

# Ecological study and forest degradation of the sacred Waldiba Monastery's dry woodland

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## Research Article

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# Abstract

Anthropogenic disturbance put the woodlands in the monasteries and churches under significant threat. To study the floristic composition and forest degradation of Waldiba monastery dry woodland in Tigray, Ethiopia, 30 plots were established along transect lines. We recorded 39 native woody species (33 trees, 5 shrubs and 1 liana) belonging to 19 families. Shannon diversity index, Simpson similarity index, evenness and dominance were 3.10, 0.94, 0.58 and 0.06, respectively. The densities of woody species were 922 stems ha<sup>-1</sup> with a total basal area of 49.27 m<sup>2</sup> ha<sup>-1</sup>. The tree species with higher IVI value were *Dichrostachys cinerea* (86.04%), *Combretum fragrans* (71.87%), *Combretum hartmannianum* (60.30%) and *Combretum* sp. (50.15%). The population structure of the woody species demonstrated various patterns. The regeneration status was not promising for vast majority of the species. *Vachellia venosa* and *C. hartmannianum* respectively are listed as endangered and vulnerable species in the IUCN red list species category. Waldiba dry woodland has undergone significant cover changes over a period of 46 years. Waldiba has lost much (65%) of its dense forest and open forest (44%) mainly due to anthropogenic disturbance. The woodland with all its biodiversity is under threat. The species with low IVI, species listed in IUCN red list and those species with none to poor regeneration status should be prioritized for in situ and ex situ conservation intervention to avert the threat. Research on reproductive ecology of the threatened endemic species is imperative, as the woodland should be managed for ecosystem services and biodiversity conservation.

## 1 Introduction

Tropical dry forests are forests in dryland areas that are distinguished by their marked dry season and low water availability. They have a ratio of potential evapotranspiration to precipitation of between one and four, and experience typically three to eight months of drought [1]. Dry tropical forests cover over 40% of the global tropical forest areas [2–4]. The largest proportion of dry forest is found in Africa [1, 3] with an area of 17.3 million km<sup>2</sup> [5]. Dry forests and woodlands are the largest remaining forest resources and covers 55 million ha in Ethiopia [4, 6, 7].

Dry tropical forests contain a wealth of unique biodiversity of immense local, regional and international significance [2, 8], are home for half a billion people [2, 4], directly support the livelihood of one billion people worldwide [1] and approximately 52 million rural households in the Horn of Africa [9]. For instance, tapping and grading of frankincense and natural gums in the drylands create a seasonal employment opportunities for 20,000 to 30,000 people in Ethiopia [10]. The unique feature of dry forests and woodlands of Ethiopia is their richness with the major gum and resin bearing species of the genera of *Acacia*, *Boswellia* and *Commiphora* [2, 4] that have high cultural, religious, economic and ecological significance [2, 7]. Despite this fact, dry forests remain among the worlds most threatened and least protected forests [4, 7, 8]. Until recently, very little attention has been given to develop, protect and sustainably manage these valuable resources. However, Ethiopian dry forests are caught in a spiral of deforestation due to competing land uses [2]. For example in Tigray, one of the largest frankincense

producing areas in Ethiopia, about 170,000 ha dry forest has been deforested and converted to croplands since the 1970s [3, 4].

In Tigrai, forest disturbance has a 3000-year history [11, 12]. As a result, large forests have been converted into arable land that today the last remaining refugia for native woody plant species are found around churches and monasteries [13–15]. As such, church/monastery forests and woodlands are considered as biodiversity hotspot, the last natural seed banks for native trees species, reference areas for local endemism and buffer against depletion and last corner stones for species distribution [13].

Waldiba monastery woodland is one of the potential natural vegetation found in Tigrai. Like other tropical dry forests, land degradation is rife due to overgrazing, illegal logging and overexploitation of the woodlands, farming its fragile lands, gold mining, settlement, burning (wildfire) and which resulted in clearing of Waldiba dry woodland [16]. Problems of dry woodland degradation in Tigrai have been reported in many studies [3, 17–21]. However, most of these studies emphasis were on the population structure and focused on only single woody species like *Boswellia papyrifera* [3, 18, 21, 22], *Adansonia digitata* [17] and *Oxytenanthera abyssinica* [19]. To the best of our knowledge, studies on floristic compositions and forest degradation the monastery dry woodland are scanty.

Majority of the floristic composition studies [23–28] are conducted in the mountain chain highlands. Only few studies [18, 29–31] have been conducted in the lowland dry woodland areas. Understanding of floristic compositions and forest health is important for biodiversity conservation and management. Therefore, this study was conducted to (1) assess the diversity of woody species in the woodland (2) determine the population structure and regeneration status of woody species and (3) identify the drivers of deforestation and forest degradation using multi-criteria decision model – the Analytical Hierarchy Process (AHP).

## 2 Materials and Methods

### 2.1 Study Area

Waldiba Monastery dry woodland is situated within Tselemti district in the north western zone of Tigrai, Ethiopia (Fig. 1). Geographically, it lies in between 13° 30' to 14° 00' North and 37° 45' to 38° 15' East in the western lowland (elevation below 1,250 m) of Tigrai. It is about 450 km far from Mekelle, the capital of Tigrai. It is bounded by three regional district (Asgede Tsimbla, Welqait and Tsegede) and by the National Regional State of Amhara. Waldiba monastery dry woodland forest is the largest state forest with an area of almost 950 km<sup>2</sup> next to Desa'a forest. The woodland is cut by Tekeze, Zarema, Tsotit and Insiya rivers. The monastery forest is surrounded by villages with 47, 000 inhabitants. Waldiba receives greater than 1000 mm rainfall annually. Besides, the mean annual temperature is around 26 °C and varies from 40.8 to 49.4 °C for the maximum and from 12.3 to 21 °C for the minimum. The hottest months are March to June.

### 2.2 Vegetation survey

## 2.2.1 Vegetation sampling

Systematic sampling method was employed for the inventory of woody species [30]. In the woodland, we laid parallel line transects in south-north direction. Along the line transects, sample plots measuring 20 m × 20 m (400 m<sup>2</sup>) were established approximately at 1 km intervals to measure trees and shrubs' attributes [32]. Overall, 30 representative sample plots were established in the woodland. Inside the plots, nested sub-plots of 3 m × 3 m (9 m<sup>2</sup>) were established to measure sapling/seedlings attributes and herb cover.

## 2.2.2 Vegetation data collection

In each sample plot, vegetation related components such as species composition, density (seedling, sapling, shrub and tree), frequency, diameter at breast height (DBH) for trees, diameter at stump height (DSH) for shrubs and some – saplings and tree height were recorded. Furthermore, environmental and disturbance variables such as topography, illegal logging, livestock pressure and fire incidence were recorded for each sample plot. Diameter tape and Suunto hypsometer were used to measure DBH and height, respectively. All woody species were identified by their local and/or scientific names. Species identification was done directly in the field using relevant reference materials [33, 34] as well as with the help of local people familiar with the flora [35, 36]. Furthermore, woody species that occurred outside the plots were also recorded to produce a more complete list of the woody plants in the study area. Finally, the woody species were classified into different growth forms based on their height and diameter: A height > 1.5 m and DBH ≥ 2.5 cm as tree, a height of ≥ 0.50 m and < 1.5 m or with DBH/DSH < 2.5 cm as saplings/shrubs and a height < 0.50 m as seedling [37].

## 2.2.3 Vegetation data analysis

Diversity was analysed using the Shannon diversity index (H) and evenness or equitability index (E) [27, 38]. Shannon diversity index takes into account the species richness and evenness [39] and it usually lies between 1.5 and 3.5 and rarely exceeds 4.5 [40]. It is considered as high (≥ 3), medium (2–3), low (1– 2) and very low when it is ≤ 1.0 [23]. The community types were identified with the multivariate hierarchical clustering (dendrogram) method using the Ward's algorithm and based on Bray-Curtis similarity index [41]. The diversity analysis and hierarchical clustering were performed in PAST software version 3.06 [42]. Likewise, structure were computed based on density, frequency, DBH and basal area per hectare and the Importance Value Index (IVI) using Microsoft excel [27, 32, 35, 36, 38, 39]. To describe population structure, individuals of recorded tree species were grouped into 10 diameter classes. Then, the structure was depicted using frequency histograms that the resulting frequency histograms were interpreted as proxy for regeneration status. Only tree species with higher IVI and one economical flagship tree were considered for analyses of population structure. The IVI and basal area of each tree/shrub species were calculated using the following equations:

$$R_D = \frac{N_i}{\sum_{i=1}^s N_i}$$

1

Where,  $R_D$  is the Relative Density of a species and  $N_i$  is number of individuals of the  $i^{th}$  species,

$$R_F = \frac{F_i}{\sum_{i=1}^s F_i}$$

2

Where,  $R_F$  is Relative Frequency of a species and  $F_i$  is number occurrences of the  $i^{th}$  species;

$$R_{DO} = \frac{B_i}{\sum_{i=1}^s B_i}$$

3

Where,  $R_{DO}$  is Relative Dominance of a species and  $B_i$  is total basal area of the  $i^{th}$  species

$$B_A = \frac{\pi d^2}{4}$$

4

Where,  $B_A$  is Basal Area,  $d$  is diameter of the tree or shrub

$$IVI = R_D + R_F + R_{DO}$$

5

Where,  $R_D$  is relative density,  $R_F$  is relative frequency and  $R_{DO}$  is relative dominance

## 2.3 Focus group discussion (FGDs) and key informant interview (KII)

To substantiate the analysis of floristic composition and to identify the major driving forces of deforestation and forest degradation and other relevant nonvisual information, FGDs and KII were undertaken. The data obtained from FGDs were used to weight and rank the major of drivers cover change using one of the multi-criteria decision making (MCDM) technique, Analytic Hierarchy Process (AHP) as per the procedures outlined in Gidey et al. (2020) and Marques (2016). As criteria, we used the proximate and underlying causes of forest degradation. Overgrazing, cultivation (irrigation development, dam construction and settlement), mining, Illegal logging and over exploitation (fuelwood, charcoal making, and house construction, poaching, over tapping, wildfire), biotic factors (insect attack) and abiotic (drought induced tree dieback) were the alternatives for proximate cause while population

pressure, poverty, policy (institutional) issues and lack of awareness were the alternatives for underlying cause.

### 3. Results

## 3.1 Vegetation survey

### 3.1.1 Floristic composition

In our study, we recorded a total of 39 (33 trees, 5 shrubs and 1 liana) indigenous woods species (Table 1) belonging to 19 families. *Combretaceae* and *Fabaceae* were the dominant families, contributing 7 species and 6 species to the total woody species composition, respectively. The remaining 17 families were represented either by two or a single species. This finding does not include the magnificent gigantic tree *Adansonia digitata* which belongs to the family *Bombacaceae* that was present in the woodland but was not recorded in the sample plots. Some species such as *C. hartmannianum* and *V. venosa* respectively are listed as vulnerable and endangered species in the IUCN red list (<https://www.iucnredlist.org/>).

### 3.1.2 Plant community types

Three plant community types were identified (Fig. 2); *Combretum* – *Terminalia*, *Boswellia* – *Ziziphus* and *Vachellia* – *Ximenia*. The *Combretum* – *Terminalia* community type were found in the altitude 958–1201 m above sea level from flat plains to hilly slopes. The main species in this community were *Combretum fragrans*, *Combretum hartmannianum*, *Combretum* sp., *Combretum molle*, *Terminalia* sp. *Terminalia brownie*, *Grewia ferruginea* and *Grewia flavescens*. The *Boswellia* – *Ziziphus* community type were found in the altitude of 835 -1201m in hilly slopes and shallow soils. The dominant species include *B. papyrifera*, *Ziziphus abyssinica*, *Ziziphus spina-christi*, *Pterocarpus lucens*, *Stereospermum kunthianum*, *Otostegia fruticosa*, *Lannea fruticosa*. The *Vachellia* – *Ximenia* community type were found in the altitudinal range of 999–1174 at slopes < 5% in the flat plain with deep soil and also around riverbanks. The main species of this community type include *V. polyacantha*, *Vachellia sieberiana*, *Vachellia etbaica*, *Ximenia americana*, *Tamarindus indica*, *Sterculata setegra*, *Dovyalis abyssinica* and *Diospyros mespiliformis*.

### 3.1.3 Woody species diversity

In our study, we found a Shannon diversity index, Simpson similarity index, evenness and dominance values of 3.10, 0.58 and 0.06, respectively. This indicates that the woodland is relatively high in species diversity, with almost even representation of each species and with low dominance of species.

### 3.1.4 Frequency, density and dominance

The most frequent species that was present in 70% of sampled plots (Table 1) was *D. cinerea* followed by *C. fragrans* (56.67%), *C. hartmannianum* (40%), *Combretum* sp. (36.67%) and *Z. abyssinica* (30%). This

indicates that the woodland is being dominated by thorny and less palatable species. The economically and ecologically important species like *B. papyrifera*, *Combretum* sp. and *Terminalia* sp. species are being replaced by those less palatable thorny shrubs (Table 1 and Fig. 3). These variation in frequency of species is attributed to the species habitat preferences, regeneration ability and disturbance degree.

We recorded a total of 922 stems  $\text{ha}^{-1}$  in Waldiba dry woodland (Table 1). The five most important woody species in terms of their density are in the order of *C. hartmannianum* (103 stems  $\text{ha}^{-1}$ ), *Dichrostachys cinerea* (99 stems  $\text{ha}^{-1}$ ), *C. fragrans* (48 stems  $\text{ha}^{-1}$ ), *V. polyacantha* (48 stems  $\text{ha}^{-1}$ ) and *Terminalia* sp. (47 stems  $\text{ha}^{-1}$ ) (Table 1). The relative density (RD) which is similar to the density (stems  $\text{ha}^{-1}$ ) also followed the same trend as of the density (Table 1). In terms of dominance (Table 1), the six most dominant tree species contributing to more than 50% of the basal cover were *B. papyrifera* (14.06%), *Combretum* sp. (9.79%), *C. fragrans* (8.91%), *C. hartmannianum* (6.86%), *Terminalia brownii* (6.74%) and *V. polyacantha* (5.44%). Mostly these species were found in mature stands with large diameter (up to 50 cm).

### 3.1.5 Basal area

The total basal area of all woody species was  $49.27 \text{ m}^2 \text{ ha}^{-1}$ . Species with the largest contribution in basal area can be considered the most important woody species in the woodland [38, 44]. The species with the largest basal area were *B. papyrifera* 6.93 (14.06%) due to its big size [45]. The other five species with the largest basal area contribution (51.82%) in addition to *B. papyrifera* were *C. fragrans* (8.91%), *Combretum* sp. (9.80%), *C. hartmannianum* (6.86%), *Terminalia brownie* (6.74) and *V. polyacantha* (5.44%). Thus, these species are considered as the most ecologically important species and the difference in basal area could be due to the presence of old growth and big diameter trees.

### 3.1.6 Important Value Index (IVI)

The most ecologically important species in the woodland (Table 1) with IVI value of more than 50 were *D. cinerea* (86.04), *C. fragrans* (71.87), *C. hartmannianum* (60.30) and *Combretum* sp. (50.15). The three ecologically important tree species in the woodland, *B. papyrifera*, *V. polyacantha* and *Sterculia africana*, had IVI value of 31.19, 31.73 and 10.77 respectively. Around 80% of the species in the forest have IVI of more than 5 indicating the woodland is composed of ecological important woody species.

*T. indica*, *Cissus petiolata*, *Commiphora africana*, *Diospyros mesphiliformis*, *G. flavescens*, *Ziziphus spina-christ* and *Otostegia fruticose* are species with IVI value of < 5% that need immediate conservation intervention. Moreover, there are endemic plants that are listed in the IUCN Red List that need special attention and conservation action. Example, despite its good stocking in the woodland and high IVI, *C. hartmannianum* is classified as vulnerable [46] and *Vachellia venosa* as endangered [47].

Table 3

Tree density ha<sup>-1</sup>, Relative frequency (RF), Relative abundance (RA), Relative dominance (RD) and Importance Value Index (IVI) of woody species

| Species                                                                                                                        | Stem<br>ha <sup>-1</sup> | BA   | RD    | RF    | RA    | IVI   |
|--------------------------------------------------------------------------------------------------------------------------------|--------------------------|------|-------|-------|-------|-------|
| <i>Dichrostachys cinerea</i> (L.) Wight & Arn.                                                                                 | 99                       | 1.54 | 12.91 | 70.00 | 3.13  | 86.04 |
| <i>Combretum fragrans</i>                                                                                                      | 48                       | 4.39 | 6.29  | 56.67 | 8.91  | 71.87 |
| <i>Combretum hartmannianum</i> Schweinf.,                                                                                      | 103                      | 3.38 | 13.45 | 40.00 | 6.86  | 60.30 |
| <i>Combretum</i> sp.                                                                                                           | 28                       | 4.83 | 3.69  | 36.67 | 9.79  | 50.15 |
| <i>Ziziphus abyssinica</i> Hochst. ex A. Rich.                                                                                 | 32                       | 1.39 | 4.12  | 30.00 | 2.82  | 36.94 |
| <i>Lannea fruticosa</i> (Hochst. ex A.Rich.) Engl.                                                                             | 19                       | 1.61 | 2.49  | 30.00 | 3.26  | 35.76 |
| <i>Combretum molle</i> R.Br. ex G.Don                                                                                          | 26                       | 1.63 | 3.36  | 26.67 | 3.31  | 33.34 |
| <i>Vachellia polyacantha</i> (Willd.) Seigler & Ebinger<br>subsp. <i>campylacantha</i> (Hochst. ex. A Rich.)<br>Kyal. & Boatwr | 48                       | 2.68 | 6.29  | 20.00 | 5.44  | 31.73 |
| <i>Boswellia papyrifera</i> (Caill. ex Delile) Hochst.                                                                         | 29                       | 6.93 | 3.80  | 13.33 | 14.06 | 31.19 |
| <i>Anogeissus leiocarpus</i> (DC.) Guill. & Perr.                                                                              | 15                       | 1.87 | 1.95  | 23.33 | 3.79  | 29.08 |
| <i>Terminalia</i> sp.                                                                                                          | 47                       | 1.99 | 6.07  | 16.67 | 4.05  | 26.79 |
| <i>Terminalia brownii</i> Fresen                                                                                               | 12                       | 3.32 | 1.52  | 13.33 | 6.74  | 21.60 |
| <i>Lonchocarpus bussei</i> Harms (L. laxiflorus)                                                                               | 7                        | 1.40 | 0.87  | 16.67 | 2.85  | 20.38 |
| <i>Pterocarpus lucens</i> Lepr. ex Guill. & Perr.                                                                              | 33                       | 1.37 | 4.23  | 13.33 | 2.79  | 20.35 |
| <i>Mimusops kummel</i> Bruce ex A.DC.                                                                                          | 28                       | 1.37 | 3.58  | 13.33 | 2.78  | 19.69 |
| <i>Stereospermum kunthianum</i> Cham                                                                                           | 12                       | 0.72 | 1.52  | 16.67 | 1.47  | 19.66 |
| <i>Ximenia americana</i> L.                                                                                                    | 12                       | 0.35 | 1.52  | 16.67 | 0.72  | 18.90 |
| <i>Dovyalis abyssinica</i> (A.Rich.) Warb.                                                                                     | 26                       | 0.37 | 3.36  | 10.00 | 0.75  | 14.12 |
| <i>Diospyros mespiliformis</i> Hochst. ex A. DC                                                                                | 33                       | 0.18 | 4.34  | 6.67  | 0.36  | 11.36 |
| <i>Oxytenanthera abyssinica</i> (A.Rich.) Munro                                                                                | 15                       | 1.16 | 1.95  | 6.67  | 2.35  | 10.97 |
| <i>Sterculia africana</i> Lour.) Fiori                                                                                         | 2                        | 1.92 | 0.22  | 6.67  | 3.89  | 10.77 |
| <i>Dalbergia melanoxydon</i> Guill. & Perr.                                                                                    | 8                        | 0.44 | 0.98  | 6.67  | 0.89  | 8.53  |
| <i>Grewia ferruginea</i> Hochst. ex A.Rich.                                                                                    | 7                        | 0.28 | 0.87  | 6.67  | 0.56  | 8.10  |
| <i>Vachellia sieberiana</i> (DC.) Kyal. & Boatwr.                                                                              | 4                        | 0.29 | 0.54  | 6.67  | 0.58  | 7.79  |

| Species                                                                                | Stem<br>ha <sup>-1</sup> | BA           | RD         | RF         | RA         | IVI        |
|----------------------------------------------------------------------------------------|--------------------------|--------------|------------|------------|------------|------------|
| <i>Maytenus senegalensis</i> (Lam.) Exell                                              | 3                        | 0.26         | 0.43       | 6.67       | 0.52       | 7.62       |
| <i>Jasminum floribundum</i> R.Br. ex Fresen.                                           | 7                        | 0.02         | 0.87       | 6.67       | 0.04       | 7.58       |
| <i>Jasminum grandiflorum</i> subsp. <i>floribundum</i><br>(R.Br. ex Fresen.) P.S.Green | 25                       | 0.11         | 3.25       | 3.33       | 0.23       | 6.82       |
| <i>Vachellia etbaica</i> Schweinf. Kyal. & Boatwr.                                     | 17                       | 0.45         | 2.17       | 3.33       | 0.92       | 6.42       |
| <i>Albizia amara</i> (Roxb.) Boivin                                                    | 2                        | 0.90         | 0.22       | 3.33       | 1.82       | 5.37       |
| <i>Vachellia venosa</i> Hochst. ex Benth.                                              | 3                        | 0.82         | 0.33       | 3.33       | 1.67       | 5.33       |
| <i>Commiphora africana</i> (A.Rich.) Engl.                                             | 8                        | 0.11         | 0.98       | 3.33       | 0.22       | 4.53       |
| <i>Diospyros mesphiliformis</i> Hochst. ex A.DC.                                       | 3                        | 0.31         | 0.33       | 3.33       | 0.64       | 4.30       |
| <i>Tamarindus indica</i> L.                                                            | 1                        | 0.35         | 0.11       | 3.33       | 0.72       | 4.16       |
| <i>Cissus petiolata</i> Hook.f.                                                        | 2                        | 0.23         | 0.22       | 3.33       | 0.47       | 4.03       |
| <i>Grewia flavescens</i> Juss.                                                         | 4                        | 0.05         | 0.54       | 3.33       | 0.09       | 3.97       |
| <i>Ziziphus spina-christi</i> (L.) Desf.                                               | 3                        | 0.11         | 0.33       | 3.33       | 0.23       | 3.89       |
| <i>Otostegia fruticosa</i> (Forssk.) Schweinf. ex<br>Penzig ( <i>O. repanda</i> )      | 1                        | 0.14         | 0.11       | 3.33       | 0.28       | 3.72       |
| Hareg Hazo*                                                                            | 2                        | 0.00         | 0.22       | 3.33       | 0.01       | 3.56       |
| <b>Total</b>                                                                           | <b>922</b>               | <b>49.27</b> | <b>100</b> | <b>100</b> | <b>100</b> | <b>300</b> |

(\*) Refers to local name for unidentified liana

### 3.1.7 Population Structure

In Waldiba dry woodland, we selected and analysed the population structure of six ecologically important species (Fig. 3). The selected woody species demonstrated various patterns of population structure, implying different population dynamics of each species. Only *D. cinerea* demonstrated a normal (inverted J shape) population growth pattern with good reproduction and recruitment capacity. The others showed either bell-shaped, J-shaped or irregular growth pattern with missing diameter class in the lower or upper or middle diameter classes. For instance, *B. papyrifera* showed a hampered seedling, sapling and shrub recruitment and a very low stocking in the upper diameter class (2 stems/ha) implying the high level of threat facing to the species due to its limited reproduction and recruitment capacity.

### 3.1.8 Regeneration Status

The distribution of seedlings, saplings and mature trees/shrubs in Waldiba dry woodland shows three distinct patterns. The first class, good regeneration, includes species represented by all three stages and includes *V. polyacantha*, *C. hartmannianum* and *D. cinerea*. The second class, poor regeneration, is represented by seedling and mature trees/shrubs but no saplings and includes *D. melanoxylon*, *D. abyssinica*, *T. brownii* and *X. americana*. The third class, fair regeneration, is represented by sapling and mature trees/shrub but not seedling and comprises *G. ferruginea* and *J. floribundum*.

## 3.2 Drivers of deforestation and forest degradation in Waldiba dry woodland

We collate information on the factors of deforestation and forest degradation from FGDs and KII. The data collected from the FGDs were used to prioritize the drivers of forests cover change using AHP, a multi-criteria decision making. The overall objective of AHP was to identify and select the driving force for forest degradation using the criteria proximate and underlying causes and their respective alternatives discussed below.

The informants' notice that the forest cover is dwindling and declare that both the proximate (87.50%) and underlying (12.5%) causes are the main reasons for the forest cover change (Figs. 4 and 5). Uncontrolled grazing, illegal logging, crop land expansion, mining, biotic and abiotic factors with their respective % weighted Eigen (absolute %) values of 37.86% (43.27%), 18.32% (20.97%), 12.23% (13.98%), 10.05% (11.49%), 5.08% (5.80%) and 3.95% (4.52%) were the main proximate drivers of forest cover change (Figs. 4 and 5). Whereas, population increase, poverty, lack of awareness and institutional (policy) issues with their respective weighted and absolute values of 7.43% (59.40%), 2.57% (20.59%), 1.46% (11.70%) and 1.04% (8.31%) were the main underlying causes for cover change.

Of the proximate drivers that need much attention is the uncontrolled livestock grazing as it could also be the underlying cause of other degradations. People herd their cattle in Waldiba from villages found around the woodland (Asgede Tsimbla, Tselemti, Sheraro and Tsegede) and from distant districts as far as Inticho (~ 235km) and even from Eritrea as far as Mendefera in the past. During the rainy season, the livestock graze the grasses found in the woodland. However, during dry season the herders chopped tree branches to feed the leaves for their livestock. In most cases, they do not do proper lopping, rather they cut the trees at some point above the ground that might be difficult for the tree to rejuvenate or regrow. Mass movement of livestock in a certain locations has also impacted on the regeneration of the flagship tree species, *B. papyrifera* and *A. digitata*. Furthermore, to cook their food, the herders also cut trees that are with good calorific value and less smoke. There is less tendency to using of dead trees that are present in the woodland. When the herders fall short of ranches, they also burn the woodland to get space for their calves and to construct house for themselves.

The other major stakeholder who are drivers of forest degradation (LULC) are gold miners, the monks of the monastery, tappers and poachers. For traditional gold mining, vast area of the woodland is destroyed. Moreover, the gold miners and the tappers use wood and wood product for making utensil, digging (tapping) material, shelter construction, cooking and heating. Likewise, due to lack of awareness, the

monks are also involved in logging of trees for food cooking and shelter making. What makes worse is they cut good stand of rare and vulnerable tree trees like *Combretum sp.* to construct shelter for its hardy nature and resistant to termite attack. The poachers are involved in biodiversity loss through the killing wildlife apart from the use of wood for cooking and shelter. The situation was further affirmed from the KII. As a result of poaching for bush meat many wildlife like *Minilik* bush back and Antelope have been once sheltered in the woodland have been lost or greatly reduced.

## 4 Discussions

### 4.1 Floristic composition, diversity and community types

Floristic composition of a vegetation can be described in terms of species richness, abundance, dominance, and frequency [41, 48]. In this study, a total of 39 indigenous woods species including trees, shrubs and lianas were recorded. *Combretaceae* and *Fabaceae* were the dominant families. The dominance of *Combretaceae* and *Fabaceae* in the present study is in line with those reported for Dambos ecosystem in northern Mozambique [49] and Eastern Ghats of Andhra Pradesh [50]. Similarly, *Combretaceae* and *Fabaceae* were reported to be the most species rich families in the woodlands of Hirimi [31], Kafta-Sheraro National Park [29], Metema [41], Xobe, Island Safari and Shorobe [36], Xobe and Shorobe [35] and Mopane [39].

In Ethiopia, the family *Fabaceae* is the most species rich family with 678 species [29, 51] while *Combretaceae* is common woodland species [29, 31, 35, 36, 39, 41, 52]. The dominance of these two families could be attributed to their efficient pollination and successful seed dispersal mechanisms. Furthermore, the leguminous species (*Fabaceae*) contains drought tolerant, deciduous, nitrogen fixing and spiny species that are well adapted to the prevailing drought conditions [23, 29] of dry woodlands.

Patterns of species community are associated with environmental factors like climate, topography (slope, aspect, altitude), soil as well as anthropogenic and livestock disturbances [31]. In the present study, three plant community types were identified from the agglomerative hierarchical cluster analysis. This by far lower than those reported for Hirimi [31] due to low altitudinal variation in the present study.

Factors like anthropogenic and environmental influences have a strong impact on species richness, forest structure and composition [53]. The species richness of the woodland is comparable with those reported for Metema [41], Xobe and Shorobe [35, 36], Mopane [39] but slightly lower than that of Kafta-Sheraro National Park [29] and Hirimi woodland [31] with the same ecological setting.

Species diversity is the most often used depiction of ecological diversity [54]. The relatively high diversity and evenness indices indicates that the need to conserve the floristic diversity of the study site and also protect the woody vegetation from human disturbances [45]. The Shannon diversity values recorded in the present study were higher than those reported for Gera woodland in Abergele [18], South Nandi forest in Kenya [26], Kafta Sheraro National Park [29], Mopane woodlands [39], islands of Lake Ziway [30], Tara Gedam and Ababay forests [45], Xobe and Shorobe [35], Island Safari, Shorobe and Xobe [36],

Kumarakata Reserve Forest and the Hojai Reserve Forest [55] and lower than those reported for Hirni [31], Metema [41], Ryukyu Archipelago [56] and Eastern Ghats [50]. Likewise, the evenness is comparable with other studies conducted on other dry woodlands [35, 36, 39].

*D. cinerea* followed by *C. fragrans* (56.67%), *C. hartmannianum* (40%), *Combretum* sp. (36.67%) and *Z. abyssinica* (30%) were the most frequent species. It is indicated that species relative frequency reflects the pattern of distribution and gives an approximate indication of the heterogeneity of a stand [30, 41, 45]. Thus, the frequency increment of species could be as a result of a wide adaptability range and dispersal mechanisms [44].

Basal area is used to explain the crowdedness of a stand of natural vegetation (Table 1). A stand of large trees is more crowded than with the same number of trees of smaller diameter [23]. The total basal area of the forest in the present study was  $49.27 \text{ m}^2 \text{ ha}^{-1}$  which is greater than the normal basal area value,  $23\text{--}37 \text{ m}^2 \text{ ha}^{-1}$  set for virgin tropical forests in Africa. The species with the largest basal area was *B. papyrifera* 6.93 (14.06%) due to its big size [45] and it was followed by *C. fragrans* (8.91%), *Combretum* sp. (9.80%), *C. hartmannianum* (6.86%), *Terminalia brownie* (6.74) and *V. polyacantha* (5.44%). Thus, these species are considered as the most ecologically important species and the difference in basal area could be due to the presence of old growth and big diameter trees. The basal area of the woodland was greater than that of Hirni [31], Metema [41], South Nandi forest [26], Zengena Forest [57] and Eastern Ghats of Andhra Pradesh [50], comparable with that of Ishigaki forest [56], Abeyaye forest [45] and less than that of Okinawa forest [56], Tara Gedam [45], Kumarakata Reserve Forest [55] and islands of Lake Ziway [30].

The total density of mature woody plants was in the present study  $922 \text{ stems ha}^{-1}$ . This value is higher than those reported for other similar woodlands like Hirni [31], Galilla, Debre Sina, Tullu Guddo, Funduro and Tsedacha [30] Eastern Ghats of Andhra Pradesh [50] and Metema [41] and lower than Tara Gedam and Abeyaye [45]. These differences in density could be attributed to the variation in natural regeneration and dispersal pattern of species, the inability/ability of individuals to withstand the harsh environmental conditions (low rainfall regime, high temperature), disturbance degree, livestock trampling and grazing and other biotic and abiotic factors [41].

Species with highest dominance indices might be considered the most important species in the studied woodland [41]. IVI value is an important parameter that expresses the structural importance or ecological significance of species in a given ecosystem [26, 38, 41, 45, 58]. The species with high IVI values are considered more important than those with low IVI values. Likewise, the IVI values can be used to prioritize species for conservation. Species with lower IVI values need high conservation efforts while those with higher IVI values need monitoring management [38] and less conservation efforts [45]. The IVI value of the present study is higher than other similar woodlands like Hirni [31], Metema [41], islands of Lake Ziway [30], Tara Gedam [45], Komto forest [38], Island Safari, Shorobe and Xobe [36] and Shorobe [35] and comparable with Xobe [35] and Mopane woodland [39] and lower than that of Abeyaye forest [45].

In the absence of long-term demographic data on population, the use of diameter class distributions of woody species from a single survey has been shown to be a potential and reliable tool to reveal population status dynamics and recruitment process of woody species [35, 38] as well as predict responses of the species to disturbance, to its environment and to the resultant changes in population structure [35, 38, 41]. In the present study, the population structure showed various patterns. To this effect, some researchers argued species like *B. papyrifera* are facing extinction [59, 60] and proposed to be included in the International Union for Conserving Nature (IUCN) Red List threat category as “Vulnerable” [61]. Thus, the species that show irregular population growth pattern should be considered for conservation intervention [44]. Similar findings were reported for other woodlands [30, 31, 35, 36, 41, 44, 45].

Regeneration is a central component of tropical forest ecosystem dynamics and management, conservation and restoration of degraded woodlands. Sustainable forest utilization is only possible if adequate information on the regeneration dynamics and factors influencing important canopy tree species are available [62]. The composition, distribution and density of seedlings and saplings are indicators of the future regeneration status of any woodland [38]. Such deforestation and forest degradation in church forests and woodlands were reported recently elsewhere in Ethiopia [13, 14, 63]. Congruent to the present study, the impact of transhumance on vegetation were acknowledged in Ethiopia [64, 65], and other parts of the world [66, 67].

## 5 Conclusion

This study provides valuable information on floristic composition and identified deforestation and forest degradation drivers with the help of multi criteria decision models (AHP). Floristic composition results revealed the study site harbours 39 woody specie with high level of nativity, species richness and diversity with more or less even distribution and less dominance. *D. cinerea* (86.04%), *C. fragrans* (71.87%), *C. hartmannianum* (60.30%) and *Combretum* sp (50.15%) were the most ecologically important species with higher IVI. *C. hartmannianum* and *V. venosa* respectively are listed as vulnerable and endangered species in the IUCN red list. The regeneration status was not promising for vast majority of the species. Species with low IVI values, hampered recruitment, vulnerable species, flagship species, rare, threaten and endangered species should be prioritized for in situ and ex situ conservation intervention.

Likewise, forest cover change revealed Waldiba dry woodland has undergone significant cover changes over a period of 46 years. In 1972, more than 91% of the woodland was dominated by open forest (57.37%) and dense forest (34.13%). However, fundamental cover dynamics pattern indicate a decline in the woodland (open forest and dense forest) and a shift towards bushland/scrubland, cultivated land, riverbed and grassland. Whereas in the study area, both proximate (87.50%) and underlying (12.50%) causes played a pivotal role in driving the forest cover dynamics with more than 76% of the cover change happening due to overgrazing induced illegal logging and farmland expansion.

Thus, to reduce the anthropogenic pressure and ensure the conservation, management and sustainable utilization of the woodland, there is a need to introduce participatory forest management. Furthermore, as the woodland should be managed for ecosystem service and biodiversity conservation, research on the soil seed bank, regeneration, population dynamics, biology and reproductive ecology (pollination, seed production, dispersal and germination) of the native and endemic species is imperative.

## Declarations

### Data Availability

The data used to support the findings of this study are included in the manuscript.

### Author Contributions

DBH & AN: Conception and design of the research, data collection, data analysis and interpretation, drafting and revising the manuscript. EB, ANR, AST, TG, KMH & KG: data analysis and interpretation, drafting and revising the manuscript.

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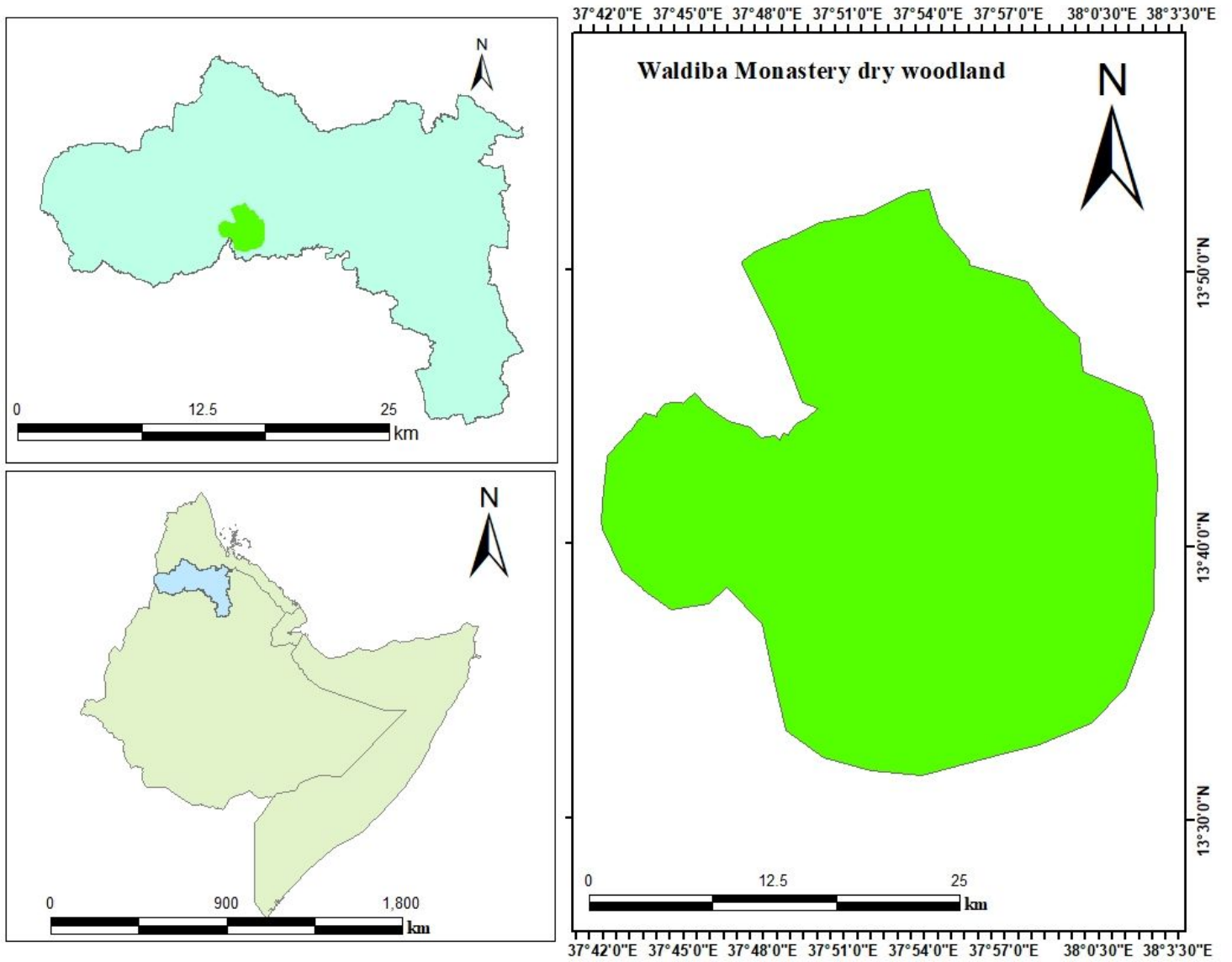
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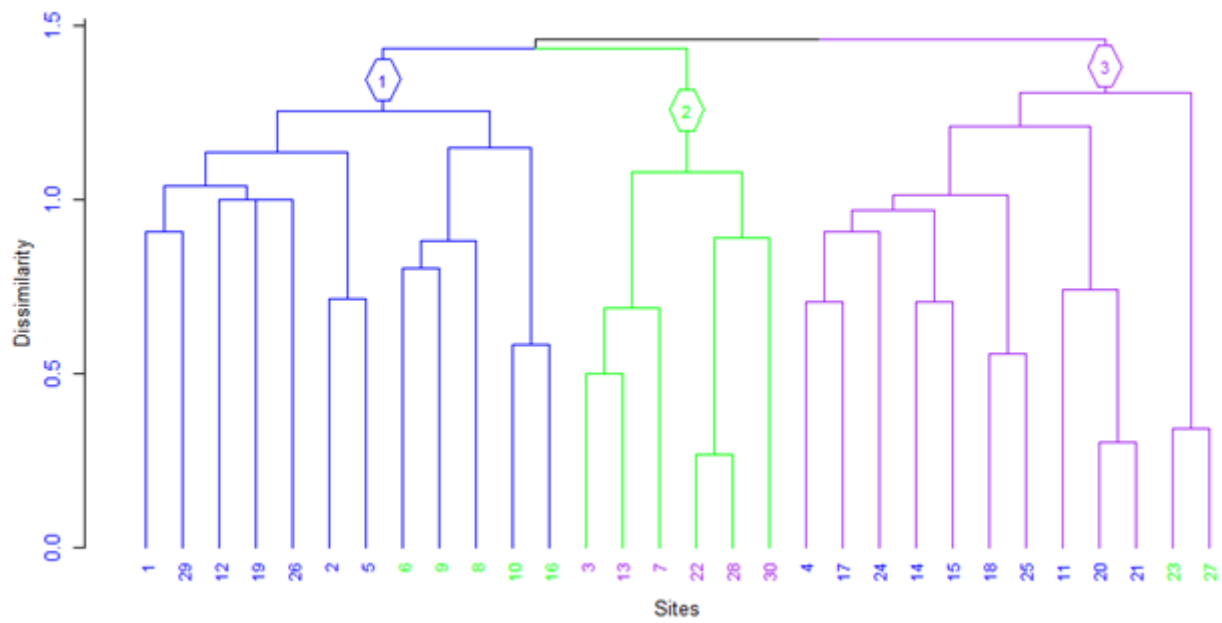
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## Figures



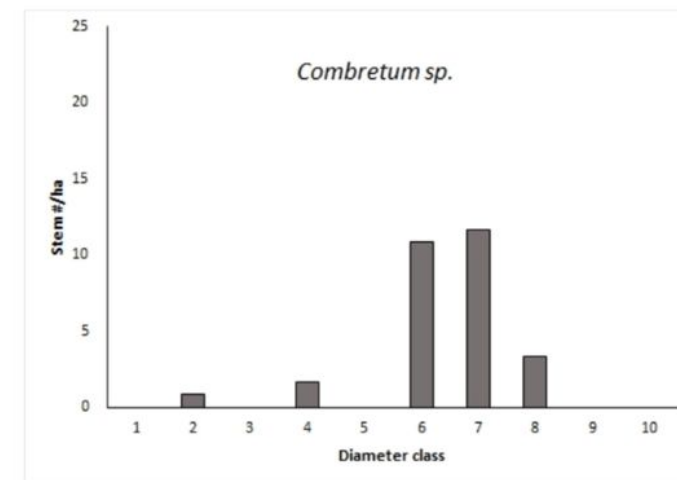
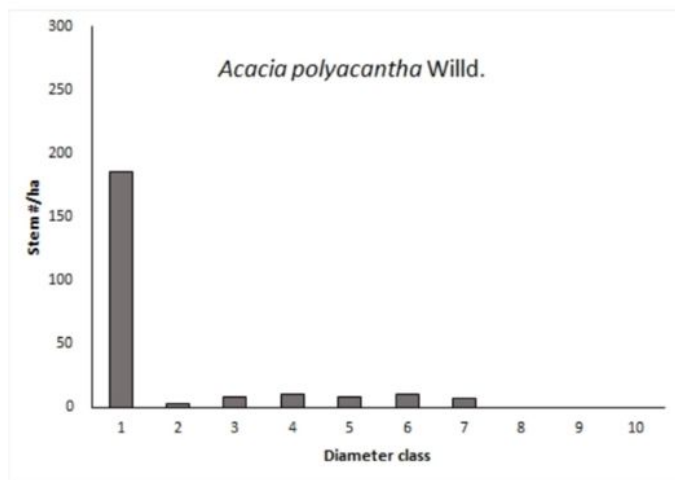
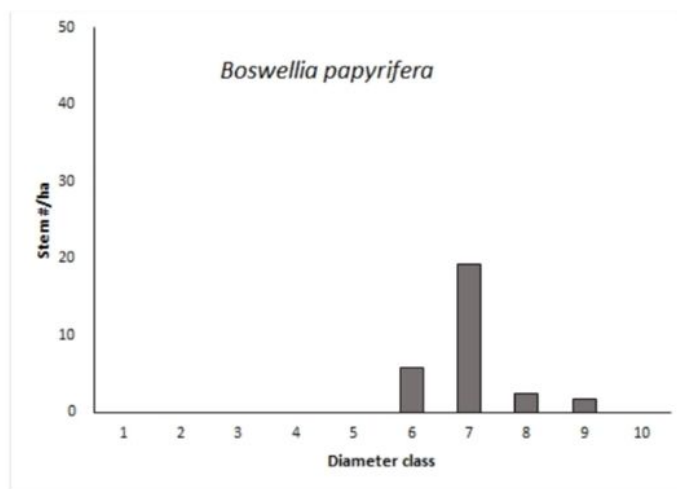
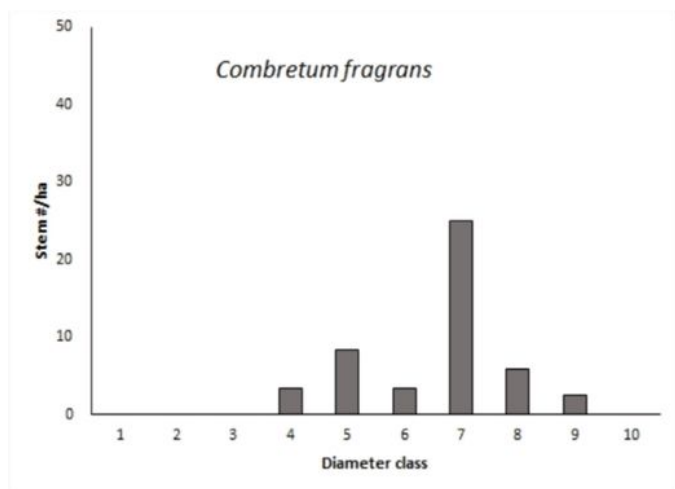
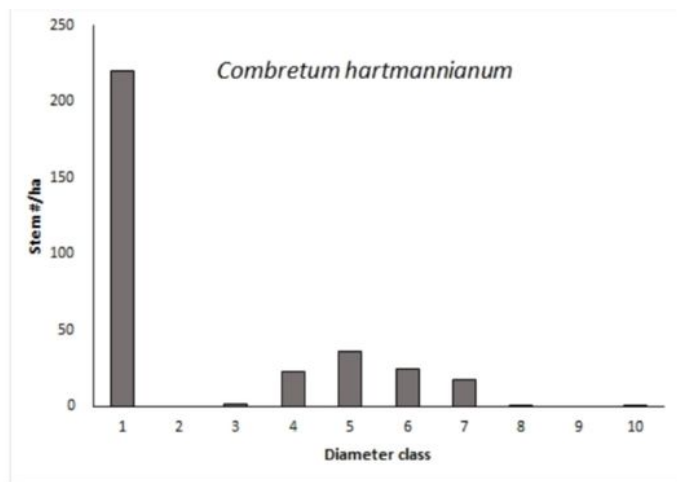
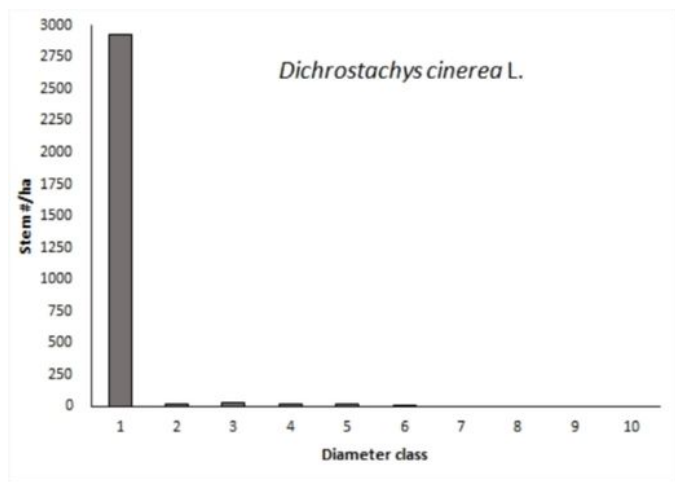
**Figure 1**

Location map of Waldiba Monastery dry woodland in Tigray, Ethiopia



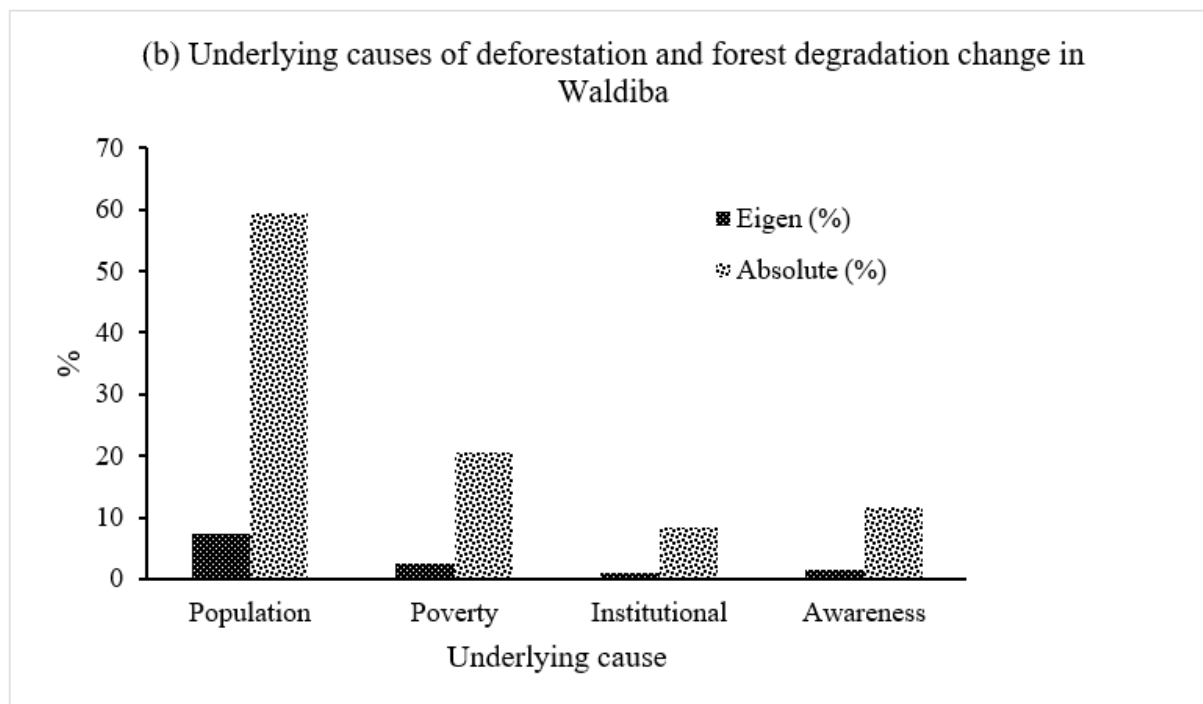
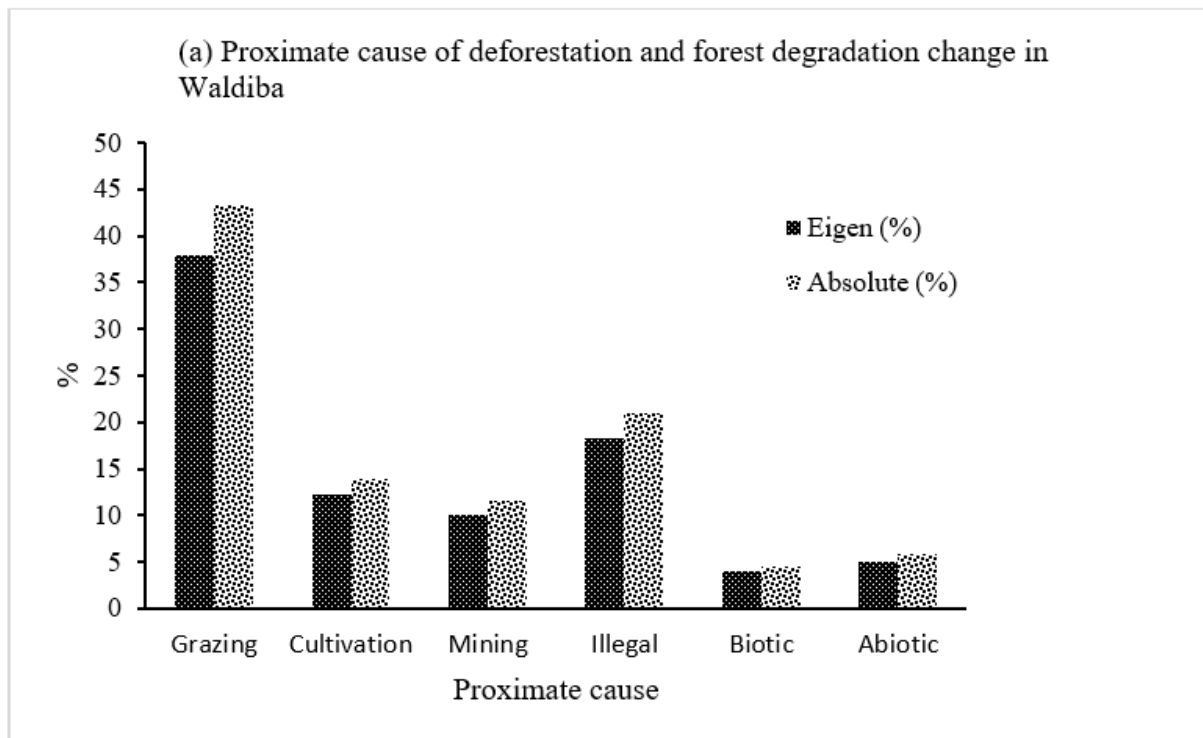
**Figure 2**

Dendrogram of the plant communities found in Waldiba monastery’s dry woodland



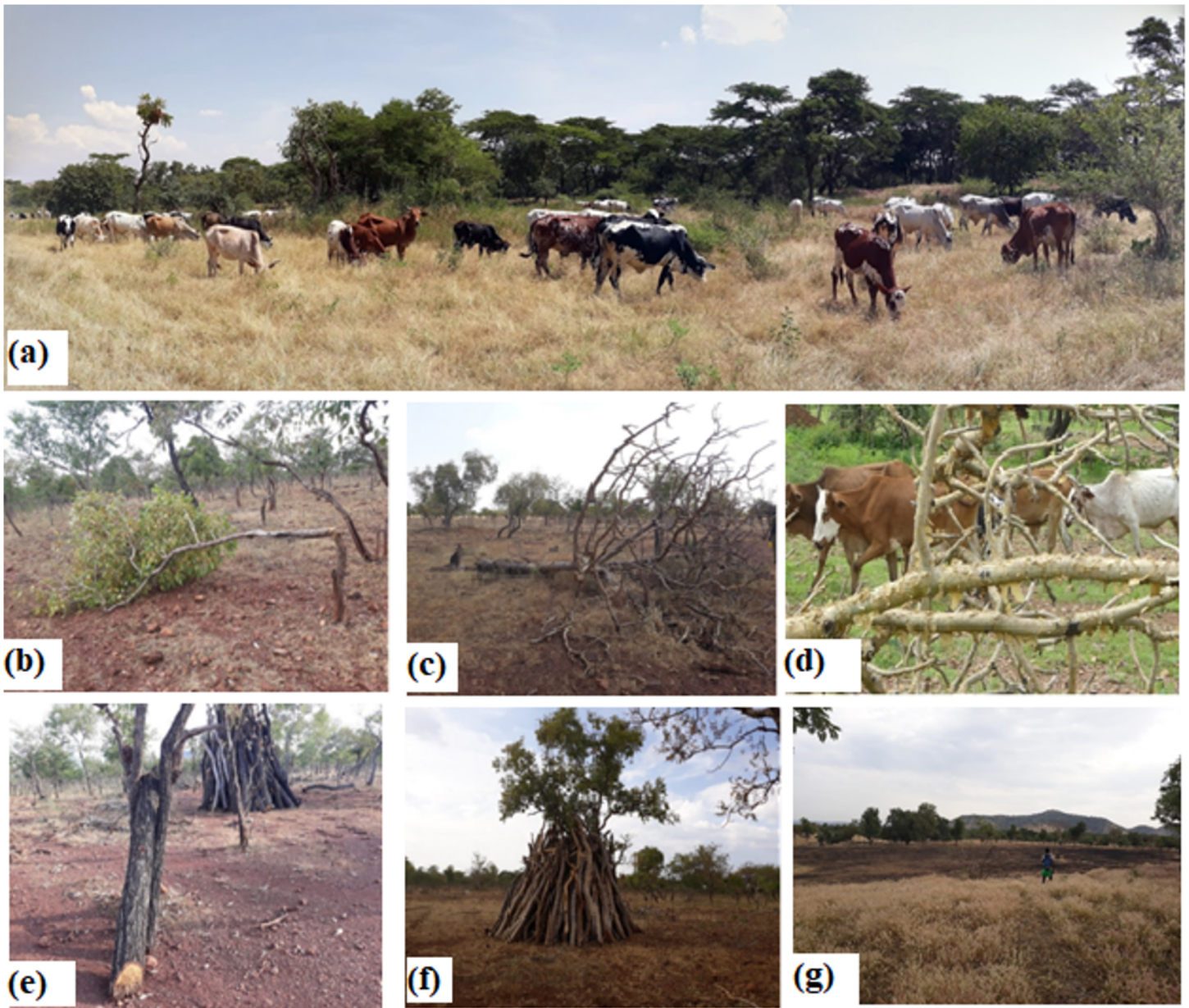
**Figure 3**

Population structure of selected dominant woody species recorded at Waldiba monastery woodland. Diameter class's number refers: (1) <2 cm, (2) ≥2<4, (3) ≥4<6, (4) ≥6<8, (5) ≥8<10, (6) ≥10<20, (7) ≥20<30, (8) ≥30<40, (9) ≥40<50, (10) >50 cm.



**Figure 4**

Proximate (a) and underlying (b) causes of deforestation and forest degradation in Waldiba



**Figure 5**

Drivers of forest cover change in Waldiba (a) uncontrolled grazing (b) a tree cut for goats browse (c) tree die back (d) dead *B. papyrifera* tree because of insect attack (long horn beetle) (e) newly cut logs of *Combretum* sp. (a vulnerable tree) by the monastery monks (f) different wood for fuel and construction piled in Waldiba and (g) burned grass for cultivated land expansion