Hindawi
International Journal of Forestry Research
Volume 2023, Article ID 7927301, 14 pages
https://doi.org/10.1155/2023/7927301

Review Article

Review on Selected Church Forests of Ethiopia: Implication for Plant Species Conservation and Climate Change Mitigation

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Received 30 December 2022; Revised 26 May 2023; Accepted 27 May 2023; Published 5 June 2023

Academic Editor: Anna Źróbek-Sokolnik

Forests are known to play an important role in the conservation of biodiversity and regulation of global climate. Global climate is regulated through sequestering and storing much more carbon from the atmosphere due to the presence of forests. However, loss of forest cover and biodiversity due to anthropogenic activities are a growing concern in many parts of the world. The problem of deforestation and loss of biodiversity is more pronounced in developing countries like Ethiopia. Because of deforestation, the species diversity and climate mitigation potential of natural forests are going to be reduced. Thus, patches of Church forests are left and found throughout the degraded landscapes. Because of their religious significance, these forests have been conserved by local communities. They are the only refuge for different plant species and store high amounts of atmospheric carbon. This is due to local communities do have higher respect and trust in them than other local institutions, which has made the Church the central institution and platform for socio-economic issues of the people. As stated by different scholars, around the Church areas, numerous indigenous and International Union for Conservation of Nature red list species existed. In terms of the diversity of species, the forest around the Church has compared to that of a natural forest. Next to the conservation role, the conserved plant species have a significant contribution to climate change mitigation through carbon stock in biomass and soil. Trees in the Church areas have long life history and are higher in stand structure parameters such as height, diameter at breast height, crown diameter, and their carbon storage potential has been maximum. Overall, Church forests are serving as hot spot sites for biodiversity conservation and have a significant role in mitigating climate change by limiting greenhouse gas emissions and increasing the amount of carbon stored in forests.

1. Introduction

Forests provide essential roles in the life support systems on our planet for both mankind and other living organisms [1–5]. They are the most productive ecosystems and important features in the landscape that provide critical and diverse ecosystem services and values to human society [6]. These ecosystem services include the provision of food, clean water, natural fibres and forest products, pollination, the regulation of climate, pests and diseases, and recreational opportunities. Furthermore, forests have roles as a home of several diversified plant species in addition to ecological and economical values [7]. Ethiopia, located in the tropics, has a wide range of ecological settings; this wide ecological condition has created diverse and conducive environments for the development of various forms of life of flora. Thus, the country is one of the most biodiversity-rich countries in the world [8]. Shreds of evidence showed that Ethiopia owns the fifth-largest floral composition in tropical Africa [9].

Convention on Biological Diversity (CBD) reported that Ethiopia has heterogeneous flora that is estimated to contain around 6,027 vascular plant species of which 10% are endemic [8]. The country is the fifth-largest floral diversity in tropical Africa [10]. Knowing the species' diversity and distribution patterns is crucial to assessing the complexity of biological resources [11]. Ethiopia is facing major problems including conservation and sustainable utilization of the remaining natural forests,

expansion of plantation forests, and restoration of degraded lands [12]. The natural vegetation types of Ethiopia are under harsh threats, and the coverage of forest ecosystems has been fragmented into small patches, and as a result, the structure of the forest and species composition has been degraded [13, 14]. Thus, biodiversity has been exposed to a high level of degradation in Ethiopia [4, 15]. Not only Ethiopia and also all types of the world's natural forests are degraded for searching forest products and agricultural expansion and settlement [16, 17].

All over the world, the rate of deforestation is aggravated at very high rates in the last decades, with negative effects on ecosystems [18]. In Ethiopia, deforestation has a long history, especially in the Northern parts of the country where this activity is accelerated. The increasing population has resulted in extensive forest clearing for agricultural use, overgrazing, and exploitation of existing forests for fuel wood, fodder, and construction materials. Due to these activities, the forest cover of the country was about 16% of the land area in the early 1950s and rapidly declined to 3.6% in the early 1980s and 2.7% in 1989 [13]. Different scholars reported deforestation status per year; as reported by [19–21], they estimated the rate of deforestation in Ethiopia as 141,000 ha·yr^{-1}, and a significant increase in the annual average deforestation rate was shown in 2015 as 210,000 ha per year. The high rate of natural forest degradation led to undesirable and negative effects on species richness and diversity. Due to deforestation and degradation of forest ecosystems especially in the northern and central highlands of Ethiopia have been preserved in ancient Church and monastery grounds [1, 3]. The only areas where one can observe trees in Central Ethiopia are in the surroundings of churches [1, 22].

Sacred forests have been recognized for their major effect on the conservation of natural resources, ecology, and climate mitigation in many parts of the world [23]. Sacred areas especially Ethiopian Orthodox Tewahido Churches (EOTC) serve as a means of preservation and management of biodiversity [1, 3, 4, 24]. Abundant plant and animal species used sacred areas as a habitat [1, 25]. Furthermore, religious areas are serving as conservation sites and hot spots area for biodiversity conservation, mostly indigenous trees and shrubs of Ethiopia [16]. Since trees and shrubs around the Church have a spiritual value attached to the churches, monasteries, and their sacred lands, the biodiversity islands of Church forests have well survived. Besides habitat for diversified plant species, the conserved plant species are used for the reduction of atmospheric CO_2 concentration through both above- and below-ground biomass, soil, and litter falls [3, 4, 7, 22]. Concerning the conservation and mitigation role of Ethiopian Church forests, numerous research studies and reports were done, and however, the outputs of those studies were scattered and do not provide comprehensive information. Thus, this review article tried to provide full and detailed evidence about the Ethiopian Church forests and their contribution to plant species conservation and mitigation of climate change.

2. Methodology

This review article is based on document analysis through a depth review of related literature from different sources. Data were obtained from the review of related literature on the Web of Published articles, researches, books, and reports. A total of 322 papers are searched from Scopus, Web of Science, and other indexed journals using keyword selections (Ethiopian Church forests, diversity, and carbon stock potential of Church forests) that have linkage with Ethiopian Church forests. However, from the total searched documents, thirty-eight publications focusing on plant species conservation and mitigation of climate change were chosen for a detailed review of their influence on biodiversity conservation and climate change mitigation potential of Ethiopian Church forests. Tables and figures are prepared by summarizing the outputs of selected publications.

3. Role of Church Forests

There are numerous sacred areas or forest patches in the world [2]. However, some of the remaining forest patches of Ethiopia are located in the areas of churches and monasteries under the protection of the Ethiopian Orthodox Tewahido Church [3, 25]. In Ethiopia, numerous sacred churches (more than 35,000) persist in a degraded landscape and might contribute to the restoration and biodiversity conservation and provide many other economic and social benefits [1, 22]. Sacred forests in Ethiopia are greater than sacred areas in Ghana (2,000 sacred forests) but lower compared to India, which is nearly 100,000 sacred forests [26]. In Ethiopia, most sacred areas are located near to churches and monasteries [27]. Ethiopia has more than 35,000 Church communities, and most of the churches from the total are located Northern and Central Highlands of Ethiopia [1, 22, 28]. Most part from the Church area is covered by different vegetation having a growth habit of trees, shrubs, and herbs [29]. In other directions, especially in the southwest of the country, Ethiopia the role of natural forests is replaced by shade coffee cultivation and home garden agroforestry systems [20]. Diverse plant species around the yard of the Church area have provided services to the communities as spiritual and medicinal values, and it offers economic and ecological benefits to the local community (Figure 1) [1, 3, 22].

3.1. Biodiversity Conservation Role of Some Church Forests in Ethiopia. The EOTC has a long history of planting, protecting, and conserving trees [1, 3–5]. Thus, churches and monasteries are not only considered religious spots but also biodiversity hotspot areas [28]. Churches and Monasteries in Ethiopia are often surrounded by patches of natural forest which are characterized by a high floral and faunal diversity with many indigenous and rare species [30, 31]. As stated by Wassie [1], the main theological bases and religious perspectives in conserving forest resources were stated as the Church on the earth signifies and symbolizes the new heaven, the holy city, New Jerusalem coming down from

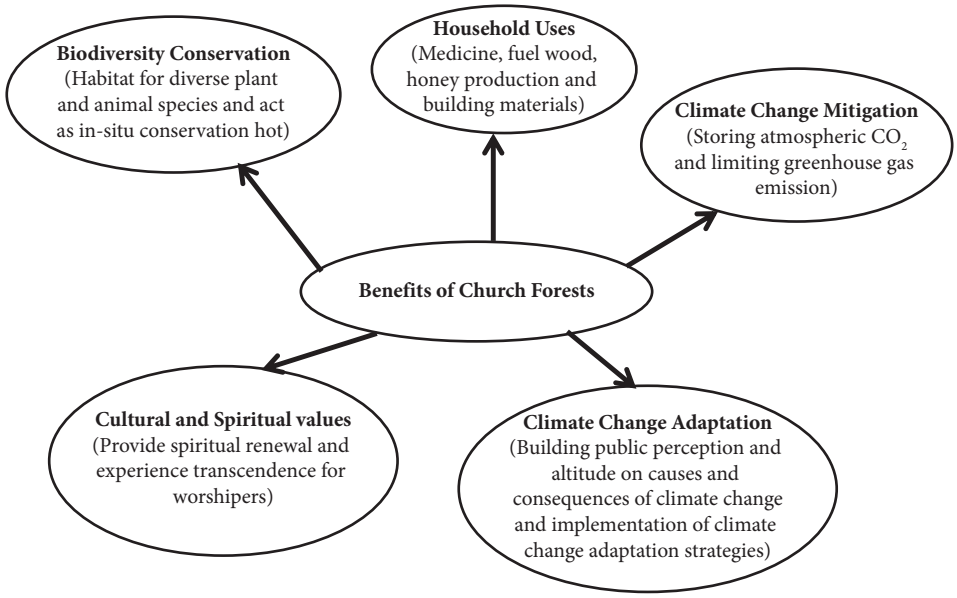

Figure 1: Benefits of Church forests (source: own synthesis from works of literature).

God out of heaven, prepared as a bride, adorned for her husband. The Church of Eden was so beautiful, and many plants, animals, and other organisms and the holy water/streams infinitely had been surpassing from these forests that were believed as proceeding out of the throne of God. The habit of ETOC in conserving plant species is coming from that history [1].

Even though the primary purpose of the EOTC is for worship, burials, and meditative religious festival, they also provide good and secure habitats for diverse plant and animal species [29] (Table 1). EOTC has a long history of planting, protecting, and preserving old-aged trees in churches and monasteries [20, 21, 43]. These tree species surrounding religious sites have a relationship with the term sacred groves and their combinations with Church forests [22]. Thus, forest resources around churches are important for biodiversity conservation and mitigating climate change [22]. Tree species richness, tree density, seedling species richness, and seedling density are significantly higher in Church forests with a wall than without a wall [44].

Church forests are serving as in-situ conservation of many indigenous species and exotic species (Table 1) [1, 32]. However, the frequency and dominance of indigenous species are significantly higher than exotic species [3, 4, 22]. A study in 78 selected Church forests reported that from the recorded 148 plant species, all species were indigenous to Ethiopia [2], and another study in Church forests in the Highland landscape of Ethiopian also reported 160 plant species were indigenous, and the rest 8 species were exotic to Ethiopia from the recorded 168 plant species [21]. The study by Wassie [1] showed that out of 125 woody species that have been registered for the South Gondar natural forests, 81 species occurred in eight Church forests in South Gondar, Ethiopia.

The life form of vegetation in the Church forest consists not only of trees but also shrubs and herbs [29]. Moreover, Wassie and his groups [27] reported that a total of 168 woody species (100 trees, 51 shrubs, and 17 liana species) representing 69 families were recorded in 28 Church forests. The contributions of Church forests to the conservation of diverse plant species in Ethiopia are summarized in (Table 1).

3.1.1. Dominate Family Categorization and Plant Species of Some Church Forests in Ethiopia. Comparatively, as shown in Table 2, Fabaceae is the most conspicuous and abundant family categorization of Church forests in Ethiopia [34, 35, 37]. Therefore, this family categorization has high relative importance related to the degree of influence on ecosystem components such as soils, plants, and animals and competition for resources (light, water, nutrients, and space) to adopt the area. Church forests in Ethiopia support the highest richness of trees and animal species that have almost disappeared in most parts of Ethiopia [1, 2]. *Juniperus procera* Hochst. ex Endl., *Podocarpus falcatus* T., *Olea europaea* L., *Croton macrostachyus* Hochst. ex Delile., *Calpurnia aurea* Benth., *Olea europaea subsp. cuspidata, Ziziphus mucronata* Willd., and *Hagenia abyssinica* (Bruce) J. F. Gmel. are common native trees grown in Church forests (Table 3). Ethiopian Scholars also proved that *Juniperus procera* Hochst. ex Endl. and *Olea africana* Mill. were the most frequent and common species in the monasteries Goba District, Southeastern Ethiopia [55], Lasta Woreda, North Wollo Zone, Amhara Region, Ethiopia [33], and six selected Church forests in North Shewa Zone of Amhara Region, Ethiopia [22]. Summarized studies on dominant family categorization and dominant woody species of the studied Church forests in Ethiopia are presented in Tables 2 and 3.

Table 1: Summarized studies on the role of Church forests in the conservation of plant species in Ethiopia.

No	Church site geographic location	Number of sites studied	Forest area (ha)	Sample forest area taken (ha)	Diversity indices		Total no. of species	No. of families	Source
					H″	E			
1	Yemrehane Kirstos Church Forest, North Ethiopia	1	200	1.36	2.88	0.79	39	29	[32]
2	Gatira George's Forest, Northeastern Ethiopia	1	2.4	0.36	2.78	0.88	34	34	[33]
3	Mahbere Sellassie Monastery Forest, Northwestern Ethiopia	1	12.7	5.4	3.27	0.855	119	42	[34]
4	Aba Asrat Monastery Forest, Northwestern Ethiopia	1		0.62	3.608	0.932	120	53	[35]
5	Tara Gedam Monastery Forest, Northwestern Ethiopia	1	625	0.16	3.26	0.87	120	57	[36]
6	Sesa Mariam Monastery Forest, Northwestern Ethiopia	1		2.04	3.81	0.85	113	54	[37]
7	Assela Teklehymanot Church Forest, Central Ethiopia	1	25	0.44	1.76	0.72	34	27	
8	Etisa Teklehymanot Church Forest, Central Ethiopia	1	23	0.28	1.19	0.81	17	15	[38]
9	Saramba Kidanemhret Church Forest, Central Ethiopia	1	22	0.24	1.63	0.71	27	20	
10	Abbo Sacred Forest, Southern Ethiopia	1	92.33	2.4	2.99	0.75	63	56	[38]
11	Debre Libanos Monastery Forest, Central Ethiopia	1	85	1.8	3.35	0.45	119	39	[39]
12	Mantogera Estifanos Church Forest, Northern Ethiopia	1	5	0.6	2.15		38	21	
13	Wolayta Debere Menekerat Abune Tekele Haymanot Church Forest, Southern Ethiopia	1	25	0.6	0.52		16	10	[40]
14	Bole Bulbula Tekle Haymanot Church Forest, Central Ethiopia	1	21	1.2	1.25		32	11	
15	Emba Kidist Arsema Church Forest, Northern Ethiopia	1	41	0.68	1.8		18	7	
16	Wonjeta St Micheal Church Forest, Southern Ethiopia	1	5	2	2.8	0.68	65	33	[4]
17	Rama Kidanemhret Monastery Forest, North, Ethiopia	1	72	2.8	2.34	0.904	69	43	[40]
18	St. Geberial and Medhaniakea Church Forest, Southern Ethiopia	2		0.6	1.73	0.81	58	28	[41]
19	Zijje Maryam Church Frest, Northern Ethiopia		5.28	0.2	3.29	0.85	48	35	[42]
20	Church Forests, Northern Ethiopia	28	17.9	0.289	—	—	168		[27]
21	Church Forests North Shewa Zone, Northern Ethiopia	6	1.6–100	—	—	—	17–60		[2]

Note. H″: Shannon-Wiener diversity index; E: evenness index.

Table 2: Summarized studies on the dominant family categorization of the studied Church forests in Ethiopia.

No	Family name	Church forest locations	Source
1	Fabaceae	Yemrehane Kirstos Church Forest, North Ethiopia; Sesa Mariaym Monastery Northwestern Ethiopia, Debre Libanos Monastery Forest, Mahbere Sellassie Monastery Forest, Northwestern Ethiopia; Gatira George's Forest, Northern Ethiopia; Selected Church Forests in Central Ethiopia, Aba Asrat Monastery Forest, Northwestern Ethiopia	[33–36, 38, 45, 46]
2	Lamiaceae	Mahbere Sellassie Monastery Forest, Northwestern Ethiopia, Aba Asrat Monastery, Northwestern Ethiopia	[34, 36]
3	Asteraceae	Aba Asrat Monastery, Northwestern Ethiopia	[36]
4	Myrtaceae,	Sesa Mariam Monastery, Northwestern Ethiopia; Selected Churches in Addis Ababa, Central Ethiopia	[38, 47]
5	Cupressaceae	Yemrehane Kirstos Church Forest, North Ethiopia; Selected Churches in Addis Ababa, Central Ethiopia, Selected Church Forests in Central Ethiopia, Church Forests along Church age gradient in Addis Ababa, Ethiopia	[33, 38, 48, 49]
6	Oleaceae	Gatira George's Forest, Northern Ethiopia; Church Forests along Church age gradient in Addis Ababa, Ethiopia; selected Churches in Addis Ababa, Central Ethiopia	[34, 38, 48]
7	Euphorbiaceae	Sesa Mariaym Monastery, Northwestern Ethiopia; Gatira George's Forest, Northern Ethiopia; selected Church Forests in Central Ethiopia	[34, 38, 46]
8	Boraginaceae	Gatira George's Forest, Northern Ethiopia; selected Church forests in Central Ethiopia	[34]
9	Myrsinaceae	Selected Church forests in Central Ethiopia; Aba Asrat Monastery, Northwestern Ethiopia	[36, 37]

3.1.2. Church Forests for the Conservation of Threatened Plant Species. Church and monastery forests provide ecosystem services through the critical conservation of plant species [56]. Around the churchyard comprise many threatened and unique species that make the preservation of these forests crucially important [53] (Table 4). Since the distribution and coverage of natural forests are reduced through different natural and human-induced factors, the distribution of a variety of plant species diversity also declines and goes to threatened. In such conditions, Church compounds are serving as in-situ conservation and hot spot sites for biodiversity resources including many endangered, threatened, and IUCN red lists plant species [1, 22, 32, 57]. *Juniperus procera* L. and *Prunus africana (Hook.f.)* Kalkman. which are listed in the IUCN red list are mostly found in Church forests of Ethiopia [58]. Therefore, protecting the remaining forests, afforestation and wise use of exciting forest resources should be given attention [59]. The roles of Ethiopia Church forests in the conservation of threatened plant species are presented in (Table 4).

3.2. Climate Change Mitigation Role of Some Church Forests in Ethiopia. Climate is rapidly changing and global warming also increased due to increases in the concentrations of greenhouse gases (GHGs) in the atmosphere mainly caused by human activities, particularly the burning of fossil fuels, expansion of agriculture, and deforestation. Comparatively concentration of carbon dioxide in the atmosphere is one of the primary causes of climate change. This led to extreme hazards to animal and plant species diversity, human life, environmental health, agricultural productivity water, and air quality. For combatting the effect of climate change forests have a significant contribution to reducing atmospheric carbon dioxide through carbon sinks [60].

Climate change mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases [61, 62]. Forest has a role in climate change mitigation through carbon sequestration in both above and below-ground biomass and soil carbon stocks [63, 64]. Compared with terrestrial ecosystems, forests have a high potential for sequestering carbon, through the process of tree growth and resultant biological carbon sequestration. However, forest coverage in Ethiopia is highly degraded due to different factors, simultaneously emission of CO_2 to the atmosphere also increased [65–67].

Forest coverage has a direct relationship with the amount of carbon stored but indirect relation with the amount of CO_2 concentration in the atmosphere. Now day's forest patches are highly concentrated around churchyards, especially in Ethiopia [28]. Those forest patches which exist near and around Churches are very important in carbon sequestration and climate regulation (Tables 5 and 6) [32, 49]. Since trees and shrubs around the Church area are well protected from different disturbances like illegal cutting, its carbon-storing potential through above- and below-ground biomass is significantly higher [49, 68]. In addition due to the presence of vegetation cover, soil erosion is reduced and soil and water are well conserved, as a result, soil organic carbon stock is well enhanced [22, 30]. The contribution of Church forests to sequestering atmospheric CO_2 can be estimated by conducting studies in selected Church forests in different geographical locations in Ethiopia. The potential of Church forests in storing CO_2 in above- and below-ground biomass, litter-fall, and soil carbon stock are summarized in Table 5.

3.2.1. Plant Species Having High Carbon Stock Potential in Some Church Forests of Ethiopia. The performances of trees also affect the amount of carbon stored means that healthy

Table 3: Summarized studies on dominant woody plant species around Church area.

No	Scientific name	Family name	Local name	Origin	Habitat	Source
1	*Olea europaea* ssp. *cuspidate*	Oleaceae	Weira	Indigenous	Tree	[22, 33, 36–38, 48, 50]
2	*Juniperus procera*	Cupressaceae	Yehabesha tsid	Exotic	Tree	[22, 33, 36, 38, 48, 50, 51]
3	*Croton macrostachyus*	Euphorbiaceae	Bisana	Indigenous	Tree	[22, 37, 49, 50, 52]
4	*Calpurnia aurea*	Fabaceae	Ginda	Indigenous	Shrub	[22, 33, 34, 46, 52]
5	*Olea africana*	Oleaceae	Olea	Indigenous	Tree	[28, 33, 35, 36, 51]
6	*Ziziphus mucronata*	Rhamnaceae	Geba/qurqura	Indigenous	Shrub or small tree	[25, 29, 53]
7	*Terminalia brownii*	Combretaceae	Abalo/weyba	Indigenous	Shrub or small tree	[2]
8	*Ziziphus abyssinica*	Rhamnaceae	Abetere	Indigenous	Tree	[2]
9	*Dichrostachys cinerea*	Fabaceae	Ader	Indigenous	Shrub	[2, 33, 37]
10	*Carissa spinarum*	Apocynaceae	Agam	Indigenous	Shrub or climber	[46, 50, 54]
11	*Maytenus arbutifolia (A. Rich.) Wilczek*	Celastraceae	Atatt	Endemic	Shrub	[27, 33, 38]
12	*Allophylus abyssinicus*	Sapindaceae	Embis	Indigenous	Tree	[33, 37, 48, 49, 51]
13	*Acacia abyssinica*	Fabaceae	Bazera gerar	Indigenous	Tree	[33, 36, 37, 48, 50]
14	*Eucalyptus globulus*	Myrtaceae	Nech bahir zaf	Exotic	Tree	[37, 38, 48, 50]
15	*Albizia gummifera*	Fabaceae	Sesa	Indigenous	Tree	[33, 46, 48, 50]
16	*Podocarpus falcatus*	Podocarpaceae	Zigba	Indigenous	Tree	[33, 34, 38, 50, 51]
17	*Celtis africana*	Ulmaceae	Qawt	Indigenous	Tree	[38, 45]
18	*Cupressus lusitanica*	Cupressaceae	Tisd	Exotic	Tree	[36, 49, 51]
19	*Pinus radiata*	Pinaceae	Pinus	Indigenous	Tree	[49, 51]
20	*Albizia schimperiana*	Fabaceae	Shimoro	Indigenous	Tree	[36, 37, 46]
21	*Acacia melanoxylon*	Fabaceae	Omedla	Exotic	Tree	[38]
22	*Cordia africana*	Boraginaceae	Wanza	Indigenous	Tree	[38]
23	Carissa spinarum	Apocynaceae	Agam	Indigenous	Shrub	[36]

Table 4: Summarized studies on the conservation role of threatened plant species in some Church forests in Ethiopia.

No	Scientific name	Family name	Local name	Location	Source
1	*Juniperus procera*	Cupressaceae	Yehabesha tsid	Yemrehane Kirstos Church Forest, North Ethiopia, Sesa Mariam Monastery, Northwestern Ethiopia	[22, 46]
2	*Hagenea abyssinica*	Rosaceae	Kosso	Yemrehane Kirstos Church Forest, North Ethiopia	[22, 37, 51]
3	*Podocarpus falcatus*	Podocarpaceae	Zigba	Yemrehane Kirstos Church forest, North Ethiopia; Sesa Mariam Monastery, Northwestern Ethiopia	[22, 46]
4	*Prunus Africana*	Rosaceae	Tiqur inchet	Sesa Mariam Monastery, Northwestern Ethiopia; Shello Giorgis, Northern Ethiopia	[46, 52]
5	*Olea europaea. ssp. cuspidate*	Oleaceae	Weira	Yemrehane Kirstos Church Forest, North Ethiopia; Church Forests along Church age gradient in Addis Ababa Ethiopia; Debra-Libanos Monastery Forest patch of North Oromia Region, Central Ethiopia	[22, 50, 54]
6	*Celtis Africana*	Ulmaceae	Qawt	Sesa Mariam Monastery, Northwestern Ethiopia	[46]
7	*Pinus radiata*	Pinaceae	Pinus	Selected Church Forests in Central Ethiopia	[38]
8	*Cupressus lusitanica*	Cupressaceae	Yeferige tsid	Selected Church Forests in Central Ethiopia	[38]
9	*Millettia ferruginea*	Fabaceae	Birbira	Aba Asrat Monastery, Northwestern Ethiopia	[36]

Table 5: Summarized studies on the role of some Church forests for climate change mitigation in Ethiopia.

No	Location of Church Forest	Number of sites studied	Average forest area (ha)	Mean carbon stock (t ha^{-1})					Source
				AGBC	BGBC	SOC	LC	Total carbon stock	
1	Teklehaymanot Monastery Forest, Southeastern Ethiopia	1	36.3	159 ± 30	42 ± 7.78	127.9	—	328.9	[55]
2	South Gondar, Amhara National Regional State, Northern Ethiopia	28	—	168	—	—	—	168	[2]
3	Church Forests in Addis Ababa, Ethiopia	1	3.714	129.85	25.97	135.94	17.83	309.59	[49]
4	Woji Abune Aregawi Debere Bereket Church Forest, Northern Ethiopia	1	21.8	33.46	8.70	86.33	2.16	130.65	[68]
5	Montogera Estifanos Church Forest, Northern Ethiopia	1	7.5	58.76	15.28	76.52	2.37	152.93	[68]
6	Mai-Anbesa Kidane Miheret Monastery Forest, Northern Ethiopia	1	33	6.00	1.47	121.90	1.33	130.7	[68]
7	Emba Kidest Arsema Mekane Andinet Monastery Forest, Northern Ethiopia	1	16.9	0.71	0.18	116.01	1.33	118.23	[68]
8	Zequala Monastery Forest, Western Ethiopia	1	197	237.20	47.60	57.62	6.99	342.47	[69]
9	Tara Gedam Forest, Northern Ethiopia	1	875	306.37	61.52	274.32	0.90	642.21	[70]
10	Meskel Gedam Forest, Northern Ethiopia	1		146.34	29.27	131.79	3.03	310.43	[71]
11	Kotebe St. Gabriel Church, Central Ethiopia	1	4.02	155.47	31.09	0.89	117.1	308.57	[51]
12	AbunAregawi Church Forest, Central Ethiopia	1	7.4	183.20	26.24	0.82	120.3	337.96	[51]
13	St.Urael church forest, Central Ethiopia	1	0.34	112.87	20.14	0.98	131.1	265.43	[51]
14	Taeka Negest Bata Mariem Monastery forest, Central Ethiopia	1	2.26	103.06	20.61	1.1	99.9	226.93	[51]
15	St. Eyakem Wehana Church, Central Ethiopia	1	1.29	105.31	21.84	0.88	112.1	241.42	[51]
16	St. Estifanos Church Forest, Central Ethiopia	1	1.39	76.32	15.26	0.83	125.9	219.7	[51]
17	Saelite Meheretst Marry Church Forest, Central Ethiopia	1	2.72	55.21	11.04	0.79	89.6	159.36	[51]
18	CMC St. Michael Church, Central Ethiopia	1	1.16	43.20	8.64	0.83	118.2	172.03	[51]
19	Lamberet St. Kidanemiheret Church Forest, Central Ethiopia	1	1.56	59.97	11.99	0.98	87.2	161.7	[51]
20	Lamberet St. Medhanialem Church Forest, Central Ethiopia	1	1.35	56.58	11.316	0.84	91.6	161.686	[51]
21	Birhanate Alem Petros wo Pawulos Church Forest, Central Ethiopia	1	0.126	30.94	6.19	3.54	99.77	140.566	[48]
22	Genete Tsige Kidus Giyorgis church Forest, Central Ethiopia	1	0.765	187.04	37.41	7.36	131.58	364.155	[48]
23	Debre Keraniyo Madihanalem Church Forest, Central Ethiopia	1	0.209	51.25	10.25	4.59	158.06	224.359	[48]
24	Re'ese Adbarat Entoto Kidist Mariam Church Forest, Central Ethiopia	1	0.082	20.03	4.01	6.59	162.27	192.982	[48]
25	Menbere Tsebaot Kidist Silasse Church Forest, Central Ethiopia	1	1.815	444.15	88.83	3.52	144.23	682.545	[48]
26	Yeka Debre Sahil Kidus Michael Church Forest, Central Ethiopia	1	0.086	21.13	4.23	3.5	128.37	157.316	[48]
27	St. Geberial and Medhaniakea Church Forest, Southern Ethiopia	2	—	61.4	12.7		48.65	122.75	[41]

Note. AGBC: above-ground biomass carbon; BGBC: below-ground biomass carbon; SOC: soil organic carbon; LC: litter carbon.

Table 6: Summarized studies on plant species having high potential in storing carbon around Church yards in Ethiopia.

No	Scientific name	Family name	Local name	Location	Source
1	*Juniperus procera*	Cupressaceae	Yehabesha tsid	Yemrehane Kirstos Church Forest, North Ethiopia; selected Churches in Addis Ababa, Central Ethiopia; Sesa Mariam Monastery, Northwestern Ethiopia	[33, 46, 48, 49]
2	*Eucalyptus globulus*	Myrtaceae	Nech bahr zaf	Selected Churches in Addis Ababa, Central Ethiopia	[48]
3	*Albizia gummifera*	Fabaceae	Sesa	Sesa Mariam Monastery, Northwestern Ethiopia, selected Churches in Addis Ababa, Central Ethiopia,	[46, 48]
4	*Olea europaea ssp. cuspidate*	Oleaceae	Weira	Sesa Mariam Monastery, Northwestern Ethiopia; Yemrehane Kirstos Church Forest, North Ethiopia; selected Churches in Addis Ababa, Central Ethiopia;	[33, 46, 49, 51]
5	*Acacia abyssinica*	Fabaceae	Bazera gerar	Selected Churches in Addis Ababa, Central Ethiopia,	[48]
6	*Cupressus lusitanica*	Cupressaceae	Tsid	Selected Churches in Addis Ababa, Central Ethiopia; Addis Ababa city selected Church Forests	[48, 51]
7	*Grevillea robusta*	Proteaceae	Grevillea	Church Forests in Addis Ababa, Ethiopia; St. Geberial and Medhaniakea Church Forests, Southern Ethiopia	[41, 49]
8	*Cordia africana*	Boraginaceae	Wanza	Church Forests in Addis Ababa, Ethiopia	[49]
9	*Acacia abyssinica*	Fabaceae	Bazera gerar	Church Forests in Addis Ababa, Ethiopia	[49]
10	*Jacaranda mimosifolia*	Bignoniaceae	Ytemnja zaf	St. Geberial and Medhaniakea Church Forests, Southern Ethiopia	[41]

Table 7: List of challenges that Ethiopian Church forests faced in selected geographical areas in Ethiopia.

No	Challenges	Location of the Church Forest that faced different disturbances	Source
1	Livestock grazing	Church Forests in Highland Landscape of Ethiopian; North Shewa zone of Amhara Region, Ethiopia; Tekle-Haymanot Monastery Forest, Southeastern Ethiopia; South Gondar Administrative Zone, Northwestern Ethiopia; Shello Giorgis Church Forest, Northern Ethiopia	[22, 27, 42, 48, 51, 54, 64]
2	Anthropogenic disturbances (for wood products and expansion of agricultural land)	Yemrehane Kirstos Church Forest, North Ethiopia; Church Forests, Northern Ethiopia; Tekle-Haymanot Monastery Forest, Southeastern Ethiopia; South Gondar Administrative Zone, Northwestern Ethiopia, Shello Giorgis Church Forest, Northern Ethiopia	[28, 51, 64]
3	Replacement of indigenous trees by fast-growing exotic species	Church Forests in Highland Landscape of Ethiopian, Church Forests, Northern Ethiopia and Church Forests, South Gondar Administrative Zone, Northwestern Ethiopia	[1, 22, 28]
4	Site cleaning for Church building	46 Sacred Groves, Northwestern Ethiopia	[1, 64]
5	Expansion of invasive species	Church Forests, Northwestern Ethiopia and Church Forests, Northern Ethiopia	[28, 64]
6	Soil and water erosion	Debre-Lebanos Church Forest, Central Ethiopia	[1]
7	Low awareness of the use of forest	Church Forests, North Shewa Zone of Amhara Region, Ethiopia	[22]
8	Expansion of farmlands	Aba Asrat Monastery Forest, Northern Ethiopia, Sesa Mariam Monastery, Northwestern Ethiopia	[42, 68]
9	Drought, wind, and aging	Sesa Mariam Monastery, Northwestern Ethiopia	[68]

and larger-diameter trees have good potential in sequestering carbon. Thus, trees around the Church have long ages and have a high diameter class so their ability in absorbing carbon dioxide is higher [33, 46, 48]. Due to the presence of those best-performed tree species, soil organic carbon (SOC) in Church forests is higher due to the addition of different organic materials into the soil, and this helps as a greenhouse gas mitigation activity under the Kyoto Protocol [64, 72, 73]. Lists of plant species having high potential in terms of carbon sequestration are presented in Table 6.

4. Challenges to the Church Forests of Ethiopia

Ethiopia faced different challenges in the development and conservation of forests [22, 27, 42, 74, 75]. Thus, habitat and species are being lost rapidly as a result of the combined effects of environmental degradation, agricultural expansion, deforestation, and over-harvesting of species [3, 4, 30]. The loss of plant species is aggravated by human and livestock population increase thus hastening the overall rural livelihood impoverishment and loss of the biological diversity in Ethiopia [3, 22, 30]. Population increment led to a decrement in economic opportunities, and this puts positive energy for land conversion of forest to agriculture and grazing, and timber exploitation for firewood and construction [30].

Even though Ethiopian Orthodox Tewahido Churches are considered sanctuaries for different plant and animal species, evidence revealed that over time decreasing both in size and density, with visible losses in biodiversity [2, 43]. The most commonly listed challenge by scholars is the grazing of seedlings and saplings [22, 29]. Ethiopia has the largest livestock population in Africa [75]; however, the livestock nutrition and the population's livestock are imbalanced. 75% of Ethiopian livestock is depending on free grazing as a feed source [76]. In addition, poor management of livestock in the field led to the disturbance of the Church area by livestock searching for feed. Livestock grazing has a direct and indirect effect on the conservation of plant species [22, 29, 42, 55].

Mainly challenges on Church forests have direct and indirect effects; the direct disturbance of Church forests through livestock grazing is the most critical challenge that significantly reduced plant species diversity. This is through browsing and trampling of small understory vegetation, so this significantly reduced plant species diversity around the Church areas. Indirectly, livestock has an indirect effect through the distraction of physical structures like soil degradation [46] when the stricter detached soil is washed by runoff and its nutrient availability is also reduced as a result of the suitability of the site for germination and initiation of seedling highly decline [77]. Then, the diversity of plant species also reduced simultaneously over time. According to studies by Wassie and his Colleagues [1], Ethiopia Church forest reported that grazing had a strong negative effect on germination, seedling survival, and growth. In addition to free grazing, wood harvesting, human encroachment, removal of forests for building for religious aspects, and replacement of indigenous trees with Eucalyptus species are recorded as challenges that faced forests in Church areas [1, 2, 22, 31]. The other big challenge is the replacement of indigenous herbs and shrub species with invasive species like *lantana camera*, and this led extinction of species [22].

The study by Cardelu's and his friends [31] found that human disturbance was high in more than half of the 44 studied Church forests in northwest Ethiopia, resulting in reduced tree species richness, biomass, and density. Furthermore, Church forests degradation is ongoing, as logging and tree dieback of species such as *Juniperus procera* L. and *Olea europaea spp. cuspidata* lead to community shifts, from dry Afromontane forest towards shrubland [78, 79]. Overall, the protection of Church forests from different disturbances is important for the conservation of biodiversity in areas threatened by deforestation and fragmentation [78–82]. Summarized studies on challenges to Ethiopian Church forests in different geographical locations in Ethiopia are presented in Table 7.

5. Conclusion

The comprehensive review of published works indicated that churches and monasteries of the EOTC are often surrounded by small natural forests characterized by a high floral and faunal diversity with many indigenous, endemic, and threatened species. The conservation roles of Church forests are the substantial contribution of EOTC, and this is due to religious thought and local people's willingness to protect and conserve them. In addition to their biodiversity conservation benefits of Church forests, they have a significant contribution to mitigating atmospheric CO_2. This is due to the presence of diverse plant species around yards of the Church areas also having a major role in the remarkable carbon stock potential to sequester atmospheric carbon dioxide. The nature of Church forests in terms of woody species composition is diverse, and stand parameters are also well-kept so they have high biomass carbon sequestration potentials. Even though Church forests have an important role in conservation and climate change mitigation, their potential is highly disturbed by different natural factors and anthropogenic encroachment. Grazing of Church areas is a frequently existing challenge listed in Ethiopia. Local people must work integrally with Church administrative workers for effective conservation and management of Church forests. Free grazing must be replaced by a cut-and-carry system to enhance the regeneration status of Church forests healthy. Apart from this, the boundary Church area must be demarcated and fenced for reducing different disturbances.

Abbreviations

AGBC: Above-ground biomass carbon
BGBC: Below-ground biomass carbon
CDD: Convention on biological diversity
CSA: Central statistical agency
DBH: Diameter at breast height
EOTC: Ethiopian Orthodox Tewahido Churches
IPCC: Intergovernmental Panel for Climate Change

IUCN: International Union for Conservation of Nature
LC: Litter carbon
SOC: Soil organic carbon.

Data Availability

The data supporting this review are from previously reported studies and datasets, which have been cited.

Conflicts of Interest

The author declares no conflicts of interest.

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