. 2009; Hokkanen et al. 2009; Aerts et al. 2016). This is due to the fact that the large network of small church forests covers a wide variety of habitat, located in different agroecological zones and managed by the respective parish. The significant role of small forest patches, such as church forests to the conservation of overall species diversity and structure, was also described by Teketay et al. (2018). However, pressures, such as free grazing, fuelwood harvesting, woody species removal to construct church buildings or expand burial sites, have been negatively affecting the species composition, community structure, and natural regeneration rate of church forests in northern Ethiopia (Reynolds et al. 2017; Wassie et al. 2009a, 2010). Furthermore, plantation of fast-growing and ornamental exotic species inside the church forests, such as *Cupressus lusitanica*, *Citrus* spp., *Eucalyptus* spp., *Grevillea robusta*, *Jacaranda mimosifolia*, *Melia azedarach*, *Pinus* spp., is strongly affecting species composition and community structure of church forests (Aerts et al. 2016; Cardelu's et al. 2019).

In general, these pressures could not only alter the ecological processes and functions of the church forests ecosystem, but also affect the ecosystem services that these church forests provide to the local community. Thus, to combat these pressures and maintain the existing ecosystem services, church forests should be supported in different ways. While stonewall construction around church forests can be a very effective management strategies to overcome the effect of free grazing (Wassie et al. 2009a; Woods et al. 2017), a proper understanding of species composition, structure, and regeneration status of church forests is required to draft long-term management plans.

In the southeast of Lake Tana located in the Amhara NRS, there is little information about the species composition and conservation status in the church forests, except for four church forests (i.e., Emashenekure Giworegis, Gebesiwit Mariyam, Wej Aregawi, and Zahara Mikael) that were assessed by Wassie et al. (2010). Furthermore, almost a decade has passed since the assessment made by Wassie et al. (2010), and, hence, the species composition and structure of the church forests have likely changed over time. To fill this important knowledge gap, we studied the composition, structure, and the regeneration status of woody species, in a network of 24 church forests located in the southeast of Lake Tana.

10.2 Materials and Methods

10.2.1 Description of the Study Area

The Lake Tana Basin has an area of 15,089 km^2 with an elevation ranging from 1782 to 4109 m above and located in the northwest highlands of Ethiopia (Lemma et al. 2018). This study was conducted in the lower elevations in southeast of Lake Tana between Bahir Dar and Debre Tabor (1794–2204 m). The main land use and land cover types are natural forests, bushland, plantation forest, urban, village, cultivated land, waterbody, wetland, woodlands, and grassland (Song et al. 2018). Cultivated land (62%) is the major land use type, followed by water bodies (20%). However, the forest cover, including plantation and woodlands, is only 5% (Song et al. 2018). This area experiences a strong seasonal rainfall regime (about 70–90% of the total rainfall occurs during June–September), but a very even monthly temperature regime (Peel et al. 2007). The annual average rainfall varies between 1250 and 1500 mm, and the mean annual temperature varies between 15.3 and 19.6 °C (Lemma et al. 2018). A total of 24 church forests located between 37° 27′ E–37° 55′ E and 11° 39′ N–11° 56′ N were selected in the southeast of Lake Tana (Table 10.1; Fig. 10.1). Church forest selection was based on accessibility, distance between the consecutive church forests (a minimum of 4 km) and variability of the surrounding matrix in the radius of 3 km. The surface area of the church forests ranged from 2 to 13 ha, and the churches in the forests were established between 340 and 2010 (EOTC, no date).

Table 10.1 List of the 24 church forests of this study with their names, abbreviations, districts, and numbers on the study area map

Church name	Abbreviation	Year of establishment	District	Number on study area map (Fig. 10.1)
Aba Gerima Mariyam	AG	1458	Bahir Dar Zuriya	2
Deber Kusekuam	DK	1008	Fogera	18
Delemo Tekelehayemanot	DT	1682	Fogera	13
Emashenekure Giworegis	ES	1660	Dera	7
Fisa Mikael	FM	1537	Dera	5
Gebesiwit Mariyam	Gma	1250	Dera	10
Hager Selam Mariyam	HSM	1363	Fogera	19
Kirekus	K	1983	Dera	12
Kulela Mesekel	KM	1422	Dera	4
Kudese Minas	Kmi	2004	Bahir Dar Zuriya	3
Meneguzer Eyesus	ME	1682	Fogera	17
Qere Giweregis	QG	1657	Fogera	16
Qere Mikael	QM	1682	Fogera	15
Robit Bat	RB	1361	Bahir Dar Zuriya	1
Seneko Medaniyalem	SeM	1682	Fogera	23
Siraba Mariyam	SiM	1563	Fogera	24
Sheleku Medaniyalem	SM	1270	Fogera	20
Shena Tekelehayemanot	ST	1682	Fogera	14
Tiwaz Abo	TA	2010	Fogera	21
Wenechet	W	340	Dera	9
Wej Aregawi	WA	1883	Fogera	22
Weyebela Kidanemehert	WK	1422	Dera	8
Zajor Mikael	ZA	1422	Dera	6
Zahara Mikael	ZM	343	Dera	11

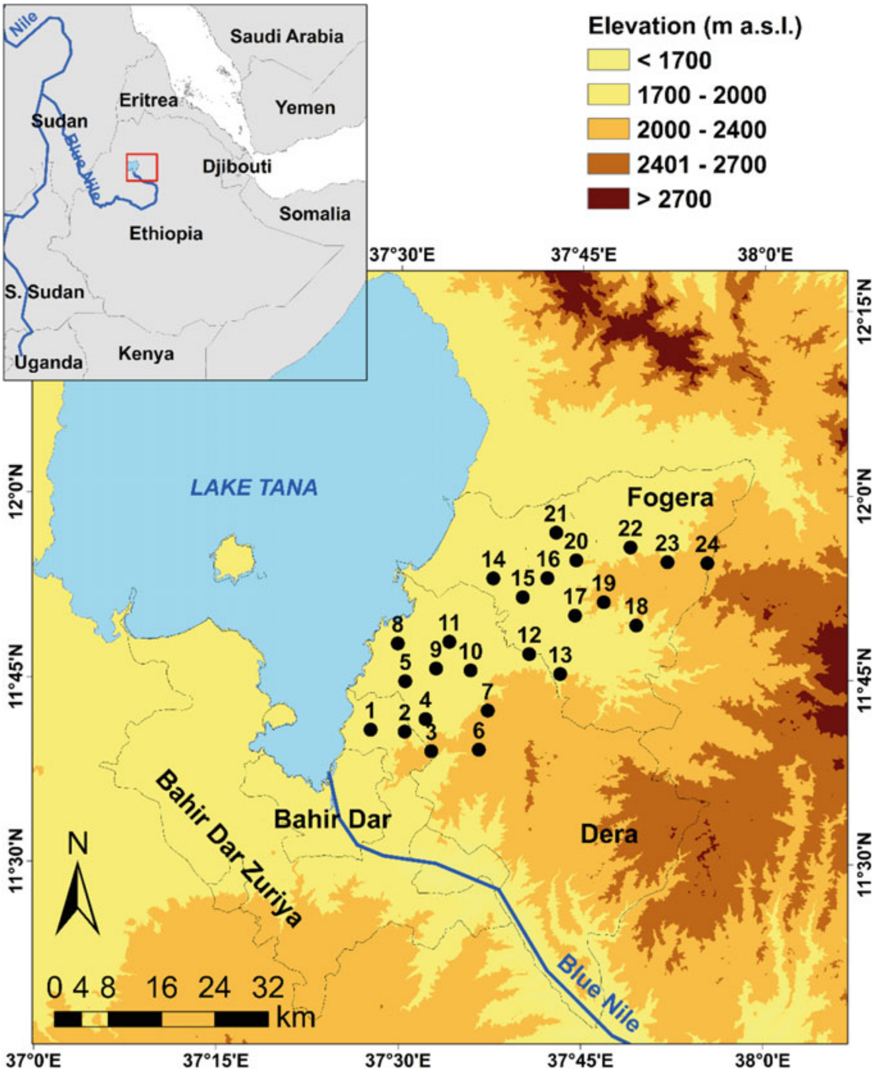

Fig. 10.1 Map of southeast of Lake Tana. Black dots and the respective numbers indicate the location and serial number of the selected 24 church forests, respectively

10.2.2 Sampling and Data Collection Methods

10.2.2.1 Vegetation Composition and Structure Survey

In each church forest, four sampling plots were systematically established in four cardinal directions (north, east, west, and south), but at different distances along the axis from the church buildings to edge of the compound (Fig. 10.2). The starting

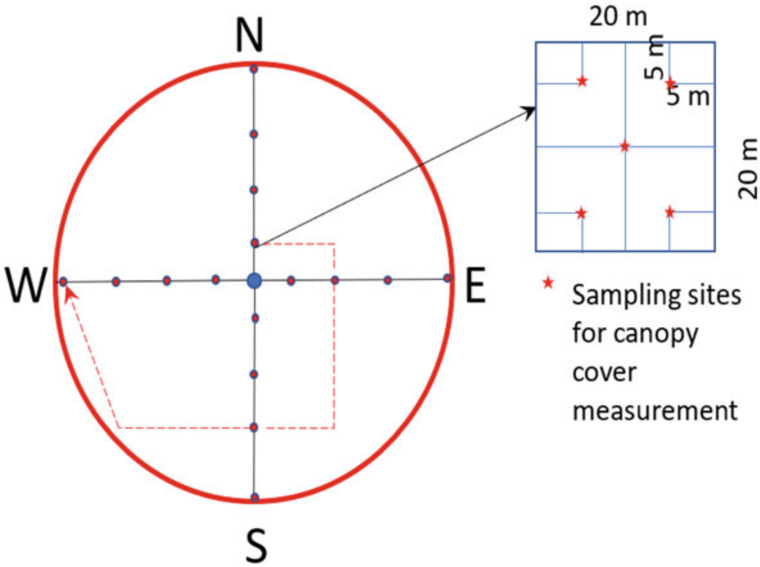

Fig. 10.2 Diagram showing sampling plot selection

direction was selected randomly and continued in a clockwise direction. A total of 96 plots with a size of 20 m × 20 m were established to identify mature and saplings individuals of the woody species. In each of the sampling plots, all woody species were identified, counted, and measured. Diameter at breast height (DBH) was measured using a diameter tape. When the height of the plant was greater than 1.6 m, DBH was measured at 1.3 m above ground level, but for smaller plants greater than 1 m, the diameter was measured at 10 cm above the ground. For trees containing buttressed stems, the DBH was measured above the buttress, and for multiple stems, all stems were counted and measured (Wassie et al. 2010). Woody plants less than 1 m height were considered as seedlings, and to score their presence and abundance, 5 m × 5 m plots were established at each corner of the large sampling plots. Identification was done to species level using identification keys (Bekele-Tesemma 2007). Species that were difficult to identify were identified in the National Herbarium Museum at Addis Ababa University. Plant nomenclature used in this article is based on the published guidelines of the Flora of Ethiopia and Eritrea, Vol. 1–8 (1989–2009) (Edwards et al. 1995, 1997; Edwards 1997; Hedberg et al. 2003). The recently updated nomenclature for *Acacia* spp. was also used (Kyalangalilwa et al. 2013). Lastly, the percent of canopy cover was measured using a convex mirror densiometer at four points within each of the main plots, and the average recording was used for each sampling plot. Maximum plant height within a church forest was taken as maximum forest height.

10.2.3 Data Analyses

The species diversity was analyzed using species richness (SR), evenness (J'), and Shannon–Wiener (H′) diversity index (Peet 1974). The relative dominance, density, frequency (Appendix 1), and diversity of each woody species and family at each church forest were computed using the equations described in Table 10.2. These values were used to calculate the importance value index (IVI) and family importance values (FIV) of woody species of each church forest in southeast of Lake Tana (Table 10.2). The IVI and FIV values range between 0 and 300. Species and families with high IVI and FIV values are considered more important ecologically than those with low IVI and FIV values, respectively.

In addition, the demographic structure of some selected keystone and dominant species was assessed using the frequency of individuals per diameter class (1–11 classes). The diameter classes were established with the range of 5 cm DBH. Demographic structural shapes such as I shape, J shape, and irregular shape show unfavorable forest structure, while broken reversed J shape indicates a healthy forest structure with continuous regeneration and ingrowth of cohorts (Alelign et al. 2007; Zegeye et al. 2011; Tadele et al. 2014). The dominant species are species that are very well represented in the church forests, whereas the keystone species are those which have social and ecological importance to local people (Wassie et al. 2009b; Gebeyehu et al. 2019): *Juniperus procera, Olea europaea, Podocarpus falcatus, Prunus africana, Ekebergia capensis* and *Mimusops kummel*.

Table 10.2 Structural measurements and formulae used for their calculation (Mueller and Ellenberg 1975; Mori et al. 1983)

Structural measurement	Equation (%)
Relative dominance	Total basal area of a species/total basal area of all species × 100
Relative density	Number of individuals of a species/total number of individuals × 100
Relative frequency	Frequency of a species/sum of all species frequencies × 100
Relative diversity	Number of a species in a family/total number of species × 100
Importance value index (IVI)	Relative dominance + relative density + relative frequency
Family importance value (FIV)	Relative dominance + relative density + relative diversity

10.3 Results

10.3.1 Species Richness, Evenness, and Diversity

A total of 115 woody species belonging to 53 families and 97 genera were identified in the 24 church forests studied, and the number of woody species ranged from 16 to 38 species per church forest (Tables 10.3 and 10.4). Of these species, 62% (n = 6268) were trees, 36% (n = 3571) were shrubs, 1.89% (n = 190) were climbers, and 0.06% (n = 6) were reed. The Kudese Minas (Kmi, 3 in Fig. 10.1) church forest had the highest number of species and genus, while Deber Kusekuam (DK, 18 in Fig. 10.1) church forest contained the lowest number of species and genus (Table 10.3).

The Kudese Minas (Kmi, 3 in Fig. 10.1) church forest had the highest number of families, while Qere Giweregis (QG, 16 in Fig. 10.1) church forest contained the lowest number of families (Table 10.3). The families with the highest number of species were Fabaceae (n = 17) followed by both Rubiaceae (n = 8) and Euphorbiaceae (n = 8). Oleaceae was represented by five species, whereas the remaining families were represented by ≤ 4 species (Table 10.4).

The overall evenness ($J' = 0.75 \pm 0.02$) and Shannon diversity index ($H' = 2.42 \pm 0.07$) of woody species were recorded in all church forests (Table 10.5). Both Delemo Tekelehayemanot (DT, 13 in Fig. 10.1) and Gebesiwit Mariya (Gma, 10 in Fig. 10.1) church forests had higher evenness than others, while church forest Kudese Minas (Kmi, 3 in Fig. 10.1) had higher Shannon diversity than other church forests. The lowest evenness and diversity were recorded at Wenechet (W, 9 in Fig. 10.1) church forest (Table 10.5).

10.3.2 Stand Structure of the Church Forests

Species and family importance ranged from 2 to 118% and 3% to 117%, respectively. The most ecologically important woody species (IVI) and families (FIV) differed between church forests (Tables 10.6 and 10.7). For example, the top three woody species in Aba Gerima Mariyam (AG, 2 in Fig. 10.1) church forest were *Millettia ferruginea* (IVI = 46%), *Ficus thonningii* (IVI = 39%), and *Grevillea robusta* (IVI = 25%), while *Mimusops kummel* (IVI = 97%), *Diospyros abyssinica* (IVI = 22%), and *Ocimum lamiifolium* (IVI = 21%) were the top three woody species in Zahara Mikael (ZM, 11 in Fig. 10.1) church forest (Table 10.6). Similarly, Fabaceae (63%), Moraceae (40%), and Proteaceae (24%) had the highest FIV values at Aba Gerima Mariyam (AG, 2 in Fig. 10.1) church forest while, Sapotaceae (93%), Rubiaceae (39%), and Fabaceae (26%) had the highest FIV values at Zahara Mikael (ZM, 11 in Fig. 10.1) church forest (Table 10.7).

The canopy cover of woody tree species at each church forest ranged from 37 to 83% with a mean of 59%. Kudese Minas (Kmi, 3 in Fig. 10.1) and Robit Bat (RB, 1

Table 10.3 Name of church forests, numbers of families, genera, species, canopy cover, and maximum height of the 24 church forests in the southeast part of Lake Tana (see full names of the churches in Table 10.1 and church forest numbers in Fig. 10.1)

Name	Family	Genera	Species richness	Canopy cover (%)	Maximum height (m)
Church name					
AG (2)[a]	24	30	30	58	32
DK (18)	12	16	16	67	30
DT (13)	17	21	21	42	25
ES (7)	21	25	27	54	27
FM (5)	20	28	29	54	30
Gma (10)	14	19	21	62	22
HSM (19)	15	18	19	67	30
K (12)	19	34	37	42	30
KM (4)	19	25	26	62	19
Kmi (3)	29	38	38	83	30
ME (17)	16	17	17	46	30
QG (16)	11	17	17	67	25
QM (15)	15	17	17	58	30
RB (1)	16	22	22	83	32
SeM (23)	21	27	29	42	27.3
SiM (24)	19	25	27	67	37
SM (20)	21	30	31	79	20
ST (14)	19	21	23	42	30
TA (21)	14	22	22	37	20
W (9)	19	24	24	62	35
WA (22)	22	29	30	62	25
WK (8)	22	31	31	58	42
ZA (6)	19	27	28	71	40
ZM (11)	21	30	30	62	30
Statistics					
Mean	19	25	26	59	29.09
Standard error	0.82	1.20	1.25	2.64	1.19
Minimum	11	16	16	37	19
Maximum	29	38	38	83	42
Statistics					
Total	53	97	115		

[a] Numbers in brackets indicate number of churches in Map 1

Table 10.4 Number of genera and species within families arranged alphabetically

Family name	Number of genera	Number of species
Acanthaceae	2	3
Anacardiaceae	2	4
Apocynaceae	2	2
Aquifoliaceae	1	1
Araliaceae	1	1
Arecaceae	1	1
Asteraceae	2	3
Bignoniaceae	1	1
Boraginaceae	2	2
Cactaceae	1	1
Capparidaceae	2	2
Casuarinaceae	1	1
Celastraceae	2	2
Combretaceae	1	1
Cupressaceae	2	2
Dracaenaceae	1	1
Ebenaceae	2	2
Euphorbiaceae	6	8
Fabaceae	13	17
Flacourtiaceae	2	2
Icacinaceae	1	1
Iridaceae	1	1
Lamiaceae	3	3
Lauraceae	1	1
Loganiaceae	1	1
Malvaceae	2	2
Meliaceae	3	3
Melianthaceae	1	1
Moraceae	1	4
Myricaceae	1	1
Myrtaceae	3	4
Olacaceae	1	1
Oleaceae	3	5
Phytolaccaceae	1	1
Pittosporaceae	1	1
Poaceae	1	1
Podocarpaceae	1	1

(continued)

Table 10.4 (continued)

Family name	Number of genera	Number of species
Proteaceae	1	1
Ranunculaceae	1	1
Rhamnaceae	1	1
Rhizophoraceae	1	1
Rosaceae	1	1
Rubiaceae	7	8
Rutaceae	3	4
Santalaceae	1	1
Sapindaceae	1	1
Sapotaceae	1	1
Simaroubaceae	1	1
Solanaceae	1	1
Sterculiaceae	1	1
Tiliaceae	1	1
Ulmaceae	1	1
Urticaceae	1	1

in Fig. 10.1) church forests had the highest canopy cover, while Tiwaz Abo (TA, 21 in Fig. 10.1) church forest had the lowest canopy cover. More than half of the church forests had a canopy cover greater than 59% (Table 10.3).

The diameter class distribution of some selected keystone and dominant species revealed four types of demographic structures. The four types of structures were broken reversed J shape, I shape, J shape, and irregular shape. The broken reversed J-shaped pattern was composed of a high number of individuals in the lowest diameter classes and progressively declining numbers in the highest diameter classes with an almost complete absence in the highest diameter classes. This pattern was, for example, exhibited by *Juniperus procera* at Delemo Tekelehayemanot (DT, 13 in Fig. 10.1), *Mimusops kummel* at Hager Selam Mariyam (HSM, 19 in Fig. 10.1) and Weyebela Kidanemehert (WK, 8 in Fig. 10.1), *Prunus africana* at Kudese Minas (Kmi, 3 in Fig. 10.1), and *Ekebergia capensis* at Kudese Minas (Kmi, 3 in Fig. 10.1) church forests.

The I-shaped pattern was formed when the numbers of individuals of a species were only presented in one of the eleven classes. *Juniperus procera* at Fisa Mikael (FM, 5 in Fig. 10.1), Hager Selam Mariyam (HSM, 19 in Fig. 10.1), Meneguzer Eyesus (ME, 17 in Fig. 10.1), Wenechet (W, 9 in Fig. 10.1) church forests, and *Mimusops kummel* at Emashenekure Giworegis (ES, 7 in Fig. 10.1) church forest were some of the species that showed I-shaped pattern.

J shape was composed of small numbers of individuals at the lowest classes and gradually increasing numbers at the highest diameter classes, and this pattern was represented by *Juniperus procera* at Wej Aregawi (WA, 22 in Fig. 10.1), *Olea*

Table 10.5 Mean, standard error, minimum, and maximum diversity values of woody species encountered in the 24 church forests in southeast of Lake Tana (see full names of the churches in Table 10.1)

Church forest name	Species richness	Shannon diversity (H′)	Pilou evenness (Jv)
Church name			
AG	30	2.9	0.85
DK	16	2.21	0.8
DT	21	2.78	0.91
ES	27	2.2	0.67
FM	29	2.36	0.7
Gma	21	2.77	0.91
HSM	19	2.62	0.89
K	37	2.76	0.77
KM	26	2.48	0.76
Kmi	38	3.08	0.85
ME	17	2.36	0.83
QG	17	2.19	0.77
QM	17	1.78	0.63
RB	22	2.36	0.76
SeM	29	2.49	0.74
SiM	27	2.35	0.71
SM	31	2.6	0.76
ST	23	2.27	0.72
TA	22	2.01	0.65
W	24	1.64	0.52
WA	30	1.97	0.58
WK	31	2.79	0.81
ZA	28	2.4	0.71
ZM	30	2.67	0.78
Mean	26	2.42	0.75
Standard error	1.25	0.07	0.02
Minimum	16	1.64	0.52
Maximum	38	3.08	0.91

europaea at Deber Kusekuam (DK, 18 in Fig. 10.1), and Gebesiwit Mariyam (Gma, 10 in Fig. 10.1) church forests. The irregular shape was formed when there was a complete absence of individuals in some diameter classes and a fair representation of individuals in other classes. *Juniperus procera* exhibited irregular-shaped pattern at Emashenekure Giworegis (ES, 7 in Fig. 10.1), Gebesiwit Mariyam (Gma, 10 in Fig. 10.1), Kirekus (K, 12 in Fig. 10.1), Kulela Mesekel (KM, 4 in Fig. 10.1), Siraba Mariyam (SiM, 24 in Fig. 10.1), Shena Tekelehayemanot (ST, 14 in Fig. 10.1), Zajor Mikael (ZA, 6 in Fig. 10.1), and Zahara Mikael (ZM, 11 in Fig. 10.1) church

Table 10.6 Importance value index (IVI) of the top three species encountered in the 24 church forests. Species are listed in rows and church forests in columns (see full names of churches in Table 10.1)

Species	AG	DK	DT	ES	FM	Gma	HSM	K	KM	Kmi	ME	QG
Acokanthera schimperi	–	–	–	–	46	–	–	–	–	–	–	–
Albizia schimperiana	–	–	24	–	–	–	–	–	–	32	–	–
Calpurnia aurea	–	–	–	–	–	–	–	–	–	–	–	–
Carissa spinarum	–	–	–	–	–	–	–	36	–	–	–	–
Celtis africana	–	–	–	–	–	–	–	–	–	–	32	–
Clausena anisata	–	33	–	–	–	–	–	–	–	–	–	–
Coffea arabica	–	–	–	–	–	–	–	–	–	–	–	–
Cordia africana	–	–	21	–	–	–	–	–	91	–	–	–
Croton macrostachyus	–	–	–	–	–	19	–	–	–	43	–	47
Diospyros abyssinica	–	–	–	–	41	23	–	–	–	–	–	–
Dodonaea angustifolia	–	–	–	–	–	–	–	23	–	–	–	–
Dracaena steudneri	–	–	–	–	–	–	30	–	–	–	–	–
Erythrina abyssinica	–	–	–	–	–	–	–	–	–	–	–	–
Eucalyptus camaldulensis	–	–	–	–	–	–	–	66	–	–	–	–
Euphorbia tirucalli	–	–	–	–	–	–	–	–	41	–	–	54
Ficus thonningii	39	–	64	–	–	–	52	–	–	–	–	–
Ficus vasta	–	–	–	–	–	–	–	–	–	–	–	–
Flueggea virosa	–	–	–	–	–	–	–	–	–	–	–	–
Grevillea robusta	25	–	–	–	–	–	–	–	–	–	–	–
Grewia ferruginea	–	–	–	–	–	–	–	–	23	–	–	–
Juniperus procera	–	–	–	45	–	–	–	–	–	–	–	–
Maytenus arbutifolia	–	–	–	–	–	–	–	–	–	–	–	–
Millettia ferruginea	46	46	–	–	–	–	–	–	–	25	–	44
Mimusops kummel	–	–	–	–	32	87	–	–	–	–	87	–
Ocimum lamiifolium	–	–	–	–	–	–	–	–	–	–	–	–
Olea capensis	–	–	–	–	–	–	–	–	–	–	–	–
Olea europaea	–	73	–	–	–	–	–	–	–	–	–	–
Pavetta abyssinica	–	–	–	–	–	–	–	–	–	–	43	–
Ritchiea albersii	–	–	–	–	–	–	–	–	–	–	–	–
Rothmannia urcelliformis	–	–	–	48	–	–	–	–	–	–	–	–
Teclea nobilis	–	–	–	36	–	–	54	–	–	–	–	–
Vernonia myriantha	–	–	–	–	–	–	–	–	–	–	–	–
Species	QM	RB	SeM	SiM	SM	ST	TA	W	WA	WK	ZA	ZM
Acokanthera schimperi	–	–	–	–	–	–	–	–	42	–	–	–
Albizia schimperiana	–	–	–	–	–	–	–	–	–	28	–	–

(continued)

Table 10.6 (continued)

Species	QM	RB	SeM	SiM	SM	ST	TA	W	WA	WK	ZA	ZM
Calpurnia aurea	35	–	–	45	–	–	–	–	–	–	–	–
Carissa spinarum	–	–	–	–	–	–	–	–	–	–	–	–
Celtis africana	–	–	–	52	–	–	–	–	–	–	–	–
Clausena anisata	–	–	–	–	–	–	–	–	–	–	–	–
Coffea arabica	–	40	–	–	–	–	–	54	–	–	–	–
Cordia africana	–	–	–	–	38	25	–	–	–	–	–	–
Croton macrostachyus	–	–	20	–	37	–	–	–	–	25	–	–
Diospyros abyssinica	–	–	–	–	–	–	–	–	–	–	–	22
Dodonaea angustifolia	–	–	–	–	–	–	–	–	–	–	–	–
Dracaena steudneri	–	–	–	–	–	–	–	–	–	–	–	–
Erythrina abyssinica	–	–	–	–	–	–	17	–	–	–	–	–
Eucalyptus camaldulensis	59	–	–	–	–	118	109	–	–	–	–	–
Euphorbia tirucalli	–	–	–	–	–	–	–	–	–	–	–	–
Ficus thonningii	46	–	–	–	–	–	–	–	–	–	–	–
Ficus vasta	–	–	73	–	–	–	–	39	52	–	–	–
Flueggea virosa	–	–	–	–	–	–	20	–	–	–	–	–
Grevillea robusta	–	–	–	–	–	–	–	–	–	–	–	–
Grewia ferruginea	–	–	–	–	–	25	–	–	–	–	–	–
Juniperus procera	–	–	–	–	–	–	–	–	37	–	80	–
Maytenus arbutifolia	–	–	–	–	33	–	–	–	–	–	–	–
Millettia ferruginea	–	27	–	–	–	–	–	–	–	35	–	–
Mimusops kummel	–	85	–	–	–	–	–	–	–	–	–	97
Ocimum lamiifolium	–	–	–	–	–	–	–	–	–	–	–	21
Olea capensis	–	–	–	30	–	–	–	–	–	–	–	–
Olea europaea	–	–	–	–	–	–	–	–	–	–	–	–
Pavetta abyssinica	–	–	–	–	–	–	–	–	–	–	–	–
Ritchiea albersii	–	–	–	–	–	–	–	39	–	–	–	–
Rothmannia urcelliformis	–	–	–	–	–	–	–	–	–	–	28	–
Teclea nobilis	–	–	–	–	–	–	–	–	–	–	31	–
Vernonia myriantha	–	–	32	–	–	–	–	–	–	–	–	–

forests. Generally, of the total 57 species assessed, 28 and 21 revealed irregular-shaped and I-shaped structures, respectively, while only five and three showed broken reversed J-shaped and J-shaped structures, respectively. However, a single species exhibited different diameter class distribution patterns across the different church forests. For example, the diameter class distribution for *Mimusops kummel* was I

Table 10.7 List of families having woody species with the top three importance value indexes in the 24 church forests in southeast of Lake Tana (see full names of the churches in Table 10.1)

Family	AG	DK	DT	ES	FM	Gma	HSM	K	KM	Kmi	ME	QG
Apocynaceae	–	–	–	–	50	–	–	35	–	20	–	–
Asteraceae	–	–	–	–	–	–	–	–	–	–	–	–
Boraginaceae	–	–	–	–	–	–	–	–	88	–	–	–
Capparidaceae	–	–	–	–	–	–	–	–	–	–	–	–
Cupressaceae	–	–	21	56	–	–	–	–	–	–	–	–
Ebenaceae	–	–	–	–	40	27	–	–	–	–	–	–
Euphorbiaceae	–	–	–	–	–	–	–	–	63	46	–	110
Fabaceae	63	66	57	–	40	–	–	26	26	60	–	98
Lamiaceae	–	–	–	–	–	–	–	–	–	–	–	16
Meliaceae	–	–	–	–	–	–	–	–	–	–	–	–
Moraceae	40	–	63	38	–	27	54	–	–	–	–	–
Myrtaceae	–	–	–	–	–	–	–	69	–	–	–	–
Oleaceae	–	68	–	–	–	–	–	–	–	–	–	–
Proteaceae	24	–	–	–	–	–	–	–	–	–	–	–
Rubiaceae	–	–	–	58	–	–	47	–	–	–	34	–
Rutaceae	–	59	–	–	–	–	51	–	–	–	–	–
Sapotaceae	–	–	–	–	–	84	–	–	–	–	83	–
Tiliaceae	–	–	–	–	–	–	–	–	–	–	–	–
Ulmaceae	–	–	–	–	–	–	–	–	–	–	28	–
Family	QM	RB	SeM	SiM	SM	ST	TA	W	WA	WK	ZA	ZM
Apocynaceae	–	–	–	–	–	–	–	–	47	–	–	–
Asteraceae	–	–	31	–	–	–	–	–	–	–	–	–
Boraginaceae	–	–	–	–	38	–	–	–	–	–	–	–
Capparidaceae	–	–	–	–	–	–	–	41	–	–	–	–
Cupressaceae	–	–	–	–	–	–	–	–	34	–	80	–
Ebenaceae	–	–	–	–	–	–	–	–	–	–	–	–
Euphorbiaceae	–	–	–	–	50	–	29	–	–	–	–	–
Fabaceae	74	34	44	71	34	23	55	–	–	68	–	26
Lamiaceae	–	–	–	–	–	–	–	–	–	–	–	–
Meliaceae	–	–	–	–	–	–	–	–	–	–	32	–
Moraceae	44	–	80	–	–	–	–	41	63	–	–	–
Myrtaceae	57	–	–	–	–	117	105	–	–	–	–	–
Oleaceae	–	–	–	40	–	–	–	–	–	–	–	–
Proteaceae	–	–	–	–	–	–	–	–	–	–	–	–
Rubiaceae	–	59	–	–	–	–	–	54	–	30	44	39

(continued)

Table 10.7 (continued)

Family	QM	RB	SeM	SiM	SM	ST	TA	W	WA	WK	ZA	ZM
Rutaceae	–	–	–	–	–	–	–	–	–	43	–	–
Sapotaceae	–	83	–	–	–	–	–	–	–	–	–	93
Tiliaceae	–	–	–	–	–	23	–	–	–	–	–	–
Ulmaceae	–	–	–	48	–	–	–	–	–	–	–	–

Table 10.8 List of church forests and the total number of species recorded with the numbers and proportions of species with important value index of <5% in the 24 church forests in southeast of Lake Tana (see full names of the churches in Table 10.1)

Church name	Total number of species	Number of species (IVI < 5%)	Proportion of species (IVI < 5%) (in %)
ZA	29	17	59
KM	26	15	58
W	24	13	54
Kmi	38	20	53
SM	31	16	52
K	37	19	51
WA	30	15	50
FM	29	14	48
WK	31	14	45
ZM	30	13	43
SiM	27	11	41
ST	23	9	39
ES	27	10	37
AG	30	11	37
TA	22	7	32
SeM	29	9	31
RB	22	6	27
DK	16	4	25
Gma	21	5	24
QG	17	4	24
QM	17	4	24
HSM	19	4	21
ME	17	3	18
DT	21	3	14

shaped at Emashenekure Giworegis (ES, 7 in Fig. 10.1), broken reversed J shaped at Hager Selam Mariyam (HSM, 19 in Fig. 10.1), and irregular shaped at Wenechet (W, 9 in Fig. 10.1) church forests (Fig. 10.3).

10.3.3 Species Richness and Stand Structure of Exotic Species

Of the total 115 woody species, 18 were exotic species (one climber, three shrubs, and 14 trees). Exotic species occurred at 19 church forests with the range from one to four species per church forest. *Eucalyptus camaldulensis* was recorded at nine church forests (38%), followed by *Cupressus lusitanica* at seven church forests (29%), and *Grevillea robusta* at six church forests (25%). The remaining exotic species occurred at ≤ 3 church forests. Relatively high densities of *Eucalyptus* spp. ranging from 13 to 1925 individuals ha^{-1} were recorded. Of the exotic species, *Eucalyptus camaldulensis* had the highest IVI in Kirekus (K, 12 in Fig. 1, IVI = 66%), Qere Mikael (QM, 15 in Fig. 1, IVI = 59%), Shena Tekelehayemanot (ST, 14 in Fig. 1, IVI = 118%), and Tiwaz Abo (TA, 21 in Fig. 1, IVI = 109%) church forests. *Grevillea robusta* (IVI = 25%) and *Cupressus lusitanica* (IVI = 21%) exhibited the highest IVI values in Aba Gerima Mariyam (AG, 2 in Fig. 10.1) and in Kirekus (K, 12 in Fig. 10.1) church forests, respectively.

10.3.4 Species Richness of Seedlings

The seedlings of a total of 62 species (57 indigenous and five exotic) were identified, in the 24 church forests. Of these, 80%, 16%, and 4% were seedlings of trees, shrubs, and climbers, respectively. Species richness of seedlings varied among the 24 church forests, ranging from 2 to 31 species per church forest with a mean and standard error of 18 ± 1.61. *Ruta chalepensis* was the only species found at the seedling stage. Zahara Mikael (ZM, 11 in Fig. 10.1) church forest had the highest total number of seedlings (391,200 ha^{-1}), while the lowest number of seedlings (200 ha^{-1}) was recorded in Delemo Tekelhayemanot (DT, 13 in Fig. 10.1) church forest (Fig. 10.4). Among the total woody species recorded in the church forests, *Diospyros abyssinica* had the highest number of seedlings (38%), followed by *Mimusops kummel* (13%). In general, thirty-three species (29 indigenous and four exotic) exhibited low densities of seedlings 100–1700 ha^{-1} (53%), whereas four (three indigenous and one exotic), seven (all indigenous), and eighteen (all indigenous) species had 2100–3700 (7%), 4200–5900 (11%) and $\geq$7600 (29%) individuals ha^{-1}, respectively.

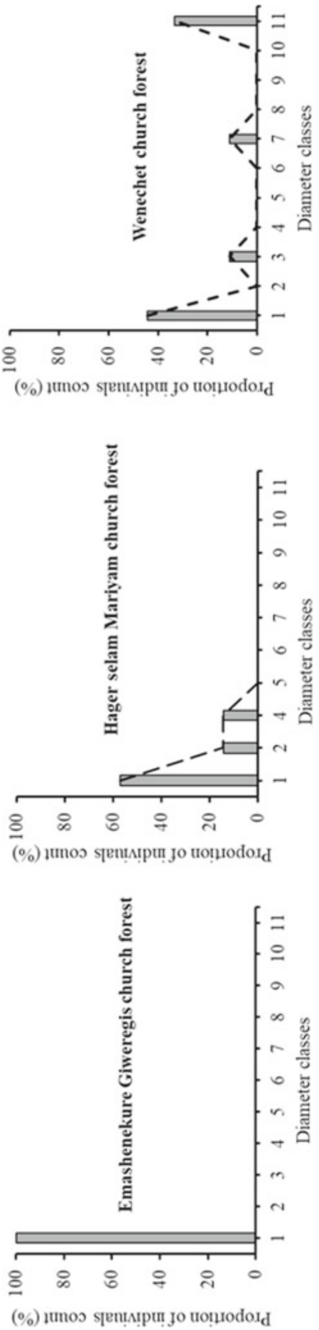

Fig. 10.3 Demographic structure of the dominant species *Mimusops kummel* in different church forests. Diameter classes: 1 = 0–5; 2 = 5–10; 3 = 10–15; 4 = 15–20; 5 = 20–25; 6 = 25–30; 7 = 30–35; 8 = 35–40; 9 = 40–45; 10 = 45–50; 11 ≥ 50 cm DBH

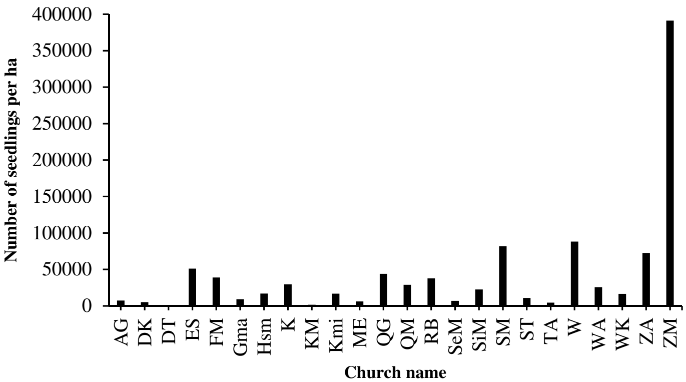

Fig. 10.4 Total number of seedlings recorded in each studied church forest in southeast of Lake Tana (see full names of the churches in Table 10.1)

10.4 Discussion

10.4.1 Species Richness, Evenness, and Diversity

In the present study, a total of 115 woody species were identified in the 24 church forests. Of the 24 church forests, four church forests (Emashenekure Giworegis, Gebesiwit Mariyam, Wej Aregawi, and Zahara Mikael) were already assessed by Wassie et al. (2010). The assessment methods were relatively similar to this study. However, except for Zahara Mikael (ZM, 11 in Fig. 10.1) church forest, the numbers of families and woody species we recorded were lower than what Wassie et al. (2010) found ten years earlier (Fig. 10.5). The continued presence of relatively high species richness at Zahara Mikael church forest was likely due to construction of stone wall since 2014, and this could avoid disturbance and increase the probability of recruitment of new seedlings. The reduction in number of woody species in the remaining three church forests could be a sign of increased disturbance from anthropogenic pressures. Among the different pressures, expansion of graveyard, second church buildings inside the church forest, plantation of exotic species, and free grazing were the major factors.

The negative effects of anthropogenic disturbances, including free grazing on woody species of church forests, particularly on seedlings, were reported by Wassie et al. (2009a). The level of disturbances, such as construction of additional church buildings, grave houses, and small house buildings where people organize themselves into associations to celebrate a chosen patron saint together *(mehabirs*) and grazing, has continuously increased in the study area (Cardelús et al. 2017; Orlowska and Klepeis 2018). Although, some species have always been rare, the presence of many species with IVI < 5% per church forest suggests that the disturbance is still ongoing. However, the presence of old remnant trees (i.e., rarely recorded trees with low IVI values) and those which are economically and ecologically important species, such as

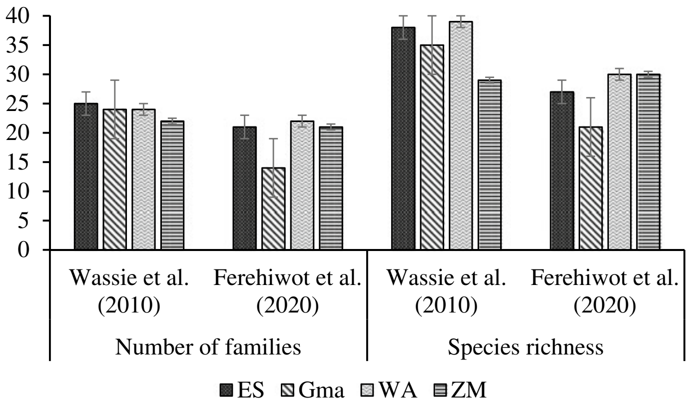

Fig. 10.5 Comparison of the number of families and species between results from Wassie et al. (2010) and the current study. The four church forests were Emashenekure Giworegis (ES, 7 in Fig. 10.1), Gebesiwit Mariyam (Gma, 10 in Fig. 10.1), Wej Aregawi (WA, 22 in Fig. 10.1), and Zahara Mikael (ZM, 11 in Fig. 10.1)

Juniperus procera, Olea europaea, Prunus africana, Podocarpus falcatus, Ekebergia capensis, Mimusops kummel, and *Cordia africana* in the compounds of churches, highlights the importance of church forests in southeast of Lake Tana for indigenous tree species and wildlife conservation similar to other sacred forests in the world (Bhagwat and Rutte 2006).

The Pilou evenness value ranges from 0 to 1, and values close to 1 indicate even representation of individuals of the occurring species in the area (Help et al. 1998). Except for Wenechet (W, 9 in Fig. 10.1) ($J = 0.52$) and Wej Aregawi (WA, 22 in Fig. 10.1) ($J = 0.58$) church forests, all church forests in the present study had evenness values (0.63 to 0.91), indicating even representation of the individuals of the occurring species in each church forest. Moreover, except for Qere Mikael ($H' = 1.78$), Wenechet ($H' = 1.64$), and Wej Aregawi ($H' = 1.97$) church forests, all church forests had Shannon diversity greater than two, which indicates medium to high species diversity (Giliba et al. 2011). The highest and lowest Shannon diversity values were recorded in Kudese Minas (Kmi, 3 in Fig. 10.1) and Wenechet (W, 9 in Fig. 10.1) church forests, respectively. In the present study, when more church forests were included, the number of newly described species increased (Fig. 10.6). Therefore, since we studied only 24 church forests out of many available church forests in the larger region of Lake Tana, more species richness and diversity could be recorded when more church forests are studied, owing to increases in the environmental heterogeneity. A similar explanation was also given by Wassie (2007).

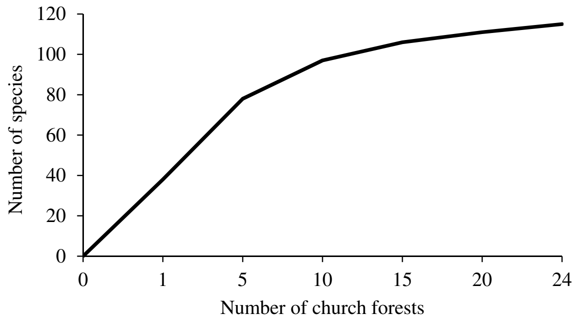

Fig. 10.6 The number of species as a function of the number of church forests inventoried

10.4.2 Demographic Structure of Woody Species in Church Forests

Investigating the IVI and FIV values are significant to understand the ecological importance of the species and families, respectively. The IVI and FIV values are good indicators to understand the current condition of the church forests since they provide important insights into the basal area, abundance, frequency, and relative diversity of the species in a particular forest area. In this study, fleshy-fruited tree species had the highest IVI in most church forests. The fruits of these species are indehiscent and consumed by a variety of birds and mammals. As these animals, particularly birds, move from one church forest to another before defecating the seeds, they could further promote seed dispersal between church forests. Therefore, this might be the probable reason why the fleshy-fruited tree species had high IVI values in different church forests. Furthermore, the highest IVI values of these species were due to their high frequency, abundance, and basal area values. The importance of woody species in a given area can be better explained by their basal area than simple stem count (Lamprecht 1989; Bekele 1994; Abyot et al. 2014; Meragiaw et al. 2018). The species that had the highest IVI values had large basal areas and, hence, could play a significant contribution to biodiversity conservation by providing habitat and food for frugivore birds and mammals as well as bee forage. However, several woody species at each church forest had low IVI values, indicating that most species had small basal areas, small numbers of individuals, and are generally rare in the church forests. For example, $\geq$50% of the woody species in seven church forests had IVI < 5%. The different anthropogenic disturbances in the study area could be the main reasons for the presence of many species with low IVI values, and this could likely affect their ecological significance. The rarity of these species could also be caused by other factors, such as their poor dispersal ability and competition for nutrients or other resources (Hubbell et al. 2001; Engelbrecht et al. 2007). Thus, woody species with a low IVI values require high conservation priority to maintain their composition and diversity.

The Fabaceae family had the highest FIV at five church forests, Sapotaceae at four church forests, and Rubiaceae at two church forests. Teketay et al. (2018) also reported that Fabaceae had the highest FIV value. The main reason why this family had the highest FIV value is likely due to its wide range of ecological adaptations. Although it was represented by only one species and small numbers of individuals, Sapotaceae had the second-highest FIV value in the study area. This is due to the fact that most individuals of this species had large basal area. Species with a large basal area (even though the density of the species is low) had more structural complexity and provide a lot of habitat for various species and also serve as shade for animals and human beings. Hence, Sapotaceae species could have significant ecological importance. They could also provide vital social values, as large trees are culturally and spiritually important in Ethiopian (Orlowska and Klepeis 2018).

The difference in canopy cover among the church forests was due to the relatively higher dominance of big old canopy tree species in some church forests than others. For example, the high canopy covers at Kudese Minas (Kmi, 3 in Fig. 10.1) and Robit Bat (RB, 1 in Fig. 10.1) church forests were due to the relative dominance of big old canopy trees such as *Albizia schimperiana, Croton macrostachyus, Millettia ferruginea,* and *Mimusops kummel.* However, Tiwaz Abo (TA) church forest had small canopy cover due to the relative dominance of *Eucalyptus camaldulensis* individuals, kept small by frequent harvesting or coppicing. According to Sabine and Miehe (1994), forests with > 80% canopy cover are considered as closed forests. Therefore, Kudese Minas (Kmi, 3 in Fig. 10.1) and Robit Bat (RB, 1 in Fig. 10.1) church forests are closed forests. However, in the present study, the majority of church forests had canopy cover <80% with a mean canopy cover of 59%, which implies that most church forests in the study area are open forests. The presence of low canopy cover in the church forests is an indication of the degradation of the primary forests to a shrubland. This could be due to anthropogenic disturbances, such as selective cutting of large canopy trees or natural disturbance due to the death of large canopy trees without any replacement. Although the death of large canopy trees in a natural system can be filled in by young trees, this was not the case in the studied church forests, probably, due to the succession being blocked by grazing or other disturbances, such as soil degradation. On the other hand, canopy cover is an indicator of the microclimate conditions that determine the species composition and structure. For example, temperature decreases with increasing canopy cover, with the greatest cooling when canopy cover exceeds 40% (Ziter et al. 2019), while light, soil water, and airflow exchange increases with decreasing canopy cover (Muscolo et al. 2014). Therefore, understanding the canopy cover is significant to conserve the old growth forests.

Based on the diameter class distribution analyses of the selected species, four types of demographic structure were revealed. Of the total 57 species structure, 49%, 37%, 9%, and 4% showed irregular-shaped, I-shaped, broken reversed J-shaped, and J-shaped patterns, respectively. The irregular-shaped, I-shaped, and J-shaped patterns represent abnormal demographic structure due to the removal of woody species at different diameter classes. The underlying reasons for such kind of demographic structure could be related to overgrazing at young stages of plants and removal of vegetation for burial activities. Celebration of some spiritual activities inside the church forests could have a negative effect on the recruitment of seedlings due to trampling. Additionally, activities such as selective cutting of trees for construction of church buildings, poor reproduction of old trees, and loss of seeds to predators could likely cause the abnormal population structure (Abyot et al. 2014). However, broken reversed J-shaped demographic structures represent relatively a healthy forest.

10.4.3 Stand Structure of Exotic Species

Eucalyptus camaldulensis had the highest IVI value in 17% of church forests in the study area. This species is mainly planted inside or around the church forests matrix for different purposes, such as construction materials, firewood, timber, ornamental, and also windbreak (Bekele-Tesemma 2007). Similarly, Burkhard et al. (2012) reported that this species was planted in the agricultural matrix around the church forests due to its multiple benefits for local communities. *Eucalyptus camaldulensis* is a strong competitor within the native tree community due to its fast growth and resilience to disturbances. Thus, the relatively high dominance and density of *Eucalyptus* spp. in the study area could negatively affect the ecological diversity and structure of the indigenous woody species. As a backlash to its strong wood provisioning performance, it can cause threats to the ecological conditions due to decreased understory cover which lead to increased soil loss rates (Nyssen et al. 2004). It also has a high water consumption rate compared with the other forest communities (Bekele-Tesemma 2007) and also reduces the regeneration potential of native tree species compared with other tree canopies (Thijs et al. 2014a). Plantations of *Eucalyptus* spp. were higher in recently established church forests compared with the old church forests within the study area (field observation). For example, the relative density of *Eucalyptus camaldulensis* was high (41%) in Tiwaz Abo (TA, 21 in Fig. 10.1), which was established in 2010 and 0.3% in Meneguzer Eyesus (ME, 17 in Fig. 10.1), which was established in 1682. This might be because most of the recently established churches are constructed at most degraded areas, and the local people prefer to plant exotic and fast-growing species than indigenous plants. Therefore, considering the ecological threat of exotic species plantation, in general, and *Eucalyptus camaldulensis* plantation, in particular, emphasis should be given for re-introduction of indigenous species in recently established church forests.

10.4.4 The Regeneration Status of Church Forests in Southeast of Lake Tana

The regeneration status of each species can be determined by looking at the pattern of their seedlings, saplings, and matured stage (Malik and Bhatt 2016). To sustain their future regeneration status, woody species should successfully complete their life cycle. When a species is present in both mature and sapling or seedling stages, it indicates the good regenerating status of the species, whereas when the species is present either in mature stage or sapling or seedling stages only, it may show an extinction debt or a colonization credit, respectively (Thijs et al. 2014b). In the present study, most woody species showed poor regeneration status, which exhibit potential extinction debt. Of the total 115 woody species, seedlings were recorded for 62 woody species with 33 species represented only by 100–1700 seedlings ha^{-1}. However, Zahara Mikael (ZM, 11 in Fig. 10.1) church forest had a large number of seedlings (391,200 ha^{-1}). The possible reason for this is because Zahara Mikael (ZM, 11 in Fig. 10.1) has been fenced with stone walls since 2014, and, thus, this could avoid grazing, creation of new paths and clearings, which are the major factors for seedling regeneration.

Of the species that had the highest IVI values, only few species at few church forests showed good regeneration status. For example, *Mimusops kummel* had higher numbers of seedlings and saplings than mature trees in Gebesiwit Mariyam (Gma, 10 in Fig. 10.1), Meneguzer Eyesus (ME, 17 in Fig. 10.1), Robit Bat (RB, 1 in Fig. 10.1), and Zahara Mikael (ZM, 11 in Fig. 10.1) church forests, suggesting that the species has a good regeneration status. However, one or two of the growth stages were missed or lower numbers of seedlings and saplings than the number of mature trees were recorded in many woody species, such as *Ficus vasta* in Gebesiwit Mariyam (Gma, 10 in Fig. 10.1), Kulela Mesekel (KM, 4 in Fig. 10.1), Seneko Medaniyalem (SeM, 23 in Fig. 10.1), Tiwaz Abo (TA, 21 in Fig. 10.1), Wenechet (W, 9 in Fig. 10.1), and Wej Aregawi (WA, 22 in Fig. 10.1) church forests, which indicate their poor regeneration status.

The presence of low numbers of seedlings could pose a threat by reducing the viable population size, which, in turn, affects the ecological function of church forests. The poor regeneration status of woody species was also corroborated by our demographic analysis. Of the selected species for structural analyses, only 5% exhibited the broken reversed J-shaped structure, which presents relatively a healthy forest with good natural regeneration and recruitment potential while the rest (95%) of the species showed abnormal population structures that confirmed the poor regeneration status of the species. The poor regeneration status of woody species in church forests in southeast of Lake Tana is primarily attributed to anthropogenic pressures, such as free grazing, vegetation removal for different purposes, and plantation of fast-growing exotic species. However, climate change and other natural factors, such as physical and chemical soil degradation, could also be considered responsible for the poor regeneration status of the woody species in the study area. Effects of anthropogenic and natural disturbance on the regeneration status of forests have been reported by previous studies (Dai et al. 2002; Tesfaye et al. 2002; Wassie et al. 2009b; Abyot et al. 2014; Meragiaw et al. 2018; Maua et al. 2020).

10.5 Conclusions

Church forests in the study area are important for regional biodiversity conservation since they are the only remnant forests and the last option to harbor woody species and their associated fauna and flora. This study characterized the species and structural composition of woody species at 24 church forests in southeast of Lake Tana. The diversity indices revealed that most of the church forests contained high species diversity. The ecologically and culturally most important woody species, such as *Juniperus procera, Olea europaea, Ficus vasta,* and families in the church forests, which were identified by means of their IVI and FIV values, have to be prioritized for conservation. Furthermore, conservation activities are also urgently required for the rare indigenous species and families that had low IVI and FIV values in all forests. For these species, the church forests are often the only safe haven of survival, and action is required to prevent their regional extermination.

The demographic structure for majority of the species showed I-shaped, irregular-shaped, and J-shaped patterns, suggesting poor regeneration status. Human influence, such as plantation of exotic species, affects the structural composition and regeneration status of church forests. Additionally, there were several species at different church forests that had lower numbers of seedlings and saplings than mature trees, which confirm the low regeneration and recruitment potential of the forests. Woody species with low IVI values and those with poor regeneration status should be prioritized for conservation. Since other patch-level and landscape-level factors could possibly affect species and structural composition of church forests, due attention should be given to such factors in future studies. Additionally, the causes of poor regeneration status of woody species and the possible options to increase their natural regeneration should be studied.

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Appendix 1: Species Name, Family, and the Relative Frequency of Occurrence in 24 Church Forests Southeast of Lake Tana, Ethiopia

Species name	Family	Relative frequency of occurrence (%)
Capparis tomentosa L	Capparidaceae	92
Justicia schimperiana (Hochst.ex Nees) T. Anders	Acanthaceae	92

(continued)

(continued)

Species name	Family	Relative frequency of occurrence (%)
Cordia africana Lam	Boraginaceae	83
Croton macrostachyus Del	Euphorbiaceae	83
Grewia ferruginea Hochst. ex A. Rich	Tiliaceae	83
Millettia ferruginea (Hochst.) Bak	Fabaceae	79
Maytenus arbutifolia (A.Rich.) Wilczek	Celastraceae	71
Mimusops kummel A. DC	Sapotaceae	71
Albizia schimperiana Oliv	Fabaceae	67
Calpurnia aurea (Ait.) Benth	Fabaceae	63
Carissa spinarum L	Apocynaceae	63
Celtis africana Burm.f	Ulmaceae	63
Pavetta abyssinica Fresen	Rubiaceae	63
Juniperus procera Hochst. ex Endl	Cupressaceae	58
Teclea nobilis Del	Rutaceae	58
Ficus thonningii Blume	Moraceae	54
Premna schimperia Engl	Lamiaceae	54
Clausena anisata (Willd.) Benth	Rutaceae	50
Vernonia myriantha Hook.f	Asteraceae	50
Acanthus sennii Chiov	Acanthaceae	42
Ocimum lamiifolium Hochst. ex Benth	Lamiaceae	42
Olea europaea L	Oleaceae	42
Coffea arabica L	Rubiaceae	38
Dracaena steudneri Engl	Dracaenaceae	38
Eucalyptus camaldulensis Dehnh	Myrtaceae	38
Diospyros abyssinica (Hiern) F.White	Ebenaceae	33
Vernonia amygdalina Del	Asteraceae	33
Cupressus lusitanica Mill	Cupressaceae	29
Entada abyssinica Steud.ex.A.Rich	Fabaceae	29
Ficus vasta Forssk	Moraceae	29
Ricinus communis L	Euphorbiaceae	29
Ritchiea albersii Gilg	Capparidaceae	29
Bersama abyssinica Fresen	Melianthaceae	25
Euclea racemosa Murr	Ebenaceae	25
Grevillea robusta R.Br	Proteaceae	25
Rhus quartiniana A.Rich	Anacardiaceae	25

(continued)

(continued)

Species name	Family	Relative frequency of occurrence (%)
Dovyalis abyssinica (A.Rich.) Warb	Flacourtiaceae	21
Flueggea virosa (Willd.) Voigt	Euphorbiaceae	21
Osyris quadripartita Decn	Santalaceae	21
Podocarpus falcatus (Thunb.) R. B. ex. Mirb	Podocarpaceae	21
Rhus vulgaris Meikle	Anacardiaceae	21
Rothmannia urcelliformis (Hiern) Robyns	Rubiaceae	21
Schrebera alata (Hochst.) Welw	Oleaceae	21
Senna singueana (Del.) Lock	Fabaceae	21
Acokanthera schimperi (A. DC.) Schweinf	Apocynaceae	17
Arundo donax L	Poaceae	17
Ekebergia capensis Sparrm	Meliaceae	17
Euphorbia tirucalli L	Euphorbiaceae	17
Ilex mitis (L.) Radlk	Aquifoliaceae	17
Acanthus pubescens (Oliv.) Engl	Acanthaceae	13
Brucea antidysenterica J.F.Mill	Simaroubaceae	13
Casuarina equisetifolia L	Casuarinaceae	13
Clerodendrum myricoides (Hochst.) Vatka	Lamiaceae	13
Dodonaea angustifolia L.f	Sapindaceae	13
Ehretia cymosa Thonn	Boraginaceae	13
Erythrina abyssinica Lam.ex DC	Fabaceae	13
Flacourtia indica (Burm.f) Merr	Flacourtiaceae	13
Gardenia fiorii Chiov	Rubiaceae	13
Jasminum abyssinicum Hochst. ex DC	Oleaceae	13
Jasminum grandiflorum L	Oleaceae	13
Phytolacca dodecandra L'H'erit	Phytolaccaceae	13
Pittosporum viridiflorum Sims	Pittosporaceae	13
Prunus africana (Hook. f.) kalkm	Rosaceae	13
Apodytes dimidiata E. Mey ex. Arn	Icacinaceae	8
Azadirachta indica A.Juss	Meliaceae	8
Citrus aurantifolia (Christm.)	Rutaceae	8
Citrus aurantium L	Rutaceae	8
Combretum molle R.Br.ex G.Don	Combretaceae	8
Dombeya torrida (J.F.Gmel.) P.Bamps	Sterculiaceae	8

(continued)

(continued)

Species name	Family	Relative frequency of occurrence (%)
Euphorbia abyssinica Gmel	Euphorbiaceae	8
Galiniera saxifraga (Hochst.) Bridson	Rubiaceae	8
Olea capensis L	Oleaceae	8
Opuntia ficus-indica (L.) Miller	Cactaceae	8
Piliostigma thonningii (Schumach.) Milne-Redh	Fabaceae	8
Rhamnus prinoides L' Herit	Rhamnaceae	8
Rhus glutinosa A.Rich	Anacardiaceae	8
Schefflera abyssinica (Hochst. ex A. Rich.) Harms	Araliaceae	8
Senna didymobotrya (Fresen.) Irwin and Barneby	Fabaceae	8
Vachellia abyssinica (Hochst. ex. Benth.) Kyal. and Boatwr.	Fabaceae	8
Abutilon figarianum Webb	Malvaceae	4
Albizia anthelmintica (A. Rich.) Brogn	Fabaceae	4
Bridelia micrantha (Hochst.) Baill	Euphorbiaceae	4
Buddleja polystachya Fresen	Loganiaceae	4
Cassipourea malosana (Baker) Alston	Rhizophoraceae	4
Clematis hirsuta Perr. and Guill	Ranunculaceae	4
Croton dichogamus Pax	Euphorbiaceae	4
Delonix regia (Boj.ex Hook.) Raf	Fabaceae	4
Dichrostachys cinerea (L.) Wight and Arn	Fabaceae	4
Dolichos sericeus E. Mey	Fabaceae	4
Eucalyptus saligna Smith	Myrtaceae	4
Ficus ingens (Miq.) Miq	Moraceae	4
Ficus sycomorus L	Moraceae	4
Gladiolus psittacinus Hook. F	Iridaceae	4
Gossypium arboreum L	Malvaceae	4
Hippocratea africana (Willd.) Loes	Celastraceae	4
Indigofera arrecta Hochst. ex A. Rich	Fabaceae	4
Lepidotrichilia volkensii (Giirke) Leroy	Meliaceae	4
Mangifera indica L	Anacardiaceae	4
Myrica salicifolia A. Rich	Myricaceae	4

(continued)

(continued)

Species name	Family	Relative frequency of occurrence (%)
Oxyanthus speciosus Dc.	Rubiaceae	4
Persea americana Mill	Lauraceae	4
Phoenix reclinata Jacq	Arecaceae	4
Psidium guajava L	Myrtaceae	4
Sapium ellipticum (krauss) pax	Euphorbiaceae	4
Senna petersiana (Bolle) Lock	Fabaceae	4
Sesbania sesban (L.) Merr	Fabaceae	4
Solanecio gigas (Vatke) C. Jeffrey	Asteraceae	4
Solanum giganteum Jacq	Solanaceae	4
Stereospermum kunthianum Cham	Bignoniaceae	4
Syzygium guineense (Willd.) DC	Myrtaceae	4
Urera hypselodendron (A. Rich.) Wedd	Urticaceae	4
Vachellia lahai (Steud. and Hochst. ex. Benth.) Kyal. and Boatwr.	Fabaceae	4
Vangueria apiculata K. Schum	Rubiaceae	4
Vangueria madagascariensis Gmel	Rubiaceae	4
Ximenia americana L	Olacaceae	4

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