Research article

Woody species diversity and carbon stock of church forests along age gradient in Dangila district, Awi-zone, Ethiopia

Geremew Bitew Sewagegn,*, Dagm Fikir Abate, Yohannis Gebremariam Girma

Ethiopia Biodiversity Institute, Bahir Dar Biodiversity Center, Bahir Dar, Ethiopia
Forest Research Center and Associated Laboratory TERRA, School of Agriculture, University of Lisbon, Portugal
College of Agriculture and Environmental Sciences, University of Gondar, Gondar, Ethiopia

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ABSTRACT

Ethiopian Orthodox Tewahido Churches comprise remnant native woody species around their premises that are important for biodiversity conservation and carbon sequestration. The current study was conducted to examine woody species diversity and carbon stock of church forests along age gradient in Dangila district, Awi-zone, Ethiopia. A list of documented churches was taken from parish council and tourism that categorized into three age gradients i.e., >200yrs, 100–200yrs and ≤100yrs. Then one church was purposively selected from each age gradient. At each of the selected churches, three Gentry transect lines were laid down systematically in three cardinal directions with 120° interval. Tree height and DBH were measured and saplings were counted within 2m width; whereas, seedling with height <1m was counted from three plots of 2 m x 2 m size along the transect line. Woody species diversity and evenness were computed using Shannon diversity and Evenness indices and carbon stock estimation was done by allometric equation. A total of 91 woody species belong to 45 families and 77 genera were recorded in the church forests. Woody species community structure along age gradients showed an inverted J-shape. The mean Shannon diversity of old, middle and recent age gradient was 2.85 ± 0.21, 2.74 ± 0.13 and 2.37 ± 0.49 respectively. Woody species richness is statistically significant along age classes. The mean total biomass carbon stock along old, middle and recent age gradients was 64.58 ± 23.58, 65.22 ± 63.47 and 18.65 ± 11.02 metric ton respectively. Hence, old aged churches play a better role for indigenous woody species conservation and carbon sequestration.

1. Introduction

The forest resources of Ethiopia have been facing intense degradation and deforestation because of agricultural land expansion, urbanization and overgrazing that result in significant loss of forest biodiversity and ecosystem services (Gebeeyehu et al., 2019). Due to this, Ethiopia has lost about 60% of its intact natural forests since 1900 (Gobena, 2018); and small isolated patch remnant Afromontane forests are left around churches (Healey, 2016). These patches of natural forests have been survived as a result of the traditional conservation effort of the ancient Ethiopian Orthodox Tewahido Church (EOTC) (Tilahun et al., 2015), through spiritual, social and cultural taboos, rules and customs in the church yard (Bayrak and Marafa, 2017). EOTC has a long history of planting, protecting and preserving old-aged trees in its premises and serving as a hot spots of biodiversity, mainly indigenous trees and shrubs of Ethiopia (Tilahun et al., 2015; Yilma and Derero, 2020).

The sacred grounds of ancient churches and monasteries contain natural forest vegetation that constitutes important habitats for a variety of species with a complex structure than non-sacred forests (Gobena, 2018). The older churches are surrounded by primary forests while recently established churches are observed with secondary forests. It indicates older church forests are characterized by a high floral and faunal diversity of indigenous species; which in turn give prestige to the religious sites and as a shelters for endemic, rare and threatened species (Tilahun et al., 2015; Healey, 2016; Mekonen et al., 2019). Church forests are also essential for climate change mitigation, ecosystem function and stability (Tilahun et al., 2015) and play its own role to balance the global carbon dioxide (CO2) (Beyene et al., 2018). The highest proportion of terrestrial carbon was stored in forest ecosystems (Beyene et al., 2018). As Muges et al. (2010) estimated 2.76 billion tons of carbon was stored in the forest resources of Ethiopia (Muges et al., 2010). Among this, Dry Afromontane forests store a huge
amount of aboveground carbon compared to other terrestrial ecosystems (Mekonnen and Tolera, 2019). As a remnant dry Afromontane Forest, EOTC forests as well as the church forests in Dangila district might have a considerable role for biomass carbon storage and climate change mitigation. However, most of previous church forest studies were concentrated in South Gondar zone through different scholars such as Ruelle et al. (2017); Woods et al. (2016); Zegeye et al. (2011); Aerts et al. (2016) and to some extent in Bahir Dar Zuria areas. Only researcher Birhanu et al. (2021) studied church forests in Dangila Woreda. However, the scholars didn’t consider the effect of church establishment year for carbon sequestration, woody species diversity, evenness and richness. These studies may not represent unexplored church forests of Awi-zone in general and Dangila district in particular. The aim of the current study was therefore investigation of woody species diversity and biomass carbon stock of selected church forests along age gradient in Dangila district.

2. Materials and methods

2.1. Site description

The study was conducted in selected church forests of Dangila district, Awi zone, Amhara National Regional State. The district is located between 11°04’48”-11°24’36” N latitude and 36°34’48”-37°00’37” E longitude (Figure 1). It is 918.4 km² wide and its elevation traverses between 1500 and 2400 m.a.s.l. The topography is characterized by plain landscape (70% plain, 27% rugged and others cover 3 %). The major soil types are Lithosols, Nitosols, Vertisols, Luvisols, Gleysols, Cambisols and rocky surfaces. The mean annual temperature and rainfall records were 17°C and 1578 mm respectively (Belay, 2018). The most common tree species were Eucalyptus camaldulensis, Croton macrostachyus, Albizia gummifera, Ritchiea albersii, Prunus africana, Cordia africana, Acacia abyssinica and Dracaena steudneri. Therefore, the church forests in Dangila district were categorized as dry evergreen Afromontane Forest and grassland complex vegetation.

2.2. Sampling technique and data collection

A list of documented churches was taken from parish council and tourism office. The churches were categorized into three age gradients based on establishment year i.e., >200yrs, 100–200yrs and ≤100yrs. A preliminary survey was made and 9 churches were selected purposively from the district woreda based on their best representativeness, accessibility, budget and time (Tilahun et al., 2015; Abiyu et al., 2017). Therefore, each age gradient has three sampled church forests. Then, a reconnaissance survey was made for each of the selected churches and three modified Gentry transect lines were laid down systematically in three cardinal directions with 120° interval from the church center to the edge of the forest (Figure 2). Modified Gentry transect lines method was more appropriate for church forests because most of the church forests envelop the church and they were more or less circular (E.g.: - Figure 3). The first transect line were laid down purposively at 2m width and the length depends on the size of the church forest.

Finally, woody species inventory has been carried out within 2m width in either side of each modified Gentry transect line (Cardelus et al., 2019). The height of woody species were measured using caliper in a position which was possible to observe the tips and bottom of the trees/shrub (Abunie and Dalle, 2018; Cardelu’s et al., 2019; Woods et al., 2016). Woody individuals with DBH/DSH ≥ 5cm were measured and recorded using clinometer for biomass estimation (Yilma and

Figure 1. Map of the study area.
Derero, 2020; Gedefaw et al., 2014; Gebeyehu et al., 2019). For individuals that are branched below the breast height, the diameter was measured separately and the average was taken. The woody species with DBH < 5cm were considered as sapling and the undergrowth woody species with height of less than 1m were seedlings (Abunie and Dalle, 2018). Seedlings were counted and recorded in 2 m²/c by three quadrates (10m away from the internal wall of the church, in the center & 10m away from the outer edge of the forest) for each church forest along the Gentry transect lines (Figure 2) following (Cardelu's et al., 2019).

All woody plant species encountered in each sample quadrates were recorded and code with vernacular and local names whenever possible. Woody species identification was done by using Bekele-Tesemma (2007); Edwards et al. (1995); Hedberg & Edwards. (1989) and PlantNet software. The vegetation data collection was conducted from January–February 2021 after the main rainy season of the study area.

2.3. Analysis of woody species diversity

Woody species diversity was analyzed by using different diversity indices such as Shannon diversity index (H’), Shannon equitability/evenness index (E), density (D) and species richness (S). They provide important information about rarity and commonness of woody species in the church forests (Molla and Kewessa, 2015).

Shannon Wiener diversity index accounts for both abundance and evenness of the species present. It was important to compute and analysis woody species diversity of each church forest in the study area. Shannon diversity index could be calculated by Eq. (1) as follows:
2.4. Analysis of church forests composition and structure

2.4.1. The structure and composition the forests were analyzed by computing frequency, density, dominance and important value index

Frequency: is an indicator of homogeneity and heterogeneity of a given vegetation type. The maximum number of woody species in higher frequency classes shows homogeneity of species in the forest and vice versa (Abunie and Dalle, 2018). Frequency was used to estimate the number of times of a given species recorded at each Modified Gentry transect line of church forests. Therefore, each individual woody species in the sample area were counted and recorded. Finally, species frequency was computed by by Eq. (3) as follows below:

\[
Frequency = \frac{\text{Number of Plots in which a species occur}}{\text{Total number of plots}} \times 100
\]

Density: is the number of individual woody species within a given area. It was simply obtained by counting the number of woody species present within a 2m width Modified Gentry transect line. Species density was computed by Eq. (4) as follows:

\[
Density = \frac{\text{Total number of all trees}}{\text{Sample size in hectare}}
\]

Dominance: is the degree of coverage of a species as an expression of the space it occupied in a given area. It is usually expressed in terms of species basal area. Species dominance was crucial to explain the crowdedness of the church forest. The DBH of each species was measured and basal area was estimated by Eq. (6) within the sample area. Then, species dominance was computed by with Eq. (5) as shown below:

\[
\text{Dominance} = \frac{\text{Basal area of species A}}{\text{Sample area}}
\]

\[
\text{BA} = \pi \frac{d^2}{4}
\]

Where, \(\pi = 3.14; d = \text{diameter at breast height (cm)}; \text{BA} = \text{basal area (m}^2\).

Importance value index (IVI): is a composite index that summarizes the relative measures of species density, frequency and dominance (Mekonen et al., 2016). This index was used to determine the overall importance of each species in the community which describes the structural role and ecological success of a species in each church forest (Tegegne et al., 2018). It was also used to prioritize species for conservation. After estimating the relative density, frequency and dominance of each species using Eqs. (8), (9), and (10) respectively, IVI was calculated by Eq. (7) as shown below:

\[
\text{IVI} = \text{Relative density} + \text{Relative frequency} + \text{Relative dominance}
\]

\[
\text{Relative density} (Rd) = \frac{\text{Density of species A}}{\text{Total density of all species}} \times 100
\]

\[
\text{Relative frequency}(RF) = \frac{\text{Frequency of a species}}{\text{Sum of frequencies of all species}} \times 100
\]

\[
\text{Relative dominance} (RD) = \frac{\text{Basal area of species A}}{\text{Total basal area of all species}} \times 100
\]

2.5. Analysis of population structure and regeneration status of the forest

Woody species composition and structure are crucial to identify the presence of rare or threatened species for conservation and management planning (Zegeye et al., 2011). The woody species structure of all individuals of each species encountered in the samples was grouped into ten (10) diameter and height classes by using Microsoft Excel. These are 5–10cm (A), 10.1–15cm (B), 15.1–20cm (C), 20.1–25cm (D), 25.1–30cm (E), 30.1–35cm (F), 35.1–40cm (G), 40.1–45cm (H), 45.1–50cm (I) & >50cm (J); and ten height classes: <5m (A), 5.1–10(B), 10.1–15(C), 15.1–20(D), 20.1–25(E), 25.1–30(F), 30.1–35(G), 35.1–40(H), 40.1–45(I), >45m (J). Then, it was analyzed by categorizing each individual woody species at each DBH and height classes.

In addition, the regeneration status of the church forest was determined by recording the list of species and number of seedlings, saplings and mature trees in each sample area (Abunie and Dalle, 2018). It was also analyzed by comparing sapling and seedling total counts with that of mature trees (Atsbha et al., 2019).

2.6. Estimation of above and below ground biomass carbon stock

The carbon stock of each church forest was estimated through a nondestructive approach which involves the use of allometric equations (Yilma and Derero, 2020). The biomass of each tree was calculated using the same allometric equations because many species didn’t have species-specific allometric equations (Cardelus et al., 2019), and it consumes time and cost. Therefore, Chave et al. (2014) general allometric equation was used to determine the biomass of woody species having \(\geq 5\) cm DBH/DSH as it fits to biophysical conditions of the study area following (Yilma and Derero, 2020; Estabele et al., 2019). The carbon stock of each church forest was estimated by Chave et al. (2014) as shown in Eq. (11).

\[
\text{AGB} = 0.0673 \times (\rho \text{D}^2H^{0.976})
\]

Where, \(\text{AGB} = \text{aboveground biomass (kg), H= Height of tree (m), D= Diameter (cm) at breast height (1.3m), and } \rho= \text{Wood density (ton/m}^3\), \(0.58 \text{ton/m}^3\) (Estabele et al., 2019).

Woody species biomass was converted into carbon (C) by using Brown (2002) formula as shown in Eqs. (12) and (14). The CO₂ equivalent sequestered in the aboveground biomass = \(\text{AGC} \times 3.67\) (Pearson et al., 2007).

\[
\text{AGC} = \text{AGB} \times 0.5
\]

Where, \(\text{AGC} = \text{Aboveground carbon.}

Estimation of below ground biomass is much more difficult and time consuming due to uncertainty of root biomass measurement. Root biomass is often estimated from root-shoot ratios (R/S) by taking 25% of aboveground biomass by using Cairns et al. (1997) formula as shown in Eq. (13).

\[
\text{BGR} = \text{AGB} \times 0.25
\]

\[
\text{BGC} = \text{BGR} \times 0.5
\]

Where, \(\text{BGC} = \text{below ground carbon.}

\text{BGB} = \text{below ground biomass.}

Then the total biomass carbon stock was calculated by Eq. (15) following Pearson et al. (2005) formula.

\[
\text{TBC} = \text{AGC} + \text{BGC}
\]

Where, \(\text{TBC} = \text{total biomass carbon stock (ton/ha).}

2.7. Statistical analysis

Descriptive statistics such as mean, standard deviation, minimum and maximum values were determined for the major variables of interest, such as species richness, evenness, Shannon diversity, species density, basal area and biomass carbon stock. Analysis of variance (ANOVA) and multiple comparison test (LSD) were used to examine the level of significance for each parameter under investigation along age gradient. Pearson’s correlation analysis method also used to examine the relationship between parameters such as species richness, evenness, Shannon diversity, density, basal area and biomass carbon stock among each church forests (Estubalew et al., 2019). All the aforementioned descriptive and inferential analysis was performed by using SPSS version 20 and PAST software.

3. Result and discussion

3.1. Floristic composition

A total of 91 woody species were identified in the study area. It is comparable with the findings of Yilma and Derero (2020) who reported 90 woody species in 17 churches of Addis Ababa and Tilahun et al. (2015) who reported 92 woody species in six monasteries of North Shewa. However, it is also greater than Woods et al. (2016) who found 64 woody plant species from 13 church forests in South Gondar and Mequanint et al. (2020) who found 70 species in 24 churches of North-West Ethiopia and lower than Wasse et al. (2010) reported 168 species in 28 different churches of South Gondar.

The encountered woody species belong to 45 families and 77 genera, from those 79 (86.81%) were indigenous while the remaining 12 (13.19%) were exotic species. Among these species 45 (49.45%) were trees, 39 (42.86%) were shrubs and 7 (7.69%) were lianas species. Fabaceae was the most diverse family and represented by 10 woody species (10.55%) followed by Asteraceae and Rutaceae each represented by 5 (5.38%) species. Whereas Apocynaceae, Arecaceae, Asparagaceae, Bignoniaceae, Capparaceae, Capparidaceae, Cashuarinaceae, Cucurbitaceae, Dracaenaceae, Flacourtiaceae, Iridaceae, Phyllolaccaceae, Podocarpaceae, Polygonaceae, Proteaceae, Santalaceae, Simaroubaceae, Solanaceae, Tiliaceae, Ulmaceae, Urticaceae, Verbenaceae, Icacinaceae and Primulaceae were the lowest families represented only by 1 (1.09%) woody species. Acacia was the most diverse genera and represented by 5 (6.49%) woody species followed by Vernonia and Ficus each represented by 4 (5.2%) and 3 (3.9%) species respectively.

3.2. Woody species diversity

Woody species richness of the studied church forest ranges from 31 up to 43 species. The highest were recorded at Agunta Maryam church forest while the lowest was recorded at Gisa Balegziabher and Debre Tiguhan church forests. The mean woody species richness of the study church forests was 35.00 ± 4.42 (Table 1). The result was comparable with Abunie and Dalle (2018) who reported 39 woody species in Yemrehane Kirstos Church Forest. However, it was lower than Hordofa et al. (2020) reported 59 species in Debre Libanos church forest and Zegeye et al. (2011) reported 113 woody species in Tara Gedam Church Forest. It was also greater than Yilma and Derero (2020) who reported 26 woody species in church forests of Addis Ababa. The variation in the number of woody species could be related to church establishment year, urbanization, agroecology, management strategy and objective.

The mean Shannon-Wiener diversity of the study area was 2.65 ± 0.35. The result was greater than ($H = 2.29$) Gra-Kahu natural vegetation, (Atsba et al., 2019); ($H = 2.27$) in church forests of Addis Ababa (Yilma and Derero, 2020) and lower than ($H = 3.5$) in church forests of Dangila district, ($H = 3.14$) in Debre Libanos church forest (Hordofa et al., 2020); ($H = 2.98$) in Tara Gedam church forest (Zegeye et al., 2011); and ($H = 2.88$) in Yemrehane Kirstos Church Forest (Abunie and Dalle, 2018). Atsba et al. (2019) noted that Shannon-Wiener diversity index considered as high when the calculated value is > 3.0, medium 2.0–3.0, low 1.0–2.0, and very <1.0. Woody species evenness also considered as high when the calculated value is 0.5 and low 0.5 (Atsba et al., 2019). Hence, the study area shows a medium Shannon-Wiener diversity ($H = 2.65$) and lower species evenness ($E = 0.42$) from other similar forests in Ethiopia. As Montagnini and Jordan (2005) noted that high woody species diversity benefits to defend against disease and complementarity (Montagnini and Jordan, 2005). The lower woody species evenness shows there was a dominance of one or few species in the community and unbalanced distribution of individuals of different species in the study area. For example: Ficus thomsonii, Apodytes dimidiata and Ficus vassa were represented only by two (2) individuals/ha; on the other hand, E. camaldulensis had 2239 individuals/ha in the studied church forests. The reason for the lower/higher variation of Shannon diversity and evenness from other similar studies might be management strategy and objective (e.g., for conservation, cash crop or social purpose), church establishment year, urbanization, site suitability, micro-climate, selective cutting and expansion of some exotic species such as Eucalyptus species and Grevillea robusta.

The mean woody species richness, evenness and Shannon-Wiener diversity of church forests decrease with decreasing church age. However, only species richness showed a statistically significant variation along age gradient (d.f = 8; p = .045) (Table 1). The result showed that woody species richness was influenced by the establishment year of the churches. The reason could be old aged churches forests were conserved for a long year period; that gives an opportunity for better soil seed bank and regeneration than recently established church forests. Old aged church forests have many indigenous mother trees that feed a seed for regeneration. On the other hand, many recently established churches planted exotic species such as E. camaldulensis and G. robusta for economical purposes.

3.3. Indigenous and exotic species diversity

A total of 12 exotic woody species were recorded from all sampled church forests of Dangila district. Out of these, E. camaldulensis was the most abundant species with a total of 2239 individuals/ha followed by G. robusta having a total of 163 individuals/ha in Dangila district.

Table 1. Church Forest area, basal area BA), above ground carbon (AGC), below ground carbon (BGC), total biomass carbon (TC), exotic species carbon (ExC), family, richness (R), evenness (E), Shannon diversity (H’) and % of exotic species richness (%) of nine church forests in Dangila district along age gradient.

| Age class | Area (ha) | BA (m²) | AGC (t/ha) | BGC (t/ha) | TBC (t/ha) | Family | ExC (t/ha) | R | E | H’ | %ex | Species life form |
|-----------|-----------|---------|------------|------------|-----------|--------|------------|---|----|-----|-----|------------------|
| Old       | 4.35      | 86.54   | 51.67      | 12.92      | 64.60     | 28.33  | 1.29*      | 39.67* | 0.45 | 2.85 | 5.85 | 19.33  | 19.33*           |
| Middle    | 3.42      | 64.57   | 52.18      | 13.04      | 65.22     | 22.33  | 2.23*      | 33.33* | 0.47 | 2.74 | 11.02 | 17.67 | 14*               |
| Recent    | 2.07      | 33.14   | 14.92      | 3.73       | 18.65     | 22     | 6.54*      | 32.00* | 0.36 | 2.37 | 19.16 | 18 | 12.67* | 1.67               |
| Mean      | 3.28      | 61.52   | 49.59      | 9.90       | 49.49     | 24.22  | 3.35       | 35.00  | 0.42 | 2.65 | 12.01 | 18.33 | 15.33             |
| F         | 3.78      | 1.154   | 1.364      | 1.364      | 1.364     | 1.364  | 1.641      | 1.831  | 0.58 | 2.58 | 2.078 | .375   | 7.149               |
| P         | 0.087     | 0.377   | 0.325      | 0.325      | 0.325     | 0.325  | 0.270      | 0.010  | 0.045 | 0.615 | 0.206 | .702               | .026              | .579               |

Means with different letter are statistically different along age gradients at 0.05 level of significance.
Table 2. Exotic and indigenous species biomass carbon stock (TBC), density (D), richness (R), evenness (E), Shannon diversity (H') density of E. camaldulensis (EcD) of 9 church forests along age gradient.

| Age gradient | Exotic species | Ec D | Indigenous species |
|--------------|----------------|------|--------------------|
|              | TBC (t/ha)     | D    | R       | E | H' |
| Old          | 1.29a          | 1374a| 2.67    | 0.8 | 0.42 |
| Middle       | 2.23b          | 1570b| 3.67    | 0.61 | 0.65 |
| Recent       | 6.54b          | 6110b| 6       | 0.43 | 0.72 |
| Mean         | 3.35           | 3018 | 4.11    | 0.61 | 0.60 |
| F            | 10.83          | 7246 | .506    | .548 | .595 |
| P            | 0.010          | .25  | .625    | .604 | .581 |

Means with different letter has a statistically significant variation along age gradient.

Table 3. Pearson correlation of indigenous and exotic species richness, Shannon diversity, and evenness along age gradient in the study area (N = 9).

| Items                  | Indigenous species richness | Exotic species richness | Indigenous species diversity | Exotic Shannon diversity | Indigenous species evenness | Exotic species evenness |
|------------------------|-----------------------------|-------------------------|----------------------------|--------------------------|---------------------|-----------------------|
| Indigenous species richness | 1                           | -0.808**                | 0.993                      | -0.388                   | 0.840**             | -0.772*               |
| Exotic species richness  | −0.808**                    | 1                       | −0.388                     | 1                        | −0.528              | 1                     |
| Indigenous Shannon diversity | 0.993                 | -0.808**                | 0.840**                    | -0.528                   | 0.502               | 0.259                 |
| Exotic Shannon diversity  | -0.695*                    | −0.808**                | 0.502                      | 0.539                    | 0.259               | 1                     |
| Indigenous species evenness| −0.772*                   | −0.681*                 | 0.303                      | −0.333                   | −0.349              | 1                     |
| Exotic species evenness  | 0.549                       | −0.681*                 | 1                          |                          |                    |                       |

**Correlation is significant at 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

3.4. Above and below ground biomass carbon stock

The mean total biomass carbon stock of the church forests in the study area was 445.41 metric ton. Hence, the mean biomass carbon stock contained within each church forest was 49.49 ± 13.79 metric ton/ha. It could generate a carbon credit of 762.64 ± 212.5 USD; assuming the price of carbon credits per ton is about 15.41 USD (Siraj, 2019). The minimum and maximum biomass carbon stock was recorded in Debre Tiguhan Kidus Urael and Gult Teklehaimanot respectively. The mean above ground and below ground biomass carbon stock of church forest in the study area was 39.59 ± 33.10 and 9.90 ± 8.27 ton/ha respectively (Table 1).

The mean total biomass carbon stock of the church forest in the district was comparable with Sekele-Mariam church forest (Mekonnen and Tolera, 2019) and lower than a similar study in Ethiopia conducted by Girma et al. (2014); Yilma & Derero (2020); Esubalew et al. (2019); Tura et al. (2013) (Table 4). The variation of biomass carbon stock might be due to selective cutting, fuel-wood extraction, over exploitation, allo-metric equation used (Mekonnen and Tolera, 2019), management practice and micro climate.

The statistical result indicates that the mean total biomass carbon stock along old, middle and recent age gradients were 64.60 ± 23.58, 65.22 ± 63.47 and 18.65 ± 11.02 ton/ha respectively (Table 1). The mean biomass carbon stock of indigenous species along old, middle and recent age gradient was 63.30, 62.99 & 12.11 ton/ha. The biomass carbon stock increased as church age increased however, the difference was statistically insignificant. On the other hand, the mean biomass carbon stock of exotic species was significantly increasing as church age increased from old to recent age gradients. The result confirms the study conducted by Lemenih and Kassa (2014) who reported that the tendency of planting exotic species was increasing whereas that of indigenous species was decreasing with increasing church age (Lemenih and Kassa, 2014). On the other hand, indigenous woody species richness was quantitatively increased as church age increased from old to recent age gradients. The result confirms the study conducted by Lemenih and Kassa (2014) who reported that the tendency of planting exotic species was increasing whereas that of indigenous species was decreasing with increasing church age (Lemenih and Kassa, 2014).

Table 4. Comparison of carbon stock (ton/ha) of church forests in Dangila district with other similar forest types in Ethiopia.

| Study areas                  | AGC | BGC | Mean total | Reference       |
|------------------------------|-----|-----|------------|----------------|
| Church forests in Dangila    | 39.59| 9.90| 49.49      | Present study   |
| Sekele-Mariam forest         | 37.54| 9.76| 47.3       | Mekonnen and Tolera (2019) |
| Zequala Monastery Forest      | 237.20| 47.60| 284.8      | Girma et al. (2014) |
| church forests in Addis Ababa| 130 | 26 | 156        | Yilma & Derero (2020) |
| Alemasaga forest              | 91.85| 22.86| 114.71     | Esubalew et al. (2019) |
| Carbon stock in church forests of Addis Ababa | 129.85 | 25.97 | 155.82 | Tura et al. (2013) |
stock of exotic species along old, middle and recent age gradients was 1.29, 2.23 & 6.54 ton/ha. The result showed a statistically significant variation (α = 95%; df = 8; & p = .010) (Table 2). It indicates exotic plantation in general and *E. camaldulensis* in particular were planted in the studied church forests for income generation, area demarcation and live fencing.

3.5. Relationship between biomass carbon stock and woody species diversity

The relationship between species diversity and biomass carbon stock has become an important consideration in the carbon cycle and climate change adaptation. Woody species diversity plays a role in supporting ecosystem processes, function and services (Gebrewahid and Meressa, 2020). The Pearson’s correlation relation of total biomass carbon stock with Shannon diversity had a quantitative positive relationship in Dangila district. However, it was statistically insignificant (r = .471 & p = .05). The result was different from Mensah et al. (2016), who stated that woody carbon stock increases with diversity in highly diverse natural forests and high productivity areas i.e. church forests (Mensah et al., 2016). The Pearson’s correlation relation of biomass carbon stock had statistically significant positive relationship with basal area at 95% confidence interval (r = .763* & p = .05) (Table 5). Therefore, the reduction of basal area due to selective cutting, fuel wood extraction, over exploitation and any other factors might reduce the biomass carbon stock of church forests in Dangila district.

3.6. Church forest structure

3.6.1. Frequency, density and dominance of woody species

**Frequency:** The overall frequent tree species were *E. camaldulensis* and *C. macrostachyus* occurring in 85.12% of the Gentry transect of church forests; whereas *Celtis aferica*, *Ekebergia capensis*, *Eriobotrya japonica* and *Galinera saxifrage* were the least frequent tree species each occurring 3.7% of the Gentry transect line in the church forests. The frequent occurrence of woody species along age gradient was varied. The highest frequent species along old, middle and recent age gradients was *Justicia schimperiana*, *Brucea antidysenterica* and *Eucalyptus camaldulensis* respectively (Appendix 1). *Eucalyptus* species was most frequently present in recently established churches surrounding indigenous and old-growth trees as protection and as a source of materials, fuel wood, and income (Sahle et al., 2021).

**Density:** The overall result revealed that *E. camaldulensis* was the highest density (2239 individuals/ha) tree species while the lowest were *E. japonica* and *C. africana* (2 individuals/ha for each). The variation in density between species might be attributed to habitat differences, habitat preferences among the species, species characteristics for adaptation, degree of exploitation and conditions for regeneration (Zegeye et al., 2011). In addition, the lowest species density indicates that the population size was too low to sustain itself within the forest unless their abundance is increased through different management practices (Molla and Kewessa, 2015). Therefore, *E. japonica* and *C. africana* were the lowest abundance tree species that requires the highest priority for conservation in the study area.

The mean woody species density of the church forests were 13976 individuals/ha; which was less than 18,508 individuals/ha in Debre Libanos church forest (Hordofa et al., 2020); and greater than 3001 individuals/ha in Tara Gedam forest (Zegeye et al., 2011) and 670 individuals/ha in Addis Ababa church forests (Yilma and Derero, 2020). The mean woody species density along old, middle and recent age gradients were 15150, 12243 and 14534 respectively however, the variation was not statistically significant at 95% confidence interval. The highest woody species density along old, middle and recent age gradients was *J. schimperiana*, *E. camaldulensis*, and *E. camaldulensis* (Appendix 1).

The density of exotic species showed a statistically significant variation from old to middle and recent church age gradients (Table 2). The result was different from a similar study conducted by (Yilma and Derero, 2020). Particularly, the density of *E. camaldulensis* along old, middle and recent age gradients were 812, 1173 and 4726 individuals/ha respectively. Even though ANOVA reveals the variation was statistically insignificant; the multiple comparison test (LSD) indicates that the density of *E. camaldulensis* in recent church age had a statistically significant variation with old and middle age churches in Dangila district (Table 2). The reason might be its fast growing nature for area demarcation, live fencing and income generation. On the other hand, the quantity of indigenous woody species density was decreased as church age decreased from old to recent age gradient in the study area. However, it was statistically insignificant at 95% confidence interval (Table 2).

**Dominance:** woody species dominance was expressed by basal area. The overall total basal area of Dangila district was 552.82 m². Hence, the mean basal area of each church forest was 61.42 ± 44.09 m² (Table 1). The result was greater than 14.6 ± 8.4 m² in Addis Ababa church forests (Yilma and Derero., 2020) and 56.1 m² in Sawo Sacred Forest (Agidew and Mezgebe, 2019); however, it was lower than 72 m² at Yemrehane Kirsto church forest (Abanie and Dalle., 2018), and 115.36 m² in Tara Gedam monastery forests (Zegeye et al., 2011). Woody species dominance ranges from 22.23 m² at Debre Tigihan Kidus Urael to 153.51 m² at Chiwagi Mikael. *E. camaldulensis* contributes the highest basal area followed by *C. macrostachyus* and *A. gymnifera*. According to the statistical result, the mean basal area along old, middle and recent age gradients was 86.54 ± 58.03, 64.57 ± 44.82 and 33.16 ± 15.48 m² respectively (Table 1). The species that contribute the largest dominance/basal area along old, middle and recent age gradient were *D. steudneri*, *C. macrostachyus* and *E. camaldulensis* (Appendix 1).

3.6.2. Importance value index (IVI)

The highest and the lowest IVI value trees species was *E. camaldulensis* and *C. africana* respectively. The species with the highest IVI value in old, middle and recent age gradients were also *J. schimperiana* (29.18), *E. camaldulensis* (41.14) and *E. camaldulensis* (136.17) respectively (Appendix 1). Woody species with the highest IVI value need less conservation efforts, whereas species having low IVI value need high conservation effort (Molla and Kewessa, 2015); and (Zegeye et al., 2011). Therefore, *J. schimperiana* & *E. camaldulensis* was the most abundant species that needs less sustainable management; whereas *Celtis africana* occurred in scarce and needs the first priority for conservation in the study area. A similar result was reported in Dangila church forests (Berhanu et al., 2021).

3.6.3. Population structure and regeneration status of the forest

The general pattern of DBH and height class distribution of church forests in Dangila district showed an inverted J-shaped (Figure 4A & B). This was similar with Tara Gedam church forest (Zegeye et al., 2011); Kuandisha forest (Berhanu et al., 2016); Debre Libanos church forest

| Table 5. The Pearson’s correlation of church forest area, basal area (BA), biomass and carbon stock (TBC), richness (R), density (D), diversity indices (H’ & E) and percent of exotic species (%Ex) of church forests along age gradient. |
|---|---|---|---|---|---|---|---|---|---|---|
| Area (ha) | BA (m²) | TBC (t/ha) | D | H’ | E | R | % Ex |
| Area 1 | 573 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| BA | .573 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| TBC | .212 | .763* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| D | .122 | .324 | .083 | 1 | 1 | 1 | 1 | 1 | 1 |
| H’ | .439 | .496 | .471 | .362 | 1 | 1 | 1 | 1 | 1 |
| E | .132 | .284 | .043 | .029 | .902** | 1 | 1 | 1 | 1 |
| R | .730* | .510 | .050 | .601 | .300 | .118 | 1 | 1 | 1 |
| %Ex | .682* | .493 | .510 | .327 | .324 | .043 | .575 | 1 |
| * Correlation is significant at the 0.05 level (2-tailed). | ** Correlation is significant at the 0.01 level (2-tailed). |
Figure 4. DBH (A) and height (B) class structure of woody plant community in church forests of Dangila district. DBH classes: 5–10cm (A), 10.1–15cm (B), 15.1–20cm (C), 20.1–25cm (D), 25.1–30cm (E), 30.1–35cm (F), 35.1–40cm (G), 40.1–45cm (H), 45.1–50cm (I) & >50cm (J); Height classes: <5m (A), 5.1–10(B), 10.1–15(G), 15.1–20(D), 20.1–25(E), 25.1–30(F), 30.1–35(G), 35.1–40(H), 40.1–45(I), >45m (J).

Figure 5. Woody species community structures along old, middle and recent age gradients of church forests in the district.
and biotic potential of the tree (Atsbha et al., 2019), rocky land, poorly
(Figure 6A) showed unhealthy population structure in the study area
pressure on remnant indigenous woody species (Mekonnen et al., 2016).
forests in Amhara region mainly found in Awi zones that could reduce the
theological thoughts and biblical basis of church forest; and plantation
major reason might be the commitment of the church followers on
2008; Tiwari et al., 2010; Atsbha et al., 2019). The church forests were
seedling
> [gummifera, Bersama abyssinica, Vepris nobilis
Millettia ferruginea, Croton macrostachyus, Eucalyptus camaldulensis, Albizia
The species that contribute the largest seedling and sapling counts were
regeneration status of the forest was considered as good since sapling >
Mean adults trees/ha Mean saplings/ha Mean seedlings/ha
| Gradients   |  Mean  |  Mean   |  Mean  |
|-------------|--------|--------|--------|
| Old age     | 1322   | 7307   | 6521   |
| Middle age  | 1293   | 6067   | 4883   |
| Recent age  | 3161   | 7706   | 3667   |
| Mean        | 1925   | 7026   | 5023   |

(Hordofa et al., 2020) and Kenech Forest (Balemlay and Siraj, 2021). The
DBH class distribution of woody species along age gradient also had an
inverted J-shape (Figure 5A - C). The distribution pattern indicates the
general trends of population dynamics and recruitment processes. A
species with the highest number of individuals in the lower DBH classes
suggests that they had good regeneration potential and vice versa
(Zegeye et al., 2011; Balemlay and Siraj, 2021). The average distribution
of seedlings, saplings and mature tree of the studied church forests were
5023, 7026 and 1925 individuals/ha respectively (Table 6). Hence, the
regeneration status of the forest was considered as good since sapling >
mean (Khumbongmayum et al., 2006; Dhaulkhandi et al., 2008; Tiwari et al., 2010; Atsbha et al., 2019). The church forests were
also showed a good regeneration status along age gradient (Table 6). The
major reason might be the commitment of the church followers on
theological thoughts and biblical basis of church forest; and plantation
forests in Amhara region mainly found in Awi zones that could reduce the
pressure on remnant indigenous woody species (Mekonnen et al., 2016).
The species that contribute the largest seedling and sapling counts were
Millettia ferruginea, Croton macrostachyus, Eucalyptus camaludelensis, Albizia
gummiëra, Bersama abyssinica, Vepris nobilis and Ritchiea abersii.
However, some tree species (i.e., *Ehretia cymosa* and *Podocarpus fal-
catus*) showed unhealthy population structure in the study area
(Figure 6A & B). The major factors might be grazing, poor germination
and biotic potential of the tree (Atsbha et al., 2019), rocky land, poorly
developed soil (Zegeye et al., 2011), and selective cutting for church
building. Moreover, individuals in young stages of any species were more
vulnerable to any kind of environmental stress and anthropogenic
disturbance (Atsbha et al., 2019). It is important to note that some of the
species were in poor regeneration status, and, thus, should be prioritized
for conservation (Zegeye et al., 2011).
As the result reveals that *E. japonica, C. africana, F. thonningii, P. fal-
catus* and *Accacia obscura* might face a great extinction in the locality
because they didn’t have seedlings and saplings. However, these species
were least concerned (plentiful in the wild) except *P. falcatu* that was
categorized as vulnerable in the wild by IUCN. The species might be
threatened with extinction in the wild unless its survival and
reproduction improves. In addition, four shrub species (*Asparagus afri-
canus, Dovyalis abyssinica, Lippia adoensis* and *Sida schimperiana*) and one
liana species (*Gladiolus candidus*) might also face a great extinction
because they occurred in a very small population number in the church
forests. *Euphorbia abyssinica*, *Ficus ingens*, *Ficus sycomorus*, *Myrica salicif-
folia* and *Senna petersiana* species face extinction in Bahir Dar Zuriya,
Dera and Fogera district church forests (Mequanint et al., 2020). These
species were locally extinct in the study area except *E. abyssinica*
(occurred with a small number of tree and sapling forms). Therefore, they
might be extinct in the studied church forests. The major reasons might
be unfavorable niche due to climate change and over exploitation. Hence,
the church forests need an attention for conservation and management in
the study area. Because forest management by the church community
might reduce extinction rates and contributes for maintaining species
richness (Wassie et al., 2010).

4. Conclusion and recommendation

4.1. Conclusion

According to the characteristic’s species recorded, the church forests
in the study area was categorized as dry Afromontane Forest and
Grassland Complex. The forests have 91 woody species that belong to 45
families and 77 genera. The most diverse family and genera were Fabaceae and *Accacia* respectively. The oldest church forests had a higher
Shannon diversity and species richness than recently established church
forests. In addition, exotic and indigenous species richness had a strong
negative relationship along age gradients. Because, the community give
more attention for planting fast growing exotic species particularly
*E. camaludelensis* in recently established churches for income generation,
area demarcation and live fencing. The community structure and
regeneration status of the church forests indicate that there were a better
level of protection in the church forests. However, it doesn’t mean that all
individual woody species were healthy because some species, i.e.,
*Podocarpus falcatu* and *Ehretia cymosa*, had an irregular population
structure in the study area.

The mean total above and below ground biomass carbon stock of the
church forest could store 145.29 and 36.33 metric tons/ha of CO₂
equivalence respectively. The lowest mean total biomass carbon stock
was recorded at recently established church forests; because biomass
carbon stock was mainly depends on tree size. The native species biomass
carbon stock was higher than exotic species in all age gradients. It
indicates that churches provide a sound conservation of indigenous tree
species in their periphery. The mean biomass carbon stock of exotic
species was highest in recently established churches due to the expansion

![A. Ehretia cymosa](image1.png)

![B. Podocarpus falcatu](image2.png)

Figure 6. Examples of woody species with irregular population structure.
of Eucalyptus plantation. Generally, the church forests in Dangila district have an important contribution for remnant woody species conservation and carbon sequestration as well as climate change mitigation.

4.2. Recommendation

Based on the results of the study, the following recommendations are made; (i), the practice of maintaining and establishing church forests around churches should be scaled up and supported by policy for a long-term development and management of forests particularly indigenous species. (ii), these remnant church forests need to be conserved though a collaboration work of governmental institutions and the community. (iii), the government should encourage churches in general and recently established churches in particular to plant and conserve indigenous species around their premises. (iv), the species with the least IVI value should be prioritized for in-situ and ex-situ conservation approaches. (v), the government should work for EOTC to get a payment for its contribution to ecosystem service. (vi), finally, the role of EOTC for herbs and wild animals as well as their potential for ecotourism needs to be investigated in the future.

Declarations

Author contribution statement

Geremew Bitew Sewagegn: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.  
Dagm Fikir Abate: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.  
Yohannis Gebremariam Girma: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Appendix

Appendix 1. Woody species relative frequency, relative density, relative dominance and IVI of the district along age gradient.

| Scientific name | Origin | Habit | Old age class | RF | Rd | RD | IVI | Middle age class | RF | Rd | RD | IVI | Recent age class | RF | Rd | RD | IVI |
|-----------------|--------|-------|---------------|----|----|----|-----|------------------|----|----|----|-----|-----------------|----|----|----|-----|
| Acacia abyssinica | I T   | 0.9  | 0.34 | 0.09 | 1.34 | 3.57 | 0.73 | 3.35 | 7.66 | 3.59 | 3.59 | 1.36 | 5.77 |
| Acacia brevijuga | I S   | 1.35 | 0.57  | 0.01 | 1.93 | 2.38 | 1.19 | 0.02 | 3.2  |
| Acacia decurrens | E T   | 0.6  | 1.19  | 0.64 | 3.83 | 0.6  | 0.6  | 0    | 1.2  |
| Acacia heptacarpa | I T  | 0.45 | 0.11  | 0    | 0.56 | 1.79 | 0.64 | 0    | 2.64 | 1.8  | 1.8  | 0.37 | 2.84 |
| Acacia obtusa    | I T   | 1.19 | 0.64  | 0.86 | 3.5  |
| Acacia pubescens | I S   | 1.8  | 0.63  | 0    | 2.43 | 1.19 | 0.37 | 0    | 2.37 | 1.8  | 1.8  | 0    | 3.45 |
| Acanthis semii  | I S   | 0.9  | 0.23  | 0    | 1.13 | 0.6  | 0    | 0    | 0.67 |
| Albizia gummifera | I T  | 2.7  | 1.54  | 2.55 | 6.79 | 2.98 | 6.3  | 15.95 | 24.25 | 2.4  | 2.4  | 0.08 | 3.3  |
| Apodytes dimidiate | I T  | 1.8  | 0.46  | 0.82 | 3.07 | 0.6  | 0.09 | 0.03 | 2.12 |
| Araucaria alpina  | I S   | 0.6  | 1.64  | 0    | 3.64 |
| Arundo donax    | I S   | 0.45 | 0.91  | 0    | 1.36 | 0.6  | 1.37 | 0    | 3.37 |
| Asparagus africanus | I S | 0.45 | 0.06  | 0    | 0.51 |
| Azadirachta indica | E T | 0.45 | 0.11  | 0    | 0.56 | 0.6  | 0    | 0.67 |
| Bolechis discolor | I T   | 1.35 | 1.54  | 1.21 | 4.1  |
| Bursamia abyssinica | I T  | 2.25 | 3.93  | 7.62 | 13.81 | 1.79 | 0.82 | 0    | 2.82 |
| Bridelia micrantha | I T | 1.19 | 0.55  | 0.01 | 2.56 |
| Brusca antisyussinica | I S | 2.7  | 1.03  | 0    | 3.73 | 4.76 | 3.01 | 0    | 5.01 | 4.79 | 4.79 | 0    | 6.36 |
| Calpurnia aurea | I T   | 0.6  | 0.18  | 0    | 2.18 |
| Capparis tomentosa | I S | 1.8  | 1.37  | 0.05 | 3.21 | 0.6  | 0.09 | 0    | 2.09 | 1.8  | 1.8  | 0    | 3    |
| Carissa spinarum | I S   | 3.15 | 3.53  | 0.72 | 7.4  | 3.57 | 2.19 | 0.03 | 4.23 | 1.8  | 1.8  | 0.15 | 4.19 |
| Cassia exquisitifolia | E T | 0.45 | 0.06  | 0    | 0.51 | 0.6  | 0    | 0.67 |
| Celtis africana | I T   | 0.6  | 0.09  | 0.26 | 2.35 |
| Citrus aurantifolia | I T  | 0.45 | 0.06  | 0    | 0.51 | 1.2  | 1.2  | 0.04 | 1.61 |

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### Appendix 1 (continued)

| Scientific name          | Origin | Habit | Old age class | Middle age class | Recent age class |
|--------------------------|--------|-------|---------------|------------------|-----------------|
|                          |        |       | RF | Rd | RD | IVI | RF | Rd | RD | IVI | RF | Rd | RD | IVI |
| *Citrus reticulata*      | I T    | 1.35  | 0.23 | 0.03 | 1.61 |
| *Clausena anisata*       | I T    | 2.25  | 3.87 | 0.06 | 6.18 |
| *Clerodendrum borneol*   | I L    | 0.6   | 0.09 | 0    | 2.09 |
| *Clematis longicapa*     | I L    | 1.35  | 1.03 | 0    | 2.38 |
| *Clematis sinensis*      | I L    |       |       | 1.2  | 1.2  |
| *Coffea arabica*         | I S    | 1.35  | 0.97 | 0    | 2.32 |
| *Cordia africana*        | E T    | 2.7   | 0.46 | 1.27 | 4.42 |
| *Croton macrostachyus*   | E T    | 3.6   | 1.71 | 22.31| 27.63| 4.76| 3.84| 31.04| 36.88| 4.79| 4.79| 3.38| 13.41|
| *Cupressus lusitanica*   | E T    | 1.19  | 1.37 | 0.59 | 3.96 |
| *Dombeya quinqueseta*    | I T    | 0.92  | 1.35 | 2.48 |
| *Dovyalis abyssinica*    | I T    | 1.35  | 0.34 | 0    | 1.69 |
| *Dracaena steudneri*     | I T    | 2.7   | 1.82 | 22.64| 27.17| 4.76| 3.84| 31.04| 36.88| 4.79| 4.79| 3.38| 13.41|
| *Echinochloa colonum*    | I T    | 1.35  | 0.34 | 0    | 1.69 |
| *Ehretia cymosa*         | I T    | 1.35  | 0.4  | 2.5  | 4.25 |
| *Ekebergia capensis*     | E T    | 2.7   | 8.38 | 1.38 | 12.46| 4.76| 15.8 | 23.34| 41.14| 5.39| 5.39| 87.92| 136.17|
| *Eucalyptus camaldulensis*| E T    | 2.7   | 3.88 | 3.87 | 7.79 |
| *Euphorbia abyssinica*   | I S    | 2.7   | 0.91 | 0.1  | 3.72 |
| *Ficus carica*           | I T    | 0.9   | 0.11 | 2.3  | 3.77 |
| *Ficus carica*           | I T    | 1.35  | 0.11 | 2.3  | 3.77 |
| *Galaniera saxifrage*    | I T    | 0.6   | 0.64 | 0    | 2.64 |
| *Gladus candidus*        | I L    | 0.6   | 0.34 | 0    | 2.09 |
| *Grevillea robusta*      | E T    | 1.35  | 2.05 | 5.85 | 9.25 |
| *Grewia ferruginea*      | I S    | 2.7   | 0.91 | 0.1  | 3.72 |
| *Hibiscus asiaticus*     | I S    | 1.19  | 0.37 | 0    | 2.37 |
| *Hypericum revolutum*    | I T    | 1.35  | 0.11 | 0    | 0.56 |
| *Jasminum sambac*        | I S    | 0.45  | 0.23 | 0    | 0.68 |
| *Juniperus procera*      | I T    | 1.8   | 0.4  | 1.42 | 3.62 |
| *Justicia schimperiana*  | I S    | 4.05  | 25.13| 0    | 29.18| 4.76| 14.52| 0    | 16.52| 1.8 | 1.8 | 0.38 | 4.57 |
| *Lippia adoensis*        | I S    | 0.45  | 0.06 | 0    | 0.51 |
| *Marua lanceolata*       | I T    | 1.8   | 2.34 | 0.75 | 4.89 |
| *Mangifera indica*       | E T    | 0.45  | 0.06 | 0    | 0.51 |
| *Maytenus arbutifolia*   | I S    | 3.6   | 6.55 | 0    | 10.16| 4.76| 7.12 | 0.01 | 9.13 | 5.39 | 5.39 | 87.92| 136.17|
| *Maytenus obtusifolia*   | I S    | 0.45  | 0.17 | 0    | 0.62 |
| *Milletia ferruginea*    | I T    | 2.25  | 3.36 | 15.18| 20.79| 1.79| 0.37 | 0.29 | 2.65 | 0.6 | 0.6 | 0.06 | 0.03 |
| *Morus alba*             | E S    | 1.2   | 1.2  | 0    | 1.35 |
| *Ocimum basilicum*       | I S    | 0.45  | 0.23 | 0    | 0.68 |
| *Olecrania integerrima*  | E L    | 0.45  | 0.34 | 0    | 0.79 |
| *Ox Watching*            | I S    | 1.8   | 1.8  | 0    | 0.01 |
| *Ox Watching*            | I S    | 0.45  | 0.06 | 0    | 0.51 |
| *Pavonia urinaria*       | I S    | 2.7   | 3.08 | 0    | 5.78 |
| *Phoenix reclinata*      | I S    | 0.45  | 0.06 | 0    | 0.51 |
| *Phyllotasia deduncula*  | I S    | 0.45  | 0.11 | 0    | 0.56 |
| *Podocarpus falcatus*    | I T    | 3.15  | 0.8  | 0.82 | 4.77 |
| *Prunus africana*        | I T    | 0.45  | 0.17 | 0.1  | 0.72 |
| *Psidium guajava*        | E T    | 0.6   | 0.46 | 0    | 2.46 |
| *Prunus eriantha*        | I L    | 0.6   | 0.46 | 0    | 2.46 |
| *Rhamnus primordialis*   | I S    | 0.45  | 0.11 | 0    | 0.57 |
| *Rubus glutinosus*       | I T    | 0.45  | 0.51 | 0.62 | 1.59 |
| *Rhus chinensis*         | I T    | 2.7   | 1.54 | 0    | 4.24 |
| *Rosa abyssinica*        | I S    | 0.45  | 0.06 | 0    | 0.51 |
| *Rubus steudneri*        | I S    | 1.35  | 0.85 | 0    | 2.21 |
| *Rumex abyssinicus*      | I S    | 0.45  | 0.17 | 0    | 0.62 |
| *Sebium sebiferum*       | E T    | 0.6   | 0.18 | 0    | 2.18 |
| *Sidea schimperiana*     | I S    | 0.45  | 0.06 | 0    | 0.51 |
| *Solanoia gigas*         | I S    | 1.8   | 2.34 | 0.01 | 4.15 |
| *Solanium xanthocarpum*  | I S    | 0.45  | 0.11 | 0    | 0.56 | 2.38| 0.27 | 0    | 2.27 | 0.6 | 0.6 | 0.06 | 0.67 |

(continued on next page)
Appendix 1 (continued)

| Scientific name | Origin | Habit | Old age class | Middle age class | Recent age class |
|-----------------|--------|-------|---------------|------------------|-----------------|
| *Stegonanthera eriachne* | I S | 0.45 0.23 | 0 0.68 | 1.2 1.2 | 0.07 1.72 |
| *Streuspermum kunthianum* | I T | 1.35 0.57 | 0.09 2.01 | 2.38 0.09 | 0 2.09 |
| *Urena lycopodanther* | I T | 1.8 1.82 0 | 0.01 3.63 | 0.6 1.46 0.11 | 3.58 0.6 0.6 0 0.82 |
| *Vernonia adenosan* | I S | 0.45 0.57 | 0 | 1.02 | 0.6 0.18 0 | 2.18 0.6 0.6 0 1.42 |
| *Vernonia amygdidal* | I S | 2.25 0.74 | 0.11 3.1 | 2.38 1.1 0.02 | 3.12 4.19 4.19 0.24 7.5 |
| *Vernonia auriculifera* | I S | 3.6 4.22 | 0.02 7.84 | 4.76 8.49 0.02 | 10.52 4.79 4.79 0 7.86 |
| *Vernonia thomsoniana* | I S | 1.8 1.8 0 | 0 3 |
| *Zeheria scabra* | I L | 0.9 0.11 | 0 1.01 |

I = indigenous, E = exotic, T = tree, S = shrub, L = liana, RF = relative frequency, Rd = relative density, RD = relative dominance and IVI = important value index.

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