



**Vegetation Ecology and
Conservation Status of Evergreen
Afromontane Forest Patches in
Awi Zone of Amhara Region,
Northwestern Ethiopia**

PhD Dissertation



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Vegetation Ecology and Conservation Status of Evergreen Afromontane Forest Patches in Awi Zone of Amhara Region, Northwestern Ethiopia

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Chair of Department or Graduate programme Coordinator

Dedication

This work is dedicated to:

My lovely wife W/ro **Emebet Mulu**, who has been with me during the good and difficult times.

And

My mother W/ro **Desta Tegegne**, who used to tell me the story of the vanished forests and wild animals in my birth place.

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List of Acronyms

AA	Afroalpine belt
AAU	Addis Ababa University
ACB	<i>Acacia-Comiphora</i> woodland and bushland vegetation
AF	Afar Floristic region
AR	Arsi Floristic region
asl	Above sea level
AUC	Area Under Curve
BA	Bale Floristic region
BA	Basal area
BoA	Bureau of Agriculture
BP	Before Present
CCA	Canonical Correspondence Analysis
CEC	Cation exchange capacity
CSA	Central Statistical Agency of Ethiopia
CTW	<i>Combretum-Terminalia</i> woodland and wooded grassland vegetation
DAF	Dry evergreen Afromontane forest and grassland complex vegetation
DBH	Diameter at breast height
DCA	Detrended Correspondence Analysis
DIVA-GIS	Diversity Analysis Geographic Information System
DSH	Diameter at stump height
DSS	Desert and semi-desert scrubland vegetation
EB	Ericaceous belt vegetation
EBI	Ethiopian Biodiversity Institute
EC	Electrical conductivity
EE	Eritrea East Floristic region
EFAP	Ethiopian Forestry Action Program
ENVI	Environment for Visualizing Images

ESRI Environmental Systems Research Institute
 ETM⁺ Enhanced Thematic Mapper
 EW Eritrea West Floristic region
 EWNHS Ethiopian Wildlife and Natural History Society
 FLV Fresh water lakes, lakeshores, marshes, swamps and flood plains vegetation
 GD Gondar Floristic region
 GG Gamo-Gofa Floristic region
 GIS Geographic Information System
 GJ Gojam Floristic region
 GSE Geological Survey of Ethiopia
 HA Harar Floristic region
 IAF Intermediate evergreen Afromontane forest
 IBCR Institute of Biodiversity Conservation and Research
 IL Illubabor Floristic region
 IUCN International Union for the Conservation of Nature
 IVI Importance Value Index
 KF Kefa Floristic region
 Landsat 1 MSS Landsat 1 Multi-Spectral Scanner
 Landsat 7 ETM+ Landsat Enhanced Thematic Mapper Plus
 Landsat TM Landsat Thematic Mapper
 TLUs Tropical Livestock Units
 MAF Moist evergreen Afromontane forest vegetation
 MD Minimum distance
 MSS Multispectral Scanner
 NBSAP National Biodiversity Strategy and Action Plan
 OM Organic matter
 PAST PAleontological STatistics
 QS Coefficient of Similarity

RDE Relative density
RDO Relative dominance
RFR Relative frequency
RV Riverine vegetation
SD Sidamo Floristic region
SLV Salt-water lakes, lakeshores, salt marshes and pan vegetation
SU Upland Shewa Floristic region
TM Thematic Mapper
TRF Transitional rainforest vegetation
TSEB Transitional semi-evergreen bushland vegetation
TU Tigray Floristic region
USGS United States Geological Survey
WG Welega Floristic region
WGG Wooded grassland of the western Gambela region vegetation
WU Upland Welo Floristic region

Abstract

The study was undertaken with the general objective of investigating the ecology and conservation status of and determining the vegetation type of forest patches of Awi Zone, northwestern Ethiopia. Vegetation and environmental data were collected from 154 sampling plots (20 m × 20 m) in the study area between December 2014 and March 2016 in dry and wet seasons. Elevation, climate, soil and land cover raster datasets were downloaded from freely available online data sources – DIVA-GIS, Worldclim, SoilGrids and USGS, respectively. Species frequency, density and structure of the forest patches were analyzed using descriptive statistical tools. Floristic diversity and evenness were computed using Shannon diversity and Evenness indices, respectively. The similarities between forest patches, between plant communities and the study area and other study areas were computed using Sorenson's similarity index. The plant community types and vegetation-environment relationships were analysed using classification and ordination tools in R package (ver. 3.2), respectively. The distribution of a new vegetation type for Ethiopia was modelled in MaxEnt (ver. 3.3.3k). The temporal and spatial Land use/cover dynamics of the study area and nearby forest patches were evaluated using various tools in ArcMap 10.2 and ENVI 5.0. The results of the study revealed that the study area harboured 212 species (122 woody and 90 herbaceous species) belonging to 169 genera and 79 families. The Shannon diversity index and evenness values of the study area were 3.7 and 0.8, respectively. The highest number of species were recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiki, Kidamaja and Degera forests. Twenty-three species were endemic to the Flora area. The density, basal area and dominance of woody species in the study area were 2172.1 stems ha⁻¹, 41.2 m² ha⁻¹ and 23.1 m² ha⁻¹, respectively. There were no significant variations of floristic richness and structure among the forest patches. The most

dominant tree species were Albizia schimperiana, Prunus africana, A. gummifera, Apodytes dimidiata, Croton macrostachyus and Ekebergia capensis. High floristic composition similarity was revealed between the forest patches. The forests of the study area had close affinity to other forests in the MAF and DAF. The hierarchical classification resulted in five plant community types which were shaped by anthropogenic and natural factors. Furthermore, the ordination analysis showed that eight environmental variables significantly affected floristic composition of plant communities and their distributions. The floristic analysis and vegetation distribution modelling revealed that the study area is part of a new vegetation type – Intermediate evergreen Afromontane forest (IAF), which was predicted to occur in Gojam and Gondar Floristic Regions. The Land use/cover change analysis showed that the forests of the study area have undergone significant negative changes in the past four decades. Consequently, 82% of the primary forest was converted into other landuse types with alarming rates of forest destruction. As a result, forest patches and a significant number of endemic and other species are threatened. To reverse these changes, among other measures, designing effective land use planning and undertaking restoration activities using prioritized species is highly recommended.

Key words: *Awı Zone, Guangua-Illala forest, intermediate forest, Khatasa forest, land cover, land use, primary forest, secondary forest.*

1. INTRODUCTION

1.1 Background

Ethiopia is a landlocked country with total area of 1.12 million km² and situated in the Horn of Africa neighbouring Kenya, Somalia, Eritrea, Sudan, South Sudan and Djibuti. The country has a diverse topography which ranges from 125 m below sea level at Denakil Depression (Afar) to 4533 m above sea level at Ras Dashen (Gondar) and has more ground above 2000 m than any other country in Africa (Friis *et al.*, 2010). The Great Rift Valley divides the country into two: the northwestern, central and western highlands and lowlands on the one side and the north eastern, southern and south eastern highlands and lowlands on the other. The rainfall patterns of the country are generally described as unimodal, bimodal or scanty and erratic. The western and southwestern part of the country gets the highest annual rainfall (unimodal); whereas the northeastern, eastern and southeastern part gets low and erratic rainfall (bimodal or erratic and scanty).

The diverse topographic factors coupled with the diverse climatic factors have created diverse vegetation types in the country, which includes desert and semidesert vegetation, grasslands, woodlands, lakeside/riverine vegetation, high forests and Afroalpine and sub-Afroalpine vegetations. The vegetation of Ethiopia is one of the richest in floristic diversity in Africa and/or in the world. Most recently, the country is recognized as one of the top 20 Megadiverse countries in the world (https://en.wikipedia.org/wiki/Megadiverse_countries). Ethiopia is also known to be one of the 12 Vavilovian centers of origin and diversity for many cultivated crops (e.g. *Eragrostis tef* and *Coffea arabica*) in the world (NBSAP, 2005). Ethiopia (including Eritrea) has been divided into 16 Floristic Regions, namely Gojam, Gondar, Bale, upland Shewa, Sidamo, Afar, upland Welo, Tigray, Welega, Illubabor, Kefa, Gamo-Gofa, Arsi, Harerge, Eritrea west

and Eritrea east (Friis *et al.*, 2010). These regions have been extensively used for the production of the *Flora of Ethiopia and Eritrea*, which is now concluded with the publication of about eight Flora volumes (Ensermu Kelbessa & Sebsebe Demissew, 2014). Hence, it is now known that 6027 vascular plant species are found in the Flora area, with about 10% endemism. Furthermore, the Afromontane vegetations of Ethiopia are one of the richest in species composition and endemism (White, 1983; Friis, 1992; Brown & Lomolino, 1998; Vivero *et al.*, 2006; Friis *et al.*, 2010).

On the other hand, studies show that most of the vegetation cover of the country is degraded and few remnant high forests are found in southwestern and western parts and as patches in conservation sites, churches and sacred areas in the country (Friis, 1992; Alemayehu Wassie *et al.*, 2005; Feyera Senbeta, 2006; Sebsebe Demissew & Friis, 2009; Friis *et al.*, 2010). And many of the high forests have been destroyed for settlement, agriculture and fuelwood as the majority of the Ethiopia's population is settled in the Afromontane areas (Friis, 1986). Recently, largescale agricultural investments, construction projects, resettlements, forest fire and expansion of cities are damaging the remaining forest patches in northwestern, western and southwestern Ethiopia (Amogne Asfaw, 2014).

Consequently, the conservation status of many of the remaining forest patches/high forests and other vegetations is very poor and the flora therein is highly threatened (Friis, 1986; Vivero *et al.*, 2006; Friis *et al.*, 2010). And the destruction of those vegetations in protected areas, National Forest Priority Areas and elsewhere has continued alarmingly. Even though no concrete evidences are available, species unknown to science and/or those species restricted in areas where anthropogenic impacts are hostile may have gone extinct (Vivero *et al.*, 2006; Ensermu Kelbessa and Sebsebe Demissew, 2014). For example, Vivero *et al.* (2006) estimated that 13

taxa, which are known from the type specimens only, have not been collected in the Flora area since the 19th Century; and at least seven taxa such as *Crotalaria boudetii* and *C. heterotricha* are presumed to be extinct.

1.2 Statement of the Problem

The size and quality of remnant forest patches of Ethiopia is deteriorating at an alarming rate due to various threats (Demel Teketay, 2005b). Those forests which are surrounded by hostile matrices such as agricultural and grazing lands and settlement are in most cases influenced by various factors such as disturbance and selective logging, which lead to gradual loss of key species; the process termed more suitably as “ecological decay” (Laurance *et al.*, 2002). Thus, the outcomes of this study will have paramount importance in identifying locally threatened species and endemic species for conservation actions.

Many plant ecological studies in Ethiopia have focused on species richness and diversity, community structure and comparisons therein (e.g. Tamrat Bekele, 1993; Demel Teketay & Tamrat Bekele, 1995; Alemnew Alelign *et al.*, 2007; Alemayehu Wassie *et al.*, 2005; Desalegn Tadele *et al.*, 2013). Various environmental factors associated with those parameters have also been focus of investigations. However, the northwestern parts of Ethiopia particularly forests of Awi Zone have not been investigated except few studies that were carried out on the genetics of a single species – *Prunus africana* (Haile Yineger *et al.*, 2014) and floristic study of single forest fragment – Zengena Forest (Desalegn Tadele *et al.*, 2013) and Kuandisha forest (Abiyot Berhanu *et al.*, 2017). Thus, this study will contribute to the development of species and forest databases for proper management of those forests in the study area.

Friis (1992), based on the assumption that patches of the southwestern Ethiopian forests (MAF) may extend further north than usually assumed, recommended that a study on forests of western Gojam might resolve the uncertainty of the classification of forests of West Gojam in the DAF. Thus, the results of this research have utmost importance to determine the vegetation types of the study area and its affinity to vegetation types in Ethiopia.

Studies on the temporal and spatial dynamics of Land use/cover changes play critical roles in selecting and designing conservation sites as well as introducing appropriate management interventions. To date no study is available on Land use/cover changes of the study area; except a study on forests in Banja district, northern part of the study area (Abyot Yismaw *et al.*, 2014). Thus, the results of this study will uncover the major land use/cover changes in the study area and assist land use planners, policy makers and conservationists to design effective land use and forest conservation plans in the study area.

1.3 Research Hypotheses and Objectives

1.3.1 Research hypotheses and questions

In this study, four major hypotheses were tested:

Hypothesis I: Species richness and structure (density, basal area and dominance) of the forest patches are different despite their inclusion in the “same vegetation type”.

Hypothesis II: The forests of the study area belong to a new vegetation type for Ethiopia.

Hypothesis III: A significant portion of plant species in the study area are at conservation risk.

Hypothesis IV: A significant portion of the primary forest of the study area has been lost due to land use/cover changes.

Thus, this study was expected to answer the following major research questions:

1. What are the floristic composition, diversity and structure of the forest patches?
2. What are the similarities between the forest patches in the study area?
3. To which vegetation type do the forests of the study area belong?
4. What are the environmental factors significantly affecting species composition of communities and their distributions in the study area?
5. What are the plant community types (associations) of the forests in the study area?
6. How is the regeneration status of woody species in the forest patches?
7. Which species are threatened and need priority and management actions?
8. Which land use types are affecting the primary forests in the study area?

1.3.2 General objective

The general objectives of this study were to investigate the ecology and conservation status and determine the vegetation type of forest patches of Awi Zone, northwestern Ethiopia.

1.3.3 Specific objectives

The specific objectives of this study were:

1. To document the floristic composition and diversity of forest patches.
2. To identify plant community types and study their similarity.
3. To assess the population structure of forest patches and each tree species.
4. To determine (reclassify) the vegetation type of the study area.
5. To investigate the conservation status of woody species and indicate IUCN status of endemic species.
6. To detect major changes in land use types and their rate of change in the study area.

2. Literature Review

2.1 Vegetation Types in Ethiopia

Various authors have classified the vegetation of Ethiopia into various types and subtypes. In the recent past, the vegetation of Ethiopia was classified into nine vegetation types including the Coastal vegetation of Eritrea (Zerihun Woldu, 1999; Sebsebe Demissew and Friis, 2009). More recently, the potential vegetation of Ethiopia is systematically revised to have 12 vegetation types and 12 subtypes (Friis *et al.*, 2010). The classification was mainly based on altitude and/or climatic variables.

The vegetation types are (1) Desert and semi-desert scrubland (DSS), (2) *Acacia-Comiphora* woodland and bushland (ACB), (3) Wooded grassland of the western Gambela region (WGG), (4) *Combretum-Terminalia* woodland and wooded grassland (CTW), (5) Dry evergreen Afromontane forest and grassland complex (DAF), (6) Moist evergreen Afromontane forest (MAF), (7) Transitional rainforest (TRF), (8) Ericaceous belt (EB), (9) Afroalpine belt (AA), (10) Riverine vegetation (RV), (11) Fresh water lakes, lakeshores, marshes, swamps and flood plains vegetation (FLV), and (12) Salt-water lakes, lakeshores, salt marshes and pan vegetation (SLV).

Five of the vegetation types, namely ACB, DAF, MAF, FLV and SLV have at least two subtypes while the remaining seven vegetation types have no subtypes. The descriptions of each vegetation type and subtype is provided in Friis *et al.* (2010). Based on Friis *et al.* (2010), forest patches of the study area have been classified as DAF. However, there is a hypothesis that the MAF may extend towards northwestern parts of Ethiopia particularly west Gojam that includes forests of the study area (Friis, 1992). Consequently, a brief description of the two vegetation

types, DAF and MAF and their subtypes is provided in the following subsections (subsections 2.1.1 and 2.1.2).

2.1.1 Dry evergreen Afromontane forest and grassland complex (DAF)

The Ethiopian highlands contribute to more than 50% of the land area with Afromontane vegetation, of which dry evergreen Afromontane forests form the largest part (Yalden, 1983; NBSAP, 2005). The DAF represents a complex system of successions involving extensive grasslands rich in legumes, shrubs and small to large sized trees to closed forest (Zerihun Woldu, 1999; Sebsebe Demissew & Friis, 2009). The DAF is multistoried forest vegetation (Zerihun Woldu, 1999). The first stratum also known as the top storey/canopy layer consists of a non-uniform, non-compact layer of tall trees. These trees are known as "emergents" because they project above the vegetation mass. Characteristic plant species at the canopy layer include *Juniperus procera*, *Podocarpus falcatus*, *Apodytes dimidiata*, *Prunus africana* and *Acacia abyssinica* (Tamrat Bekele, 1993; Zerihun Woldu, 1999; Friis *et al.*, 2010). The sub-canopy layer, which is below the canopy layer, is a mass of shorter trees of various heights such as *Allophylus abyssinicus*, *Euphorbia ampliphylla*, *Myrsine melanophloes* and *Olinia rochetiana*. The third storey usually known as shrub layer consists of species such as *Myrsine africana*, *Calpurnia aurea* and *Dovyalis abyssinica*. The ground layer is covered with grasses, ferns and mosses. However, in the drier and lower parts of the north and east, the complexity of the vegetation is greatly reduced and it may only be three-layered (Zerihun Woldu, 1999).

The DBH and height structure of trees is highly variable among various forests of the DAF depending on the location and status of disturbance. In the undisturbed forests, the DBH of mature trees usually reaches up to 270 cm, while their height can reach up to 45 m (Haile

Yineger *et al.*, 2008; Haileab Zegeye *et al.*, 2011; Desalegn Tadele *et al.*, 2013). Tree species such as *Prunus africana*, *Juniperus procera*, *Schefflera abyssinica*, *Albizia schimperiana*, *Ekebergia capensis*, *Celtis africana*, *Hagenia abyssinica*, *Croton macrostachyus* and *Cordia africana* have been reported to reach a DBH of between 80 – 270 cm and a height of 30 – 46 m in the DAF (Tamrat Bekele, 1993). In disturbed forests, the upper canopy species except few of them are usually removed for various purposes, and only short stature trees in the middle and lower canopy that have a DBH less than 50 cm and height less than 21 m remain in the forest (Tamrat Bekele, 1993; Friis *et al.*, 2010).

The DAF is subdivided into four distinct subtypes though this classification is not based on parameters such as altitude or climate; rather on characteristic species in each subtype (Friis *et al.*, 2010). The subtypes are (a) Undifferentiated Afromontane forest, (b) Dry single-dominant Afromontane forest of the Ethiopian highlands, (c) Afromontane woodland, wooded grassland and grassland, and (d) Transition between Afromontane vegetation and *Acacia-Commiphora* bushland on the eastern escarpment. Most recently, van Breugel *et al.* (2016) considered the subtype Transition between Afromontane vegetation and *Acacia-Commiphora* bushland on the eastern escarpment as a distinct vegetation type known as “Transitional semi-evergreen bushland”. The description of the subtypes and characteristic species in each subtype is provided in Friis *et al.* (2010) and van Breugel *et al.* (2016).

On the other hand, Zerihun Woldu (1999) divided the DAF into five associations; namely, *Mimusops kummel* forests, *Podocarpus falcatus* forests, *Juniperus procera* forests, *Juniperus procera-Podocarpus falcatus* forests and *Acacia abyssinica* forests. The associations resemble more of the Dry single-dominant Afromontane forest of the Ethiopian highlands and Afromontane woodland, wooded grassland and grassland subtypes (Friis *et al.*, 2010). Various

species are confined in each association type and some examples of species lists are provided in Hailu Sharew (1982), Sebsebe Demissew (1980), Tamrat Bekele (1993), Alemayehu Wassie *et al.* (2005) and Alemnew Alelign *et al.* (2007).

The DAF is found in much of the highlands in the northern, northeastern, northwestern, central, southern and southeastern parts of the country between altitudes 1800 and 3000 m and having annual rainfall between 400 and 1500 mm (Zerihun Woldu, 1999; Sebsebe Demissew & Friis, 2009; Friis *et al.*, 2010). However, the figures provided for the altitudinal ranges of the DAF are inconsistent in various literatures (e.g. Friis, 1992; Zerihun Woldu, 1999; Sebsebe Demissew & Friis, 2009; Friis *et al.*, 2010). Friis (1992) showed that at about 1500 m there is a change in forest composition, and proposed that this indicated the transition from lowland to Afromontane forest. On the other hand, Friis *et al.* (2010) indicated the distribution of DAF to be between 1800 and 3000 m and this range was used as vegetation mapping unit; even though the altitudinal range of the subtypes extend beyond the general distributional range of DAF. For example, the lower distributional limit of the subtypes Undifferentiated Afromontane forest, Dry single-dominant Afromontane forest and Transition between Afromontane vegetation and *Acacia-Commiphora* bushland extend below 1800 m and the upper distributional limit of subtype Dry single-dominant Afromontane forest extends above 3000 m (up to 3200 m). This inconsistency has also been recognized by Friis *et al.* (2010). Thus, the distributional ranges previously reported for DAF (1500 - 3200 m) in Zerihun Woldu (1999) and Sebsebe Demissew & Friis (2009) complement the distributional ranges of those subtypes even though this depends on the geographical locations of each subtype scattered in the highlands of Ethiopia.

A number of studies have been conducted in the DAF vegetation type. Some of them include in central highlands of Shewa such as Menagesha-Suba and Wof-Washa forests (Sebsebe

Demissew, 1980; Tamrat Bekele, 1993; Demel Teketay & Tamrat Bekele, 1995), Jemjem forest (Hailu Sharew, 1982), Shashemene-Munessa forest (Gemedo Dalle & Masresha Fetene, 2004; Gemedo Dalle, 2015), North Gondar Church forests (Alemayehu Wassie *et al.*, 2005), Zege Peninsula forest (Alemnew Alelign *et al.*, 2007), Tara Gedam forest (Haileab Zegeye *et al.*, 2011), Zengena forest (Desalegn Tadele *et al.*, 2013) and Kuandisha forest (Abiyot Berhanu *et al.*, 2017).

Tamrat Bekele (1993) described 10 community types of the dry Afromontane forests of the central plateau of Shewa largely dominated by trees such as *Erica arborea*, *Juniperus procera*, *Olea europaea* subsp. *cuspidata* and *Podocarpus falcatus*. The vegetation at Lake Tana has been considered by Sebald (1968) as a transition type to humid evergreen forests of southwestern Ethiopia; whereas, Friis (1986 & 1992) classified the forest as Upland dry evergreen forest and a special subtype of Undifferentiated Afromontane forest. More recently, the vegetation of Lake Tana was included in the Dry evergreen Afromontane forest and grassland complex vegetation type (Friis *et al.*, 2010).

2.1.2 Moist evergreen Afromontane forest (MAF)

The moist evergreen Afromontane forest (MAF) is in most cases characterized by one or more closed strata of evergreen trees, which may reach a height of 30 to 40 m (Feyera Senbeta, 2006; Sebsebe Demissew & Friis, 2009; Friis *et al.*, 2010). The vertical structures of moist evergreen Afromontane forests are generally 2-3 strata/layer: emergent/upper stratum (> 30 m tall), middle tree stratum (15-30 m tall) and small trees and shrubs layer (2-15 m tall) (Feyera Senbeta, 2006). The MAF occurs mainly in the southwestern highlands between (1500) 1800 and 2600 (3000) meters (Friis *et al.*, 2010). Some of the characteristic species of the MAF are *Pouteria adolfi-friedericii*, *Olea welwitschii*, *Albizia gummifera*, *A. grandibracteata*, *Macaranga capensis*,

Cyathea manniana and *Ocotea kenyensis*. Typical understory shrubs include *Chionanthus mildbraedii*, *Coffea arabica* and *Psychotria orophila*.

Previously, Sebsebe Demissew & Friis (2009) divided the MAF into two subtypes: (a) Afromontane rain forest, and (b) Transitional rainforest. The Afromontane rain forest occurs in the southwestern part of the Ethiopian highlands between 1500 and 2600 m asl, with an annual rainfall between 700 and 1500 mm (Sebsebe Demissew & Friis, 2009; Friis *et al.*, 2010). The forests on the mountains around Wondo Genet, between Kibre Mengist and Agere Salam, and the Hareenna forest on the southern slopes of the Bale Mountains represent the easternmost of this vegetation subtype (Sebsebe Demissew & Friis, 2009). The second subtype includes the Transitional rainforest, which includes forests known from the western escarpment of the Ethiopian Highlands, in Welega, Illubabor and Kefa. This subtype occurs between 500 and 1500 m, with rainfall close to 2000 mm or higher per year. However, Friis *et al.* (2010) have now considered the Transitional rainforest, including the lowland semi-evergreen forest, as a distinct vegetation type.

Thus, the MAF is now subdivided into two subtypes, which are not distinct (Friis *et al.*, 2010). The first subtype, namely Primary or mature secondary moist evergreen Afromontane forest represents the closed, mature forests. The second subtype known as Edges of moist evergreen Afromontane forest, bushland, woodland and wooded grassland includes the forest margins, clearings and areas where local edaphic or topographic conditions have favored the development of evergreen bushland, woodland, wooded grassland and grassland. Characteristic species of both subtypes are provided in Friis *et al.* (2010).

Various studies have been conducted in the MAF vegetation type. Some of them are in Moist evergreen Afromontane forests of southwestern Ethiopia which included Maji, Harena, Yayu and

Berhane Kontir forests (Feyera Senbeta, 2006), Bonga forest (Ensermu Kelbessa & Teshome Soromessa, 2008; Schmitt *et al.*, 2010), Komto forest in eastern Welega (Fekadu Gurmesssa *et al.*, 2013) and Wondo Genet forest (Mamo Kebede *et al.*, 2013). Feyera Senbeta (2006) described five plant community types which were dominated by species such as *Coffea arabica*, *Podocarpus falcatus*, *Dracaena fragrans*, *Trilepisium madagascariense*, *Syzygium guineense*, *Olea welwitschii* and *Pouteria adolfi-friedericii*.

2.2 Richness of Taxa in the Flora Area with Emphasis to DAF and MAF

The distribution and richness of taxa (species and subspecies) is highly variable in the Flora Area (Ethiopia and Eritrea). The general trend of species richness is that the southwestern, southern and southeastern parts of Ethiopia have the highest species richness, even though the values found for richness in some areas reflect high collecting intensity of samples (Friis, 2009). After the completion of the Ethiopian Flora Project, there were 243 families of vascular plants in the Flora area, of which 175 were found in both Ethiopia and Eritrea, 63 only in Ethiopia and five only in Eritrea (Ensermu Kelbessa & Sebsebe Demissew, 2014). It has also been known that 6027 taxa (species and subspecies) are found in the Flora area (3,875 taxa in Ethiopia only, 1882 common to both and 270 taxa in Eritrea only). Fabaceae, Poaceae and Asteraceae are the top three families having 678, 609 and 472 taxa, respectively. A detailed account of the number of taxa in each family and their proportion is available in Ensermu Kelbessa and Sebsebe Demissew (2014).

In terms of species richness of vegetation types, the DAF is second only to ACB having 460 woody taxa (Friis *et al.*, 2010). DAF also shares the highest number of woody taxa with ACB (102) and RV (102), followed by MAF (89), CTW (74) and EB (56). DAF is second only to

ACB having 128 woody taxa not shared with other vegetation types. On the other hand, the MAF stands fifth having 135 woody taxa from which 18 are recorded from only this vegetation type. MAF shares 89 species with DAF, 56 with RV, 36 with TRF, seven with EB, three with DSS and three species with CTW. Collectively, DAF and MAF harbor about 506 woody taxa.

2.3 Endemic Taxa of the Flora Area with Emphasis to DAF and MAF

Endemic taxa are those that are restricted to a particular geographic location and occurring nowhere else (Brown & Lomolino, 1998; Cox & Moore, 2005). Organisms can be endemic to a geographic location on a variety of spatial scales such as small area, district, province, sub-region, and region; and at different taxonomic levels such as variety, subspecies, species, genus or family. The lower taxonomic categories (variety, subspecies, species and genus) tend to be more narrowly endemic than the higher categories, such as families and orders, of which they are members. According to Brown and Lomolino (1998) and Cox and Moore (2005), taxa can be endemic to a geographical location for various reasons: a) they originated in that place and never dispersed; b) their entire range has shifted in locality subsequent to origination; or c) they now survive in only a small part of their former range (relicts).

The Ethiopian highlands particularly the Afromontane forests are among the mixed mountain and highland systems with complex zonation and they are part of the 29 biogeographic provinces of the Ethiopian/Afrotropical region of endemism (Brown & Lomolino, 1998). Moreover, the Afromontane vegetation of Ethiopia is part of the Eastern Afromontane hotspots that comprises high species richness and endemism (Friis, 1992, 2009; Friis *et al.*, 2010). According to Mittermeier *et al.* (2011), a biodiversity hotspot is defined as large regions containing exceptional concentrations of plant endemism and experiencing high rates of habitat loss. In

other words, a region must meet two criteria to qualify as a hotspot: it must contain at least 1,500 species of vascular plants as endemics; and has lost $\geq 70\%$ of its original native habitat. Accordingly, the eastern Afromontane hotspot encompasses rich taxa of flora, of which 20% of tree genera are endemic and about 75% of tree species are endemic or near endemic (Linder *et al.*, 2015). White (1983) described this region as the Afromontane archipelago-like regional center of endemism. This type of phytochorion has both more than 50 per cent of its species confined to it and a total of more than 1000 endemic species (White, 1983). According to Linder *et al.* (2015), the Ethiopian Region extends to the eastern Arc for plants.

Vivero *et al.* (2005) estimated the number of species of the entire Horn of Africa (Ethiopia, Eritrea, Djibuti and Somalia) to be more than 8000 plant species with 1920 species (24%) endemic to the region. Vivero *et al.* (2006) have estimated the updated percentage of endemic species in the Flora area (Ethiopia and Eritrea) to be 9.7% though some plant families and species were not included at the time of compiling their report. They have also reported that 428 endemic and near endemic woody taxa are present in the Flora area, of which 107 are trees and 321 are shrubs. Recently, Ensermu Kelbessa & Sebsebe Demissew (2014) reported that 647 taxa (10.7%) are endemic to the Flora area, of which 544 taxa are confined to Ethiopia, 14 to Eritrea and 89 taxa are common to both countries. Asteraceae has the highest number of endemic taxa (103), followed by Fabaceae (71) and Euphorbiaceae (45). The DAF and MAF vegetation types host a significant portion of the total endemics. For example, a review by Vivero *et al.* (2006) reported 308 endemic taxa in the highlands (1500 - 3000 m asl.) of Ethiopia and Eritrea. This number overlaps for the two vegetation types DAF and MAF, and MAF contributes the least number of endemics (Friis, 1992). Recently, the number of endemic taxa to the Afromontane

region (MAF and DAF) is known to be 339 taxa of which 310 are endemic at species level, 20 at subspecies level and nine at varietal level (Abiyot Berhanu, 2015).

It has also been reported that 135 endemic threatened woody taxa (31 trees and 104 shrubs) are found in the Flora area (Vivero *et al.*, 2006) and about 42% are restricted and/or found in the DAF and MAF (Abiyot Berhanu, 2015). Accordingly, among the Afromontane taxa, eight taxa are critically endangered, 13 taxa are endangered, 13 taxa are vulnerable, eight taxa are near threatened and the rest are least concern. However, at the time of this review no comprehensive reports were found on the status of endemic herbaceous plants except some 25 species listed in Ensermu Kelbessa *et al.* (1992). The number of threatened taxa is obviously expected to rise owing to the unprecedented rate of deforestation and over-utilization of the various vegetation types in Ethiopia. The rate of forest destruction is unabated now days and has continued alarmingly. Thus, due to the restricted geographic location of endemic taxa, they are relatively more vulnerable to anthropogenic and natural threats compared to other indigenous cosmopolitan species, which are found elsewhere (Brown & Lomolino, 1998).

2.4 Use of Predictive Models in Vegetation Distribution Modelling

Predictive modelling of species distributions is a process where the occurrence records and environmental data of selected key species are used to predict species potential distribution areas (Heglund, 2002; Rodríguez *et al.*, 2007). According to Rodríguez *et al.* (2007), detailed and reliable environmental data are needed to establish the species–environment relationships required to estimate species distributions outside sampling sites. This method has been adopted in modelling the distribution of the Transitional semi-evergreen bushland in eastern Africa using

key indicator species of vegetations as dependent variables and selected environmental variables as predictor variables (van Breugel *et al.*, 2016).

Among the various tools employed to predict species/vegetation potential distributions, the Maximum Entropy Model (MaxEnt ver. 3.3.3k) is widely used (Phillips *et al.*, 2006; Phillips & Dudik, 2008; Fourcade *et al.*, 2014). MaxEnt has the best predictive power using presence only data, being less affected by small sample sizes than other methods (Rodríguez *et al.*, 2007; Wisz *et al.*, 2008). The modelling procedure in MaxEnt basically follows four major steps: a) the presence points and environmental layers are loaded into MaxEnt; b) the software is trained using selected presence points of species; c) randomly sampled ground points are used to determine the MaxEnt distribution; d) similar areas are modeled as potential suitable areas for the distribution of the new vegetation type and suitability maps are produced; and e) selected presence records are randomly sampled by MaxEnt and are used to test the strength of the suitability (AUC).

Predictive modelling in MaxEnt, among other applications, has also been used to improve the design of a conservation reserve for endangered species (Taylor *et al.*, 2017), habitat representation of species in protected areas (Alarcón & Cavieres, 2015), evaluate the impact of climate change on species (Hu *et al.*, 2015), quantify the impact of expected land cover change on species (Gadsden *et al.*, 2012; Geary *et al.*, 2015) and evaluate the influence of expanding exotic species (Chai *et al.*, 2016; West *et al.*, 2016).

2.5 Threats to Vegetation

2.5.1 Habitat fragmentation: causes and consequences

Habitat fragmentation is a landscape-level process in which a specific habitat is progressively subdivided into smaller and more isolated fragments (Laurance, 2008). It involves changes in landscape composition (agricultural, forested, or other landscape types), structure and functions across spatial and temporal scales and occurs on a backdrop of a natural patch mosaic created by changing landforms and natural disturbances. Habitat fragmentation has been reported worldwide to be one of the leading factors for the decline of ecosystems, species and plant populations (McIntyre & Hobbs, 1999; Opdam & Wascher, 2004; Bennett & Saunders, 2010; Heinken & Weber, 2013).

In its most extreme, fragmentation results in only small isolated remnants of the native original forest, river sides or stream banks of varying size surrounded on all sides by other types of habitats usually known as the matrix - agriculture, settlement, road, dam and grazing (Euskirchen *et al.*, 2001; Gignac & Dalle, 2005; Laurance, 2008; Laurance *et al.*, 2010). Besides, increased fragmentation of forest habitats leads to the decline in size, an increase in isolation and an increase in proportion of edge habitat (Fletcher *et al.*, 2007). Habitat fragmentation has broader effects on forest ecosystems, altering such diverse processes as forest dynamics, nutrient cycling, carbon storage, and forest–climate interactions (Laurance *et al.*, 1998; Laurance, 2008; Laurance *et al.*, 2010). Species with strong ecological linkages to specific habitats may be especially vulnerable in fragments (Euskirchen *et al.*, 2001; Harper *et al.*, 2005). For example, the decline of key seed dispersers or pollinators in fragments can reduce reproduction, dispersal and establishment of dependent plant species.

Habitat fragmentation affects the demographic and genetic structure of forest plant populations through changed interactions with pollinators and limited dispersal (Honnay *et al.*, 2005; Laurance, 2008; Bennett & Saunders, 2010). Accordingly, species show varied responses to habitat fragmentation (Chen *et al.*, 1992). Some species are advantaged and increase in abundance (particularly invasive and shade-intolerant species); some remain roughly stable; while others such as shade-loving species decline, and become locally extinct.

Isolation of populations is a fundamental consequence of habitat fragmentation. It affects local populations by restricting immigration and emigration (Forman, 1995; Laurance, 2008). Isolation is influenced not only by the distance between habitats but also by the effects of human land use on the ability for seeds and spores to be dispersed through the landscape. For example, road networks interrupt horizontal ecological flows, alter landscape spatial pattern, and therefore inhibit important forest interior species (Forman, 1995). When populations become small and isolated, they become vulnerable to a number of stochastic (or chance) processes that may pose little threat to larger populations (Bennett & Saunders, 2010). Stochastic processes include environmental fluctuations and catastrophic events such as flood, fire or drought.

According to Laurance *et al.* (2010), different fragmented landscapes, which have very similar forests, soils, climate and land use histories, can diverge in species composition and structure because of fragmentation. Moreover, landscape-divergence hypothesis states that fragments within the same landscape tend to have similar dynamics and trajectories of change in species composition, which will often differ from those in other landscapes (Laurance *et al.*, 2010). Over time, this process will tend to homogenize fragments in the same landscape, and promote ecological divergence among fragments in different landscapes.

2.5.2 Forest disturbance and Land use/cover changes in Ethiopia

Disturbances in Afromontane forests include wind throw, natural and manmade fires, landslides, grazing, tree felling and clearing for cultivation (Økland, 1990; Demel Teketay, 2005b). According to Økland (1990), disturbance encompasses sudden events affecting the vegetation by increasing the density-independent mortality. Density-independent mortality is defined as a factor that affects the size of a population independent of the population density. According to Friis (1992), signs of forest disturbance by human activities first appeared around 1850 BP and it seems there was relatively early extensive destruction of montane forests in Ethiopia. Ethiopian highland agriculture has developed largely in the Afromontane areas that resulted in degradation of the Afromontane forests and further replacement by bushland and scrub in most areas (Zerihun Woldu, 1999; Friis *et al.*, 2010; van Breugel *et al.*, 2016). Patches now exist in inaccessible areas such as mountain ranges and sacred areas such as churches (Alemayehu Wassie *et al.*, 2005; Aleminew Alelign *et al.*, 2007) and conservation areas such as forest priority areas (EFAP, 1994). The fragmented landscapes are expected to undergo various changes because of environmental pressures such as disturbance exerted upon them both internally and externally.

Thus, the greatest threat to the remaining natural forests in Ethiopia is man-made: clearing for expansion of agricultural and grazing lands and uncontrolled exploitation of timber and fuel wood (Tamrat Bekele, 1993; Edwards & Ensermu Kelbessa, 1999). Rapid population growth has also been regarded as the major cause of deforestation (Taye Bekele *et al.*, 1999) as high population demands more land and fuel, which are both directly or indirectly obtained at the expense of forest destruction and unsustainable utilization (Edwards & Ensermu Kelbessa, 1999;

Taye Bekele *et al.*, 1999; Alemnew Alealign *et al.*, 2007). This has also been a major cause for land use/cover changes particularly forest cover changes in Ethiopia.

The definition of land use and land cover is provided in Anderson *et al.* (1976). Accordingly, land use refers to, "man's activities on land which are directly related to the land". On the other hand, land cover is defined as "the vegetation and artificial constructions covering the land surface". Land use/cover change particularly forest cover change encompasses activities such as forest clearing for agricultural land, grazing land and settlement, and construction of dams and roads which has resulted in fragmentation of natural forest habitats in Ethiopia and elsewhere (Forman, 1995; Edwards & Ensermu Kelbessa, 1999; Martínez-Garza & Howe, 2003; Lunt & Spooner, 2005).

The primary forest cover of Ethiopia was reduced to 16% in the 1950s and 3.6% in the 1980s from the original 35% cover before the 1950s (Taye Bekele *et al.*, 1999; Reusing, 2000). The destruction was mainly caused by land use changes for agriculture, settlement and grazing (Bedru Sherefafa, 2006; Alemu Mekonnen and Bluffstone, 2007; Eyayu Molla *et al.*, 2010; Binyam Alemu *et al.*, 2015; Solomon Melaku, 2016). Consequently, about 150,000-200,000 ha of forest cover is believed to disappear annually as result of anthropogenic influences, and the northern part of Ethiopia is the most affected (EFAP, 1994; Reusing, 2000).

Generally, Land use/cover change affects forests (Eyayu Molla *et al.*, 2010), soil physical and chemical properties (Teshome Tsegaw, 2007), bird biodiversity (Girma Mengesha, 2014), Carbon emissions (Houghton *et al.*, 2012), climate (Mahmood *et al.*, 2010) and hydrology (Rientjes *et al.*, 2011; Koch *et al.*, 2012; Hassen Yesuf *et al.*, 2015; Mesfin Anteneh *et al.*, 2016).

3. MATERIALS AND METHODS

3.1 Study Area

The study was conducted in forest patches of Guangua-Illala and Kahtasa forests in Awi Zone in Amhara National Regional State, northwestern Ethiopia (Fig. 1). The study area is part of the Gojam Floristic Region (west Gojam), western Ethiopian highlands (Friis *et al.*, 2010).

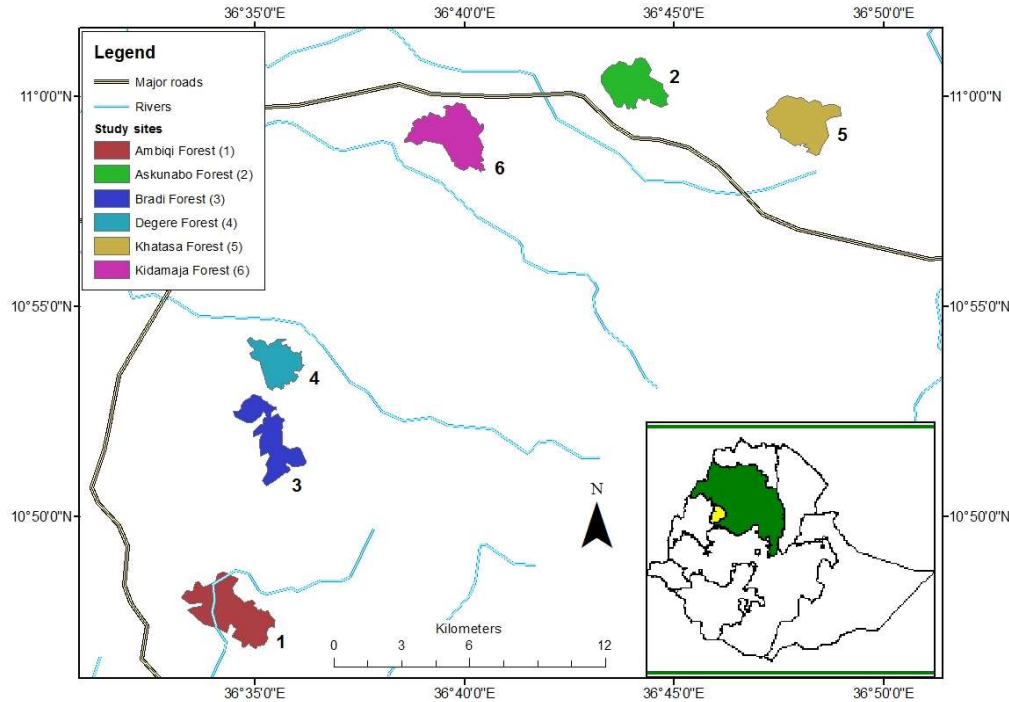


Figure 1. Map of forest patches in Awi Zone, Amhara National Regional State (ANRS). Areas marked with dark green and yellow in the overview map are ANRS and Awi, respectively.

Six forest patches were selected after a reconnaissance survey in the forests of Awi Zone; and their altitude and grid reference was noted. The forest patches were selected based on the following criteria: the forest patches had to be (1) relatively undisturbed; (2) accessible by car and/or on foot (should take a maximum of three hours from main roads to forest on foot); and (3) as much as possible, along a major “virtual line transect” from southwest to northeast as altitude more or less increases in this direction in forests of Awi Zone.

The area, location and elevation of the forest patches is given in Table 1. The forest patches are located between latitudes 10°47' N - 11°02' N and longitudes 36°32' E - 36°48' E. The altitudinal range lies between 1830 and 2660 m asl. Although it was not possible to obtain area and description of each forest patch from responsible offices, an attempt was made to measure the area of each forest patch for the interest of this study. Hence, the total area of forest patches is 2,920 ha; sizes ranging from 327 to 651 ha.

Table 1. Area, location and elevation of forest patches in Awi Zone, northwestern Ethiopia.

Forest Patch	Area (ha)	Location (Degrees)		Altitude (m)		
		Latitude	Longitude	Minimum	Maximum	Range
Ambiqi*	651	10.796062	36.572550	1979	2068	89
Bradi	458	10.865151	36.589589	1830	2069	239
Degera	327	10.895444	36.592982	1867	2106	239
Kidamaja*	563	10.985000	36.662105	1853	2082	229
Askunabo	417	11.005853	36.731569	2063	2348	285
Khatasa*	504	10.989947	36.799781	2243	2660	417
Total	2920	-	-	1830	2660	830

** Portions of the forests have been cleared for crop cultivation and secondary forest growth dominate.*

The forest patches belong to two (National) Regional Forest Priority Areas known as Guangua-Illala forest, which encompasses five forest patches, and Khatasa forest. Guangua-Illala forest is the largest and the forest patches therein, namely Ambiqi, Bradi, Luns-Degera, Askunabo and Kidamaja; are located at various distances (average 20.4 km) northeast, south, southeast and east of Chagni town because of deforestation of relatively plain areas for agriculture and settlement (pers. com.). Khatasa forest is situated 25 km northeast of Chagni Town. The topography,

geology and soil, vegetation and wildlife and climate of the study area is briefly described in the following subsections. However, it was not possible to get information for each forest patch except climate data at four locations which are representative of the study sites. The Zege Peninsula and Islands of Lake Tana, from which secondary data were used for vegetation distribution modelling are described in Alemnew Alelign *et al.* (2007) and IBCR-GTZ (unpublished data).

3.1.1 Topography

The topography consists of areas with gentle to steep slopes (Fig. 2). The landscape is composed of agricultural and grazing areas, settlements, rivers valleys, hills and small to medium sized mountains (at the northern side of the study area). The slope of the largest part of the study area (69%) ranges from 0 to 25% and the remaining has slopes above 25%. Flat land and steep slopes each account to about 7% of the study area. Flat land and gentle slopes are mostly utilized for agriculture, settlement and grazing lands; whereas moderate and steep slopes above 25% slope gradient usually consists of primary/high forests, although in some areas of Bradi, Degera and Khatasa forests the steep slopes are utilized for growing crops and settlement. A number of perennial rivers and small streams cross the study area.

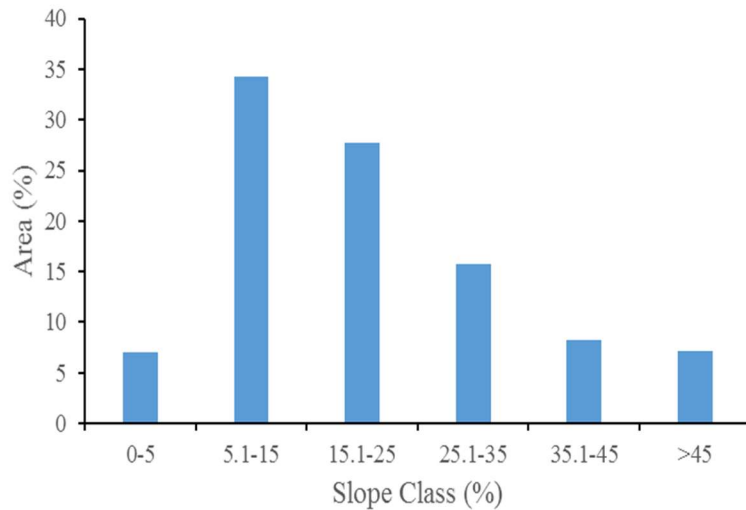


Figure 2. Percentage of areas in slope classes (%) in the study area.

3.1.2 Geology and soils

The bulk of the plateau where the Afromontane vegetation occurs consists of volcanic rocks (Mohr, 1972). Accordingly, the northeast (Khatasa forest), east, southeast and southern (Ambiqi forest) parts of the study area are dominated by pre-Cambrian rocks; the north and northwestern parts (Askunabo forest) are of early tertiary volcanics while the central part (Bradi, Degera and Kidamaja) is dominated by late tertiary volcanics (GSE, 2010). Generally, the soils of the study area belong to five textural classes (Fig. 3). Most of the soil samples fall in the clay and clay loam textural classes; while few of them are silty clay loam, silt loam and sandy clay loam.

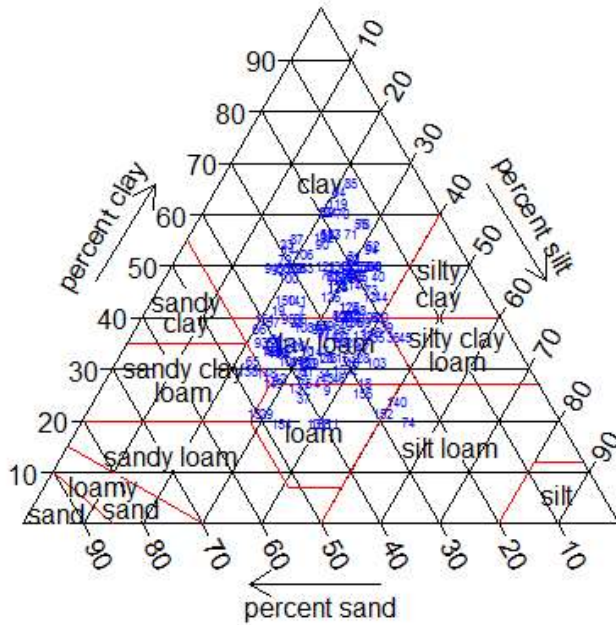


Figure 3. Soil textural triangle of the sampling plots in the study area

3.1.3 Vegetation and wild animals

Vegetation: The vegetation of Amhara National Regional State covers about 14% of the total area of the region, which is 21,783 km² (BoA, 2012). These include in order of coverage, shrublands 5.7%, woodlands 4.7%, natural dense forest 3%, plantation forests 0.4% and riverine forest 0.1%. The vegetation of Awi Zone covers about 23% of the total area of the Zone, which is 2,007.5 km². These include, in order of coverage, shrublands 14.5%, natural dense forest 5.5%, woodlands 2.8%, plantations 0.5% and riverine forest 0.1%. Remnant forest patches of Awi Zone belong to four vegetation types (Fig. 4): (1) Dry evergreen Afromontane forest and grassland complex, (2) *Combretum-Terminalia* woodland and wooded grassland, (3) Riverine vegetation (not shown on the map) and (4) Fresh water lakes, lakeshores, marsh and flood plain vegetation (Friis *et al.*, 2010). The vegetation of north, northwest, west and southwest lowlands of Awi Zone belongs to *Combretum-Terminalia* woodland and wooded grassland; whereas the

northeast, central and southeast highlands contain fragmented forests of the Dry evergreen Afromontane forest and grassland complex vegetation type. Few wetlands and crater lakes are found scattered in northeastern part of the zone. The study area for vegetation study holds a significant portion (27%) of primary forests in Awi Zone; while the study area for Land use/cover changes study includes most of the primary forests of the zone. The primary forests of the forest patches are generally categorized under the Dry evergreen Afromontane forest and grassland complex vegetation and Riverine vegetation types (Friis *et al.*, 2010). The forest patches are surrounded or intercepted by matrices of grazing areas, farms, settlement areas and roads.

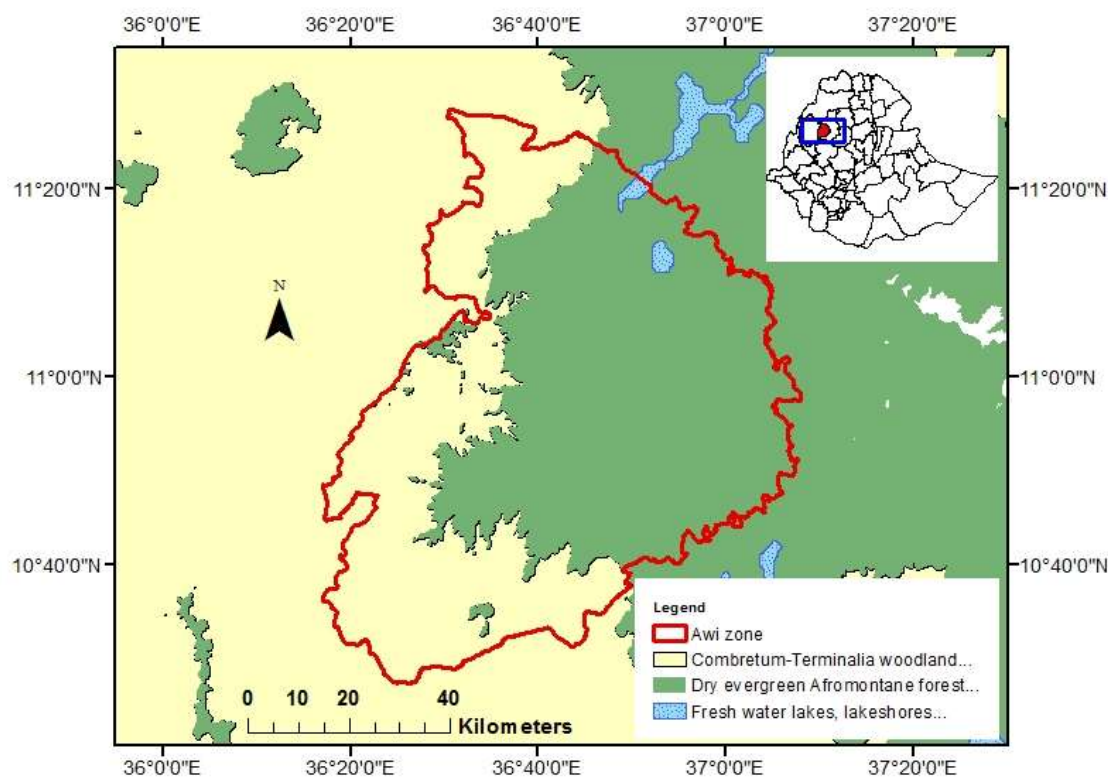


Figure 4. Potential vegetation types of Awi zone.

Wild animals: The majority (54.5%) of known Important Bird and Biodiversity Areas (IBA) of the Amhara National Regional State are identified as biodiversity hotspots (EWNHS, 2010).

Consequently, the study area has been recognized as Important Bird and Biodiversity Area (EWNHS, 1996; Birdlife International, 2016). Assessment of bird species that are found in different habitats of Awi Zone indicated the existence of 214 bird species, of which 28 species belonging to the Afrotropical highland biome (EWNHS, 1996). Two globally threatened bird species are known to exist in the area, the Ethiopian and Eritrean endemic - Rouget's rail (*Rougetius rougetii*) and the Ethiopian endemic - Abyssinian long claw (*Macronyx flavicollis*). Mammals such as Bush Pig, Leopard, Hyena, Anubis Baboon, Colobus Monkey, Common Duiker, Serval Cat and Common Bush Buck are also found in the forests (Agriculture and Natural Resources Office, unpublished data).

3.1.4 Human and livestock population

The human population of Awi Zone is projected to be 1,143,639 heads with a density of 116 heads/km² in the years 2014 - 2017 (CSA, 2013a). Among the total population, 84% live in rural areas, while the remaining 16% live in urban areas (Table 2). The majority of the population are Agaw (60%), followed by the Amhara (38%); all other ethnic groups made up 1.7% of the population. On the other hand, the livestock (cattle, sheep, goats, horses, mules and donkeys) population is projected to be 635,448 Tropical Livestock Units (TLUs) with a density of 64 TLUs/km² in the years 2014 - 2017 (CSA, 2013b).

Table 2. Projected human population of Awi Zone in the years 2014-2017.

	Total Population			Urban Population			Rural Population		
Gender	Male	Female	Total	Male	Female	Total	Male	Female	Total
Total	571,821	571,818	1,143,639	93,370	88,845	182,215	478,451	482,972	961,423
Percent	50	50	100	8	8	16	42	42	84

3.1.5 Climate

Daniel Gemechu (1977) classified the rainfall pattern of the study area as unimodal. Based on meteorological data from four stations (Khatasa, Askunabo, Kidamaja and Ambiqi), most of the study area gets rain at least nine months with variable intensity (Fig. 5). The annual precipitation ranges from 1685 to 1870 mm.

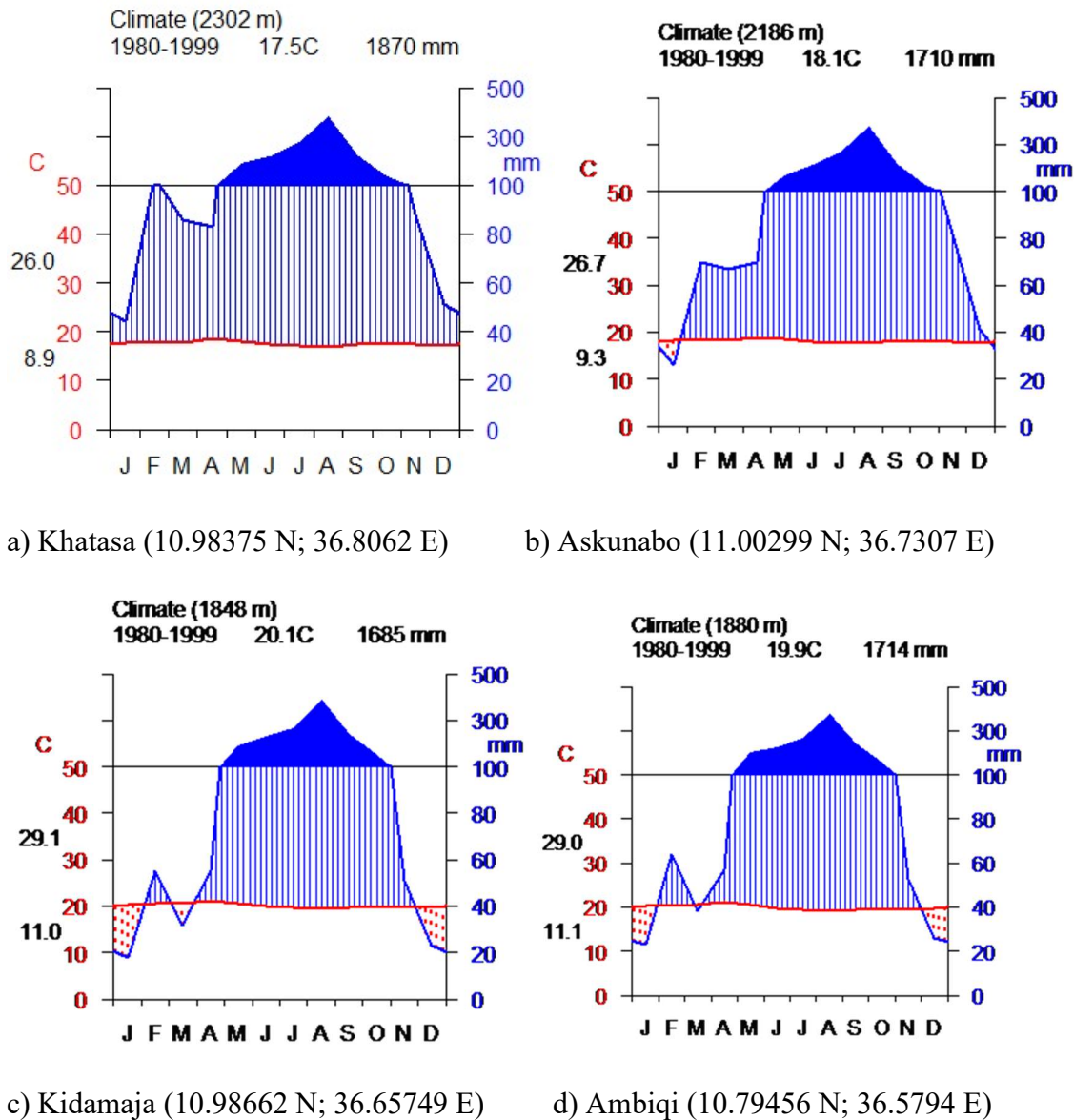


Figure 5. Climatic diagram of meteorological stations in the study area.

The highest precipitation of wettest month (August) is 388 mm at Khatasa; while the driest month (January) is 18 mm at Kidamaja. The wettest months are May to October with high peaks in August; whereas the driest months are December to February for all forest patches except Khatasa, which is slightly different. The annual mean temperature of the forest patches ranges between 17 ° C and 22 ° C. The highest annual mean temperature was recorded at Kidamaja; whereas the lowest was recorded at Khatasa. Generally, the Ambiqi, Bradi, Degera and Kidamaja forests have comparable altitudinal ranges and the climate was also found to be similar.

3.2 Data Collection

A reconnaissance survey was conducted in June 2014. Following this, preliminary data were collected to have information on vegetation stands as well as major environmental variables of the forest patches. Afterwards, detailed data collection was conducted in dry and wet seasons (to include short-lived annual species which only grow in wet seasons) from December 2014 to March 2016 on the following parameters were collected.

3.2.1 Vegetation data

A total of 154 sampling plots of each 400 m² (20 m x 20 m) were taken from all forest patches (Table 3). The number of sampling plots varied per forest patch based on forest cover, altitudinal differences (gradients) and habitat variability of forest patches. The distance between two consecutive plots along a line transect was 200 m. The first line transect was aligned randomly at one side of the forest by avoiding the forest edge (at least 50 m into the forest). The distance

between two parallel line transects was 300 m. The transects were laid against altitudinal gradients in order to capture representative samples of the forest. The scientific and local names, abundance and percentage canopy cover for each woody species were recorded in each plot. The habits of species were identified based on the conventions in the *Flora of Ethiopia and Eritrea*. Diameter of each woody species having a diameter of ≥ 2.5 cm at Breast Height (DBH) was measured using a tree caliper. When the ball of a tree was at breast height, diameter was measured above the tree ball.

Table 3. Number of line transects and their orientation and number of plots investigated in each forest patch.

Forest patch	Ambiqi	Bradi	Degera	Kidamaja	Askunabo	Khatasa	Total
No. of Line Transects (LT)	5	7	6	5	7	6	36
Orientation of LTs	<i>SW-NE</i>	<i>E-W</i>	<i>SW-NE</i>	<i>SW-NE</i>	<i>SW-NE</i>	<i>SW-NE</i>	-
Plot Range	115-130	1-31 & 56	32-55	95-113	57-94 & 153-156	132-152	1-156*
No. of Plots (P)	16	32	24	18	42	22	154
Total Area (ha)	0.64	1.28	0.96	0.72	1.68	0.88	6.16
P/LTs (Ratio)	3.20	4.57	4.00	3.60	6.00	3.67	4.28

* **Note:** two numbers, 111 and 114 were not used as plot numbers. *E* - east, *W* – west, *SW* – southwest, *NE* - northeast

In cases where the tree or shrub branched at about breast height, DBH was measured separately for each branch. The heights of all individuals of woody species with DBH ≥ 2.5 cm was measured with a Hypsometer (Nikon Laser Rangefinder Forestry Pro) and meter tape as appropriate. Where slope, topography and/or crown structures made it difficult to use hypsometer, heights were visually estimated. The heights of lianas were not measured due to the difficulty in tracing individual lianas as they interlaced with similar or other individuals. For measuring abundance of seedlings of woody species 2 m x 2 m sub-plots, one at each corner and

one at the center of each 400 m² quadrat (total area 20 m² per plot), were used. Seedling in this study is defined as individuals of a woody species having a DBH of below 2.5 cm or a height of below 1.5 m (Maria *et al.*, 1995). The percent foliage cover of each herbaceous species was also estimated in each subplot and the mean cover was computed. All plant specimens were collected, temporarily tagged with plot numbers followed by English alphabets (fast method), pressed and brought to the National Herbarium (ETH) for identification and storage.

Unidentified and identified specimens in the field were identified and confirmed, respectively at the National Herbarium (ETH) of Addis Ababa University by using the various volumes of the Flora of Ethiopia and Eritrea (Hedberg & Edwards, 1989; Edwards *et al.*, 1995; Phillips, 1995; Edwards *et al.*, 1997; Hedberg *et al.*, 2003; Mesfin Tadesse, 2004; Hedberg *et al.*, 2006, 2009a, 2009b). The specimens were also compared with authenticated specimens. Botanical names and authorities were verified using the species and family lists in Volume 8 of the Flora of Ethiopia and Eritrea (Hedberg *et al.*, 2009b). A new collection number with initials of the collector followed by three-digit number was assigned for each plant specimen at the ETH/EBI. Voucher specimens are deposited at the ETH and at the Herbarium of Ethiopian Biodiversity Institute (EBI).

3.2.2 Environmental data

3.2.2.1 Geographic data

Data on altitude, latitude and longitude for each plot and each forest patch were collected using Garmin GPS. Slope (percent) and aspect were measured with Saunto Clinometer and Compass, respectively. The qualitative values of aspect were converted to ordinal scales (Zerihun Woldu *et al.*, 1989): N = 0, NE = 1, NW = 1.3, E = 2, W = 2.5, SE = 3, SW = 3.3, S = 4. Aspect is a useful

parameter, which indicates the total amount of solar energy received (Tamrat Bekele, 1993; Måren, 2015).

3.2.2.2 Soil data

Separate soil samples were collected at five points, four at the corners and one at the center of the main plot, up to a depth of 30 cm using Soil Augur. And the soil samples were mixed, put in plastic bag and wrapped. The soils were air-dried and transported to Bahirdar Soil Research and Fertility Improvement Center (Soil Laboratory) for analysis. Soil Texture (Clay, Sand and Silt), Organic matter (OM), Acidity/Alkalinity (pH), Electrical Conductivity (EC), Total Nitrogen (N), Exchangeable cations (Ca, Mg, K, Na), Cation Exchange Capacity (CEC) and Available Phosphorus (P) were determined.

3.2.2.3 Forest disturbance

The extent of forest disturbance was determined by a subjective ordinal scale based on discussions with local people and careful observations. Two important parameters, namely cutting and grazing were selectively used. Accordingly, the scale of cutting and grazing were scored from zero (absent) to four (highly present). The scales and meanings are as follows: 0 - none, 1 – rare (rare trampling or 1 stump in the plot), 2 – low (low trampling or 2 stumps in the plot), 3 – medium (medium trampling or 3-4 stumps in the plot), 4 - high (high trampling or > 4 stumps in the plot).

3.2.2.4 Climate data

Twenty years' climate data layers (1980-1999) of 19 bioclimatic variables were downloaded at country level (Ethiopia) from <http://www.worldclim.org>, a freely available online climate

database. WorldClim is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km² (Hijmans *et al.*, 2005). The bioclimatic variables are Annual Mean Temperature, Mean Diurnal Range, Isothermality, Temperature Seasonality, Maximum Temperature of Warmest Month, Minimum Temperature of Coldest Month, Temperature Annual Range, Mean Temperature of Wettest Quarter, Mean Temperature of Driest Quarter, Mean Temperature of Warmest Quarter, Mean Temperature of Coldest Quarter, Annual Precipitation, Precipitation of Wettest Month, Precipitation of Driest Month, Precipitation Seasonality, Precipitation of Wettest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter and Precipitation of Coldest Quarter. Additional five-year climate data was acquired from the Meteorological Agency of Ethiopia, which was highly incomplete. For example, the temperature data of most of the meteorological stations that are closer to the forest patches, namely Khatasa, Askunabo, Bradi and Ambiqi were not available. Hence, the freely available climate dataset was used for producing climatic diagrams of forest patches. To produce climatic diagrams, the climate data that correspond to four meteorological stations closer to the forest patches, namely Khatasa, Askunabo, Kidamaja and Ambiqi was extracted from the climate layers using DIVA-GIS ver. 7.5 (Hijmans *et al.*, 2012). The 19 bioclimatic variables were also used to model the potential distribution of the new vegetation type (section 3.2.3).

3.2.3 Vegetation distribution modelling data

3.2.3.1 Dependent variable (species data)

Non-overlapping 120 presence point locations (longitude and latitude) of ten indicator species combinations, namely *Albizia gummifera*, *A. schimperiana*, *Celtis africana*, *Cordia africana*, *Croton macrostachyus*, *Millettia ferruginea*, *Mimusops kummel*, *Prunus africana*, *Rothmania*

urcelliformis and *Vepris dainellii* were selected from the study area (Awi), Zege Peninsula and Islands of Lake Tana forests and saved as comma separated values (CSV) file format. Indicator species are species restricted to one or a few habitat types (communities) and potentially represent a better ecological indicator of environmental change (Kent and Coker 1992; De Cáceres & Legendre, 2009). Secondary data on the indicator species of the Zege Peninsula and Islands of Lake Tana forests were extracted from the IBCR-GTZ Forest Inventory Database with kind permission from the Ethiopian Biodiversity Institute (IBCR-GTZ, unpublished data). The two additional forests were selected based on the similarities of indicator species composition with the study area and, besides their inclusion in the DAF with uncertainty (Friis *et al.*, 2010), their affinities to the southwestern moist evergreen Afromontane forests (Sebald, 1968; Friis, 1992; Friis *et al.*, 2010).

3.2.3.2 Predictor variables (environmental and climatic data)

Climate data layers of 19 bioclimatic variables (see section 3.2.2.4), elevation and 48 soil data layers at a resolution of 30 arc-seconds (1 km x 1 km grid) were used as predictor variables. Soil data layers, namely bulk density, cation exchange capacity (CEC), electrical conductivity (EC), pH, clay, silt, sand and organic carbon at depths of A (0-2.5 cm), B (2.5-10 cm), C (10-22.5 cm), D (22.5-45 cm), E (45-80 cm) and F (80-150 cm), were downloaded from <https://www.soilgrids.org>. SoilGrids is a system for automated soil mapping based on global soil profile and environmental covariate data (Hengl *et al.*, 2014). The extent, resolution and spatial reference of all environmental layers were adjusted to the same level using geoprocessing, data management and spatial analyst tools in ArcMap 10.2. Afterwards, the environmental layers were converted from raster to Ascii files for modelling purposes.

3.2.4 Land use/cover data

Landsat raster images of the years 1973, 1987, 2001 and 2014 were acquired from the Earth Explorer website (<http://earthexplorer.usgs.gov/>) (Table 4). The images with high resolution and minimum or no cloud cover were selected from a number of images for each period. The images taken in January and February were found to have no cloud cover and these months were preferred for all periods.

Table 4. List of raster images used for the Land use/cover change analysis.

Year	Resolution	Sensor	Acquisition date
1973	57 m	Landsat 1 MSS	01/15/1973
1987	30 m	Landsat TM	01/13/1987
2001	30 m	Landsat 7 ETM+	02/05/2001
2014	28.5 m	Landsat 7 ETM+	02/01/2014

For identification of major land use types in the study area, field visits were carried out in December 2014. Accordingly, four major Land use/cover types were recognized in this study: primary forest (high forest), secondary forest/scrub/plantation, grazing land/grassland and agriculture. FAO (2010) defines forest as “Land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*.” However, this definition does not clearly separate shrublands from primary forests. On the other hand, White (1983) defined forest as a continuous stand of trees where the canopy varies in height from 10 to 50 m or more, and usually consists of several layers or storeys. Consequently, the definition of forest, shrubland and grassland by White (1983) was adopted in modified form that suits the classification purposes.

Primary forest or high forest in this study includes large and old trees with closed canopies having several layers/storeys. Secondary forest/scrub/plantation indicates a change in land use from primary forest, agriculture or grazing land to secondary growth of scrub/bushland; as well as plantations, such as introduced species. Grazing land/grassland is a land usually utilized for grazing domestic animals that has sparsely scattered trees/shrubs; grass/herbs being the dominant cover. Agricultural land (agriculture) in this study is defined as a land that is utilized for production of crops and settlement.

At least 40 reference data (location data – latitude and longitude) were collected from each land use type using stratified random sampling procedure for construction of Error/confusion matrix. Local people particularly elders were consulted about the age of the land use type using open ended questionnaires, that is the periods in which that land use type remained in the same state.

3.3 Data Analysis

3.3.1 Vegetation data preparation

The percent canopy/foilage cover was transformed to ordinal scales and assigned to one of the nine cover-abundance classes according to the modified 1-9 Braun-Blanquet scale (van der Maarel, 1979; DCR-DNH, 2011). The scales are $1 \leq 0.1\%$, $2 = 0.1$ to 1% , $3 = 1$ to 2% , $4 = 2$ to 5% , $5 = 5$ to 10% , $6 = 10$ to 25% , $7 = 25$ to 50% , $8 = 50$ to 75% , and $9 > 75\%$. The three-column data, abundance or cover, were imported to R Package 3.2 (R Core Team, 2015) and matrified to carry out the analysis for various parameters.

3.3.2 Floristic composition and diversity

Floristic richness, diversity and evenness indices of the study area, sites and plant communities were calculated using R Package 3.2 (R Core Team, 2015). Among the various coefficients widely used to compute diversity of a community, species diversity (α diversity) and turnover (β diversity) are the most commonly used (Krebs, 1999). The indices focus on the relative species richness and abundance and/or the pattern of species distribution. Species richness represents the number of different species in a given area or community. The Shannon index, sometimes referred to as the Shannon-Wiener Index or the Shannon-Weaver Index, is one of several diversity indices used to measure diversity (Krebs, 1999). The index assumes individuals are randomly sampled from an infinitely large population and all the species from a community are included in the sample. The index is often used for identifying areas of high natural or human disturbance and the value usually falls between 1.5 and 3.5, rarely exceeding 4.5 (Maguran, 1988; Økland, 1990; Krebs, 1999). A high Shannon index indicates high diversity and often low disturbance whereas low Shannon index shows low diversity and often high disturbance.

Turnover (β diversity) measures the change in species composition from place to place, or along environmental gradients (Whittaker, 1972). In other words, β -diversity measures the change in diversity of species among set of habitats. A high β -diversity index indicates a low level of similarity among areas or communities, while a low beta diversity index shows a high level of similarity (Økland, 1990). Values of $\beta < 1$ are rather low and $\beta > 5$ can be considered as high (Zerihun Woldu, 2014). The variations of floristic richness among the forest patches was tested using One-Way ANOVA in PAST software Package (ver. 3.04) (Hammer *et al.*, 2001).

3.3.3 Vegetation structure

3.3.3.1 Frequency and Relative Frequency of species

Frequency is defined as the probability or chance of finding a species in a given sample area or plot. Frequency in this study is expressed as a percentage of the total number of plots in which individuals of a given species were recorded divided by the sum total number of the plots taken in the study area. The following formula were used in Microsoft Excel spreadsheet programme.

$$F = \frac{P_i}{\sum_{i=1}^s P_i} \times 100,$$

Where, F is the frequency of a species and P_i is number of plots in which the i^{th} species (s) was recorded;

$$R_{fr} = \frac{F_i}{\sum_{i=0}^s F_i} \times 100,$$

Where, R_{fr} is the relative frequency of a species and F_i is frequency of the i^{th} species (s).

3.3.3.2 Population structure (DBH and height class distributions)

The study on the population structure, which is defined as the frequency distribution of individuals in arbitrarily defined DBH or height classes, was carried out for woody species based on most widely used DBH and height classes in Ethiopia (e.g. Gemedo Dalle, 2015; Abiyot Berhanu *et al.*, 2017; GTZ-IBCR, unpublished data). Diameter was classified into 9 classes of 5 cm interval and height into 10 classes of 5 m interval. DBH classes include: 2.5 – 7.5, 7.6 – 12.5, 12.6 – 17.5, 17.6 – 22.5, 22.6 – 27.5, 27.6 – 32.5, 32.6 – 37.5, 37.6 – 42.5 and >42.5. Height classes are ≤ 5 , 5.1 – 10, 10.1 – 15, 15.1 – 20, 20.1 – 25, 25.1 – 30, 30.1 – 35, 35.1 – 40, 40.1 – 45 and > 45. To show the population structure, the density of individuals falling in the DBH or height classes were summed up and diagrams were produced using Microsoft Excel spreadsheet

programme. The population structure is important indicator of forest reproduction and recruitment health (Schulz *et al.*, 2009).

3.3.3.3 *Woody species density, basal area and dominance*

Woody species density in this study is expressed as number of individuals of a species per hectare. The density and relative density of woody species were computed in Microsoft Excel spreadsheet programme. The total species density, which is expressed as the sum total of all individuals of all species in a hectare was also computed. The relative density was calculated using the following formula:

$$R_{de} = \frac{D_i}{\sum_{i=1}^s D_i} \times 100,$$

Where, R_{de} is the relative density of a species and D_i is density of the i^{th} species (s);

Basal area ($m^2 ha^{-1}$) measured as the cross-section area of a tree at breast height, is computed from the measurement of DBH/DSH as follows in Microsoft Excel spreadsheet programme:

$$B_a = \pi d^2/4, \text{ where } \pi = 3.14, B_a \text{ is basal area, and } d \text{ is DBH (m).}$$

However, since DBH was measured in centimeters, the formula was modified in such a way that the B_a will be in square meters. Thus, $B_a = \pi d^2/40,000$ or $0.0000785d^2$, where d is DBH in centimeters. The mean basal area of all investigated plots was converted to mean basal area per hectare. Basal area provides a better measure of the relative importance of tree species than simple stem counts (Tamrat Bekele, 1993).

The dominance and relative dominance were calculated as follows.

$$D_o = B_i \times N_i,$$

Where Do is dominance of a species, B_i is mean basal area per species and N_i - number of individuals in the i^{th} species

$$R_{do} = \frac{Do_i}{\sum_{i=0}^s Do_i} \times 100,$$

Where, R_{do} is relative dominance and Do_i is dominance of the i^{th} species (s).

The variations of structure (density, basal area and dominance) among the forest patches was tested using One-Way ANOVA in PAST software Package (ver. 3.04) (Hammer *et al.*, 2001).

3.3.4 Prioritization of species for conservation

3.3.4.1 Endemic species

Endemic species to the Flora area (Ethiopia and Eritrea) were identified based on the Flora of Ethiopia and Eritrea volumes (Vol. 1-8). The IUCN status of endemic species was determined by comparing with Ensermu Kelbessa *et al* (1992) and Vivero *et al.* (2005). The threat categories are: extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient and not evaluated. The definition and criteria of those categories is provided in Vivero *et al.* (2005).

3.3.4.2 Prioritization of woody species

The efforts to protect plant biodiversity must be prioritized because resources for nature conservation are limited (Arponen, 2012). The Importance Value Index (IVI), besides its use in indicating the relative ecological importance of a given woody species at a particular site, is one of the important tools used to identify threatened woody plants in a specific site or area (Kent and Coker, 1992). The IVI of a species signifies the sum of its relative density (RDE), relative frequency (RFR) and relative dominance (RDO). That is, $IVI = RDE + RFR + RDO$. The IVI

was computed in Microsoft Excel spreadsheet programme. Consequently, woody species having the least IVI values were prioritized for the purpose of conservation and management interventions.

3.3.5 Vegetation classification (plant communities)

A plant community is generally recognized as a relatively uniform piece of vegetation in a uniform environment, with a recognizable floristic composition and structure, that is relatively distinct from the surrounding vegetation (van der Maarel & Franklin, 2013). An important quantitative criterion in identifying different plant communities is the frequency and abundance of species in sampling units (Dai *et al.*, 2006). To identify plant communities, the cover–abundance data were analyzed and classified using the Cluster and Vegan packages in R Package 3.2 (Oksanen *et al.*, 2014). Clustering is a multidimensional analysis that consists in partitioning the collection of sampling plots (Legendre & Legendre, 1998). The optimal number of clusters was determined by plotting the within groups sum of squares against number of clusters. The resulting graph was used to decide the cut level subjectively. Consequently, after determining the optimum number of clusters, Hierarchical Agglomerative Clustering technique using the Ward’s method was employed to classify sites and species. The method is often called “bottom up method”, that construct a tree-like hierarchy. Ward’s method is the most commonly used and robust method among the hierarchical classification techniques (Scheibler & Schneider, 1985; Singh, 2008; Zerihun Woldu, 2014).

However, not every species contributes equally in identifying communities and key indicator species are usually used for community classification. Indicator species are species restricted to one or a few habitat types (communities) (De Cáceres & Legendre, 2009). They potentially

represent a better ecological indicator of environmental change than habitat generalists, owing to the greater susceptibility of the specialist to local or regional extinction. According to Legendre (2013), good indicator species should be found mostly in a single group (community) or a limited number of groups of a typology, and be present at most of the sites (plots) belonging to that or these groups. To identify indicator species for naming of plant communities, an indicator species analysis was carried out using the indicator value (IndVal) method in R package “indicspecies” ver. 1.7.1 (De Cáceres & Legendre, 2009; De Cáceres, 2013). The indicator value index (IndVal) is based only on within-species abundance and occurrence comparisons; its value is not affected by the abundances of other species (Dufrene and Legendre, 1997). The index is maximum (its value is 1 or 100%) when the individuals of a species are observed at all plots belonging to a single cluster (community). The significance of the indicator value of each species was assessed by a Monte Carlo (randomization) test procedure.

3.3.6 Vegetation-environment relationship (Ordination)

To understand the relationship between the plant communities and environment, ordination method was employed. The ordination method (unimodal or linear model) is often selected based on the length of the first DCA axis in various ecological studies (e.g. Feyera Senbeta, 2006). Accordingly, a gradient length exceeding four implies a strong unimodal response between the species and environmental variables (Legendre & Legendre, 1998). On the other hand, if the length is < 4 , data are homogeneous and a linear response is expected.

However, according to Zerihun Woldu (2014), the unimodal model is closer to reality of ecological data and is more suitable for heterogeneous datasets (structured by strong or long ecological gradients, with high species turnover and many zeroes in the species matrix). Thus, in

this study a Canonical Correspondence Analysis (CCA) was used in R Package 3.2 (R Core Team, 2015) as recommended by Jongman *et al.* (1987) and ter Braak and Šmilauer (1998). According to ter Braak and Šmilauer (1998), CCA is preferred for most ecological data sets (since unimodality is common) and it is also appropriate to use CCA under a linear model, as long as one is interested in species composition. Moreover, the ordination diagram generated by CCA visualizes not only a pattern of community variation but also the main features of the distributions of species along the environmental variables (ter Braak, 1987).

Before the CCA analysis, forward and backward stepwise selection of environmental variables was carried out to identify variables that could significantly explain the variability of species or plant community distributions. This is based on the assumption that the large majority of the explanatory variables may add little to the explanation since it is highly likely that many of them are collinear (significantly correlated to each other) (Graham, 2003; Dormann *et al.*, 2012; Zerihun Woldu, 2014). According to Dormann *et al.* (2012), there is some degree of collinearity between predictor variables in all real-world data. The Pearson correlation coefficient between environmental variables and its significance was calculated in PAST software Package (ver. 3.04) (Hammer *et al.*, 2001).

3.3.7 Similarity between communities, forest patches or study areas

Ecological resemblance refers to similarity or dissimilarity between samples in terms of their species composition - two samples sharing the same species in the same abundances show the highest similarity (and lowest dissimilarity), and the similarity decreases and dissimilarity increases with the differences in their species composition (Zerihun Woldu, 2014). There are various indices of similarity or dissimilarity. The most commonly applied indices include

Bray/Curtis dissimilarity, Jaccard or Steinhaus and Sørensen's similarity indices. For comparing plant communities or associations as well as forest patches and study areas, the most commonly used index that is Sørensen's similarity index was employed in PAST software package (ver. 3.04) (Hammer *et al.*, 2001). The Sørensen's similarity index, also known as Sørensen's similarity coefficient, is a statistic used for comparing the similarity of two samples, communities or forest patches. The shorthand version of the formula, as applied to quantitative data is:

$$QS = \frac{2a}{2a + b + c}$$

where b and c are the species numbers in communities, forest patches or study areas b and c ; a - the number of species shared by the two and QS is the Sørensen's similarity coefficient.

3.3.8 Vegetation distribution modelling

3.3.8.1 Modelling procedure

To determine the distribution of the new vegetation type, predictive vegetation distribution modelling (suitability analysis) based on the distribution of combinations of indicator species was employed. The Maximum Entropy Model (MaxEnt ver. 3.3.3k) was used for modelling the new vegetation type in Ethiopia (Phillips *et al.*, 2006; Phillips & Dudik, 2008). The suitability categories based on the AUC values were: Not suitable (0.0 - 0.05), Poorly suitable (0.05 - 0.2), Slightly suitable (0.2 - 0.31) and Suitable (0.31 - 0.88). In addition to the test data, the potential distribution areas for the new vegetation type were verified using field notes from those areas (Sebsebe demissew & Friis, unpublished data). To produce the final distribution map, the Ascii file map output of MaxEnt was edited in ArcMap 10.2 using Data Management and Spatial Analyst tools (ESRI, 2013). An Attribute table was built for calculating area coverage of each

category. Moreover, elevation ranges of the “Suitable” areas were mapped to show the elevational diversity of the new vegetation type.

3.3.8.2 Model calibration and variable selection

The default settings of MaxEnt were used except the Random seed, Regularization multiplier, Random test percentage and Maximum iterations, which were changed to “yes”, 3, 30% and 5000, respectively for better model performance (Young *et al.*, 2011). The environmental variables with significant percentage contributions to the model were selected based on the following stepwise selection procedures. Firstly, the model was run using climate layers and soil layers separately and in combination and the performance of each variable was assessed using percentage contribution of each variable to the model. Secondly, variables with percentage contributions to the model were selected and all variables with zero percent contribution were removed from the analysis. And finally, the model was run again using selected variables to produce the final distribution model. According to Young *et al.* (2011), the higher the contribution, the more impact that particular variable has on predictive modelling of species (vegetation) distributions.

3.3.9 Land use/cover change

Five major steps were followed for the analysis of temporal and spatial dynamics of Land use/cover in the study area (Fig. 6). They are preprocessing of images, image classification, accuracy assessment, post classification image processing and change detection. Change Detection Statistics is used to compile a detailed tabulation of changes between two classification images.

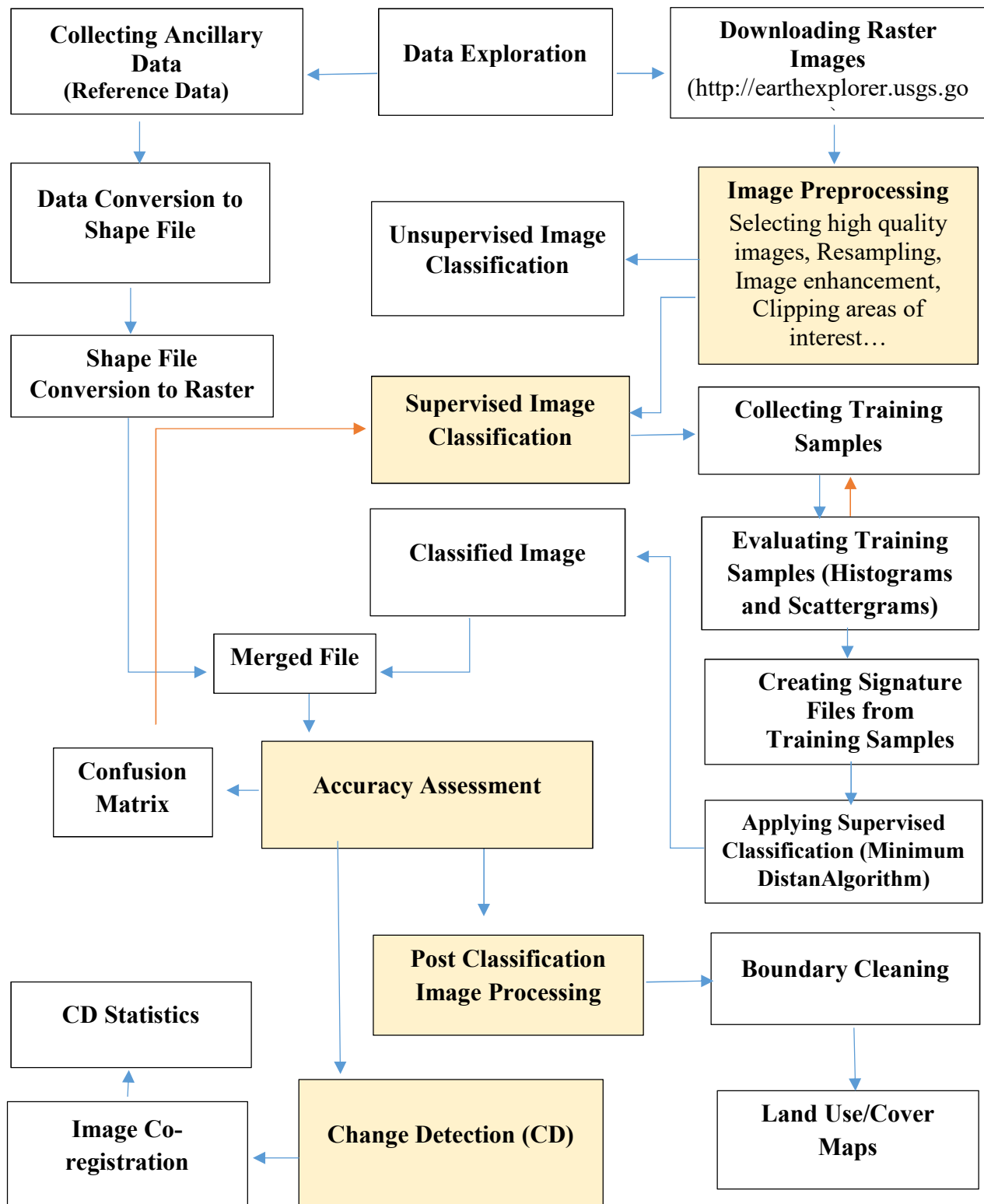


Figure 6. Workflow of major activities in Land use/cover classification and change detection in the study area.

3.3.9.1 Preprocessing of raster images

Image preprocessing techniques involved georeferencing, resampling, clipping and enhancing color, brightness and resolution. A polygon with an area of 831.6 km² (83,160 ha); which encompasses the six forest patches and other nearby forest patches, was constructed using digitization tools in ArcMap 10.2 (ESRI, 2013). The polygon was digitized by using the 1973 image and exported as shape file for later use for clipping the raster images. The 1973 image was used on the assumption that the forest cover was in better conservation status compared to later years. The spatial references of all the raster images and the clipping polygon were corrected to Adindan UTM Zone 37 N and each image was clipped by the polygon. The 1973 and 2014 raster images were resampled to a pixel size of 30 m x 30 m by the “nearest neighbor assignment” method. This method is the fastest of the interpolation methods and it is primarily used for discrete data, such as a Land use/cover classification, since it does not change the values of the cells (ESRI, 2013). Moreover, the pixel correction is primarily useful for comparison purposes of the classified images. The resampled images were enhanced and corrected using the image analysis tool in ArcMap for clear identification of the potential land use classes. Consequently, the images were exported as ENVI 5.0 file format for classification purposes.

3.3.9.2 Image classification

Unsupervised and Supervised classification techniques were performed in ENVI 5.0. Unsupervised classification was carried out to see how distinct potential classes were. Then supervised classification was employed for final image classification purposes. The goal of supervised classification is to assign each cell in the study area to a known class/land use (Richards, 1999). The analysis was carried out based on the following four major steps: a) the input bands of each raster image were identified; b) At least 30 training samples were produced

for each class from known locations of desired classes (Primary forest, secondary forest/scrub, grazing land and agriculture); c) a signature file was developed from the training samples; and d) the minimum distance (MD) algorithm was employed to classify land uses for each period using raster images and signature files. The MD algorithm uses the mean vectors for each class and calculates the Euclidean distance from each unknown pixel to the mean vector for each class.

3.3.9.3 Post classification image processing

Post classification image processing of the classified images was carried out in ArcMap. The Boundary Clean tool was used for cleaning ragged edges between zones. Consequently, the Land use/cover maps were produced using the mapping tools.

3.3.9.4 Accuracy assessment

A thematic map derived from a classification may be considered accurate if it provides an unbiased representation of the Land use/cover of the region it portrays (Congalton, 1991; Foody, 2002; Congalton & Green, 2009). Accordingly, accuracy assessment was carried out for each period to ensure that the Land use/cover classes were properly classified. The reference data (latitude and longitude), which were collected from field for each land use type, were plotted and saved as point shape file in ArcMap (Congalton, 1991; Powell *et al.*, 2004; Congalton & Green, 2009). The shape file was converted to raster and merged with the classified images. Consequently, an error or confusion matrix or contingency table was produced for each period and the producer's and user's accuracy as well as overall accuracy and Kappa coefficient were computed in ArcMap and spreadsheet programmes (Foody, 2002; Congalton & Green, 2009). According to Congalton and Green (2009), error matrices are very effective representations of map accuracy because the individual accuracies of each map category are plainly described

along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. Generally, the error matrix compares counts of agreement between reference data and classified image data by class (Powell *et al.*, 2004). The Kappa (K') analysis is a discrete multivariate technique used in accuracy assessment to determine statistically if the Producer's accuracy is significantly different from the User's accuracy or if there is an agreement between the two (Congalton & Green, 2009). The short hand version of the formula is as follows.

$$K' = N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (X_{ik} * X_{ki}) / N^2 - \sum_{i=1}^r (X_{ik} * X_{ki})$$

Where r is the number of rows in the matrix, X_{ii} is the number of observations correctly classified in row i and column i , X_{ik} and X_{ki} are the marginal totals of each land use class in row i and column k , respectively and N is the total number of samples. The value falls between 0 and 1 (inclusive), meaning no and perfect agreement, respectively.

3.3.9.5 Change detection and rates of change

Change detection analysis encompasses a broad range of methods used to identify, describe and quantify differences between images of the same scene at different times or under different conditions (Richards, 1999). The classified input images were co-registered before change detection analysis. Among the various tools in ENVI 5.0, change detection statistics, which compiles a detailed tabulation of changes between two classified images, was computed as it is a recommended approach. A matrix, where the columns holding the "initial state" classes and the rows representing "final state" classes, was produced in the form of area (ha) and percentage changes. To determine extent and rate of change of land use types per temporal scale, the

following variables were employed and MS Excel spreadsheet programme was used for the computation.

$$A_c = A_2 - A_1$$

$$E_c = A_c / A_1 \times 100 \text{ or } (A_2 - A_1) / A_1 \times 100$$

$$R_c = E_c / (t_2 - t_1) \text{ or } (A_2 - A_1) / A_1 (t_2 - t_1) \times 100$$

whereas A_c is change area, A_1 and A_2 areas in time 1 and 2, E_c percent change extent, R_c rate of change, t_1 and t_2 are time 1 and time 2.

4. RESULTS

4.1 Floristic Composition and Diversity

4.1.1 Floristic composition

A total of 212 species belonging to 169 genera and 79 families were recorded in the study area; 208 species in sampling plots and four species outside sampling plots (Table 5; Appendix 1). In terms of habit, 122 species are woody (Liana 24, Shrub 62, Tree 36) and 90 are herbaceous. Angiosperms are represented by 204 species, gymnosperms by one species and Pteridophytes by seven species. Among the Angiosperms, the family Asteraceae was the richest family (18 species), followed by Acanthaceae and Fabaceae (13 species each), Euphorbiaceae (12 species) and Lamiaceae (10 species). Pteridophytes were represented by four families and seven species, namely Aspleniaceae (two species), Polypodiaceae (two species), Pteridaceae (one species) and Selaginellaceae (two species). *Juniperus procera* (Cupressaceae) was the only species of Gymnosperms.

Table 5. Floristic richness of the six forest patches in the study area.

Forest Patch	Woody Species Richness	Herbaceous Species Richness	Total Richness
Ambiqi	55	30	85
Askunabo	64	44	108
Bradi	62	48	110
Degera	56	21	77
Khatasa	58	53	111
Kidamaja	55	23	78
Total	122	90	212

The highest richness among the forest patches was recorded in Khatasa forest, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forest patches. In terms of woody species

richness, Askunabo was the richest, followed by Bradi, Khatasa, Degera, Kidamaja and Ambiqi forests. Khatasa forest harbored the highest richness of herbaceous species, followed by Bradi, Askunabo, Ambiqi, Kidamaja and Degera forests. The species, which were recorded outside sampling plots are *Echinops kebericho* Mesfin, *Erythrina brucei* Schweinf., *Guizotia abyssinica* (L. f) Cass. and *Sapium ellipticum* (Krauss) Pax. *G. abyssinica* is a cultivated crop which was collected as an escape from areas of cultivation.

4.1.2 Floristic diversity

The Shannon diversity index and evenness of the study area were 3.7 and 0.8, respectively. Among the forest patches, the highest Shannon index was observed in Bradi forest, followed by Kidamaja, Degera, Khatasa, Askunabo and Ambiqi (Table 6). Shannon evenness value was also in the same order with little variations, the highest being for Bradi and Kidamaja forests and the least evenness for Ambiqi forest.

Table 6. Indices of diversity and evenness of the forest patches in the study area

Forest Patch	Evenness index (J)	Alpha Diversity index (H')	Beta Diversity index (β)
Bradi	0.81	3.35	5.45
Degera	0.79	3.18	4.66
Askunabo	0.74	3.08	6.48
Kidamaja	0.81	3.24	4.88
Khatasa	0.78	3.18	6.01
Ambiqi	0.73	2.91	5.94
All (Study area)	0.8	3.7	5.6

The highest diversity index per plot (Appendix 2) was - plot 7 ($H'=2.87$), followed by 44 ($H'=2.82$), 32 ($H'=2.73$), 137 ($H'=2.64$), 31 ($H'=2.63$), 96 (2.61) and 1 (2.60). Plots 1, 7 and 31 belong to Bradi forest while 32 and 44 to Degera, 96 to Askunabo and 137 to Khatasa forests. Thus, the highest diversity index per plot was in Bradi forest, followed by Degera, Kahtasa and Askunabo forests. Shannon evenness values were generally higher than 0.7. In other words, more even distribution of individuals of species were observed in the study area and each forest patch. Accordingly, the highest evenness value was in plot 7 ($J = 0.93$). Plot number 2 exhibited an evenness value of 0.91, and six plots each, namely 43, 99, 1, 108, 80 and 133 had a value of 0.90. The overall Whittaker's beta diversity index of the study area was 5.6. The highest beta diversity index was in Askunabo, followed by Khatasa, Ambiqi, Bradi, Kidamaja and Degera forests.

4.1.3 Floristic composition similarities between forest patches

The similarities between forest patches were generally strong ($QS > 0.5$). Accordingly, Bradi and Degera forests exhibited the highest similarity (Table 7). Moreover, Kidamaja forest showed strong similarities with Ambiqi, Askunabo and Bradi. Relatively the least similarity was observed between Khatasa and Degera forests.

Table 7. Floristic composition similarity indices of the six forest patches.

Ambi- Ambiqi, Asku- Askunabo, Brad- Bradi, Dege- Degera, Khat- Khatasa, Kida- Kidamaja.

	Ambi	Asku	Brad	Dege	Khat
Asku	0.69	-			
Brad	0.75	0.71	-		
Dege	0.61	0.72	0.78	-	
Khat	0.62	0.69	0.65	0.54	-
Kida	0.71	0.72	0.72	0.67	0.62

4.1.4 Endemic species and their IUCN status

Twenty-three endemic species (10.8% of total) to the Flora area (Ethiopia and Eritrea) were recorded in the study area (Appendix 3). Four taxa, namely *Rhus glutinosa* subsp. *glutinosa*, *Otostegia tomentosa* subsp. *tomentosa*, *Lippia adoensis* var. *adoensis* and *Guizotia abyssinica* were shared with Eritrea; while the remaining 19 species belonged to Ethiopia. Among the total endemics, 10 species are shrubs, eight species herbs, three species trees and two species lianas. Generally, 15 families were represented in the endemic species list. Among them, three families were represented by the largest number of endemic species. Asteraceae was the first family having five endemic species, followed by Acanthaceae (three species) and Fabaceae (three species). The remaining twelve families have a single species each in the endemic species list. Among the endemic species, four species are near threatened, six species vulnerable and 13 species are least concern (Table 8).

Table 8. Number of species in the IUCN redlist status by habit in the study area

IUCN Status	Herb	Shrub	Liana	Tree	Total
Near threatened	1	3	-	-	4
Vulnerable	2	3	1	-	6
Least concern	5	4	1	3	13
Total	8	10	2	3	23

4.2 Structure of Forests and Species

4.2.1 Frequency and relative frequency of woody species

The most frequent woody species in the study area was *Rytigynia neglecta* (83%), followed by *Croton macrostachyus* (68%), *Vepris dainellii* (62%), *Albizia schimperiana* (57%) and *Maytenus*

arbutifolia (54%) (Appendix 4). Species, namely *Albizia schimperiana*, *Maytenus arbutifolia*, *Erythrococca trichogyne*, *Bersama abyssinica*, *Albizia gummifera* and *Landolphia buchananii* occurred from 50% to 57% of the sampling plots. Generally, about 95% of the species had below 50% frequency; 33% of the species each occurred in a single plot; while 12.5% of species each occurred in two plots. The relative frequency of species was between 0.04 and 6% with similar orders as their frequencies.

Even though the frequency value differs for each forest patch, *R. neglecta* was among the first three most frequent woody species in the five forest patches, except Khatasa. In Ambiqi forest, the five most frequent woody species, in order of their frequency, were *C. macrostachyus*, *R. neglecta*, *B. abyssinica*, *Carissa spinarum* and *M. arbutifolia*. In Askunabo forest, *R. neglecta* was the most frequent species, followed by *Deinbollia kilimandscharica*, *E. trichogyne*, *C. macrostachyus* and *A. gummifera*. In Bradi forest, the highest frequency was for *Rothmania urcelliformis*, followed by *V. dainellii*, *R. neglecta*, *A. schimperiana* and *C. macrostachyus*. In Degera forest, *R. urcelliformis* was the most frequent species, followed by *R. neglecta*, *E. trichogyne*, *V. dainellii* and *Celtis africana*. In Kidamaja forest, *R. neglecta* was the most frequent, followed by *C. macrostachyus*, *V. dainellii*, *Ehretia cymosa* and *R. urcelliformis*. In Khatasa forest, *B. abyssinica* had the highest frequency, followed by *Apodytes dimidiata*, *M. arbutifolia*, *Canthium oligocarpum* and *Teclea nobilis*.

4.2.2 Density and relative density of woody species

The total abundance of woody species with DBH ≥ 2.5 cm in the study area was 13380 stems; while the total density was 2172.1 stems ha⁻¹ (Appendix 4). The top most abundant species with abundance value of above 500 individuals were *Rytigynia neglecta*, *Rothmania urcelliformis*,

Deinbolia kilimandscharica, *Albizia gummifera*, *Croton macrostachyus*, *Bersama abyssinica*, *Vepris dainellii* and *Maytenus arbutifolia*. *R. neglecta* was the most abundant species with abundance of 1349 individuals and a density of 219 stems ha⁻¹. The first five species have densities of 100 stems ha⁻¹ and above. Generally, 25% of the species have densities of one stem ha⁻¹. The relative density ranged between 0.01 and 10.1%, the highest being for *R. neglecta*.

The highest density was documented in Ambiqi forest (2437.5 stems ha⁻¹), followed by Degera (2340.6 stems ha⁻¹), Khatasa (2179.5 stems ha⁻¹), Kidamaja (2158.3 stems ha⁻¹), Bradi (2080.5 stems ha⁻¹) and Askunabo (2059.5 stems ha⁻¹) forests. Consequently, 22 species scored a density of 100 stems ha⁻¹ or higher in all forest patches. In Ambiqi forest, five species, namely *C. spinarum*, *R. neglecta*, *C. macrostachyus*, *M. arbutifolia* and *Vernonia auricullifera* had densities more than 100 stems ha⁻¹. In Bradi forest, seven species, namely *Rothmania urcelliformis*, *R. neglecta*, *V. dainellii*, *Millettia ferruginea*, *A. schimperiana*, *Maesa lanceolata* and *Lepidotrichilia volkensii* had the highest densities among species. Similar trends were observed in Degera forest, the first three species having the highest densities as in Bradi, followed by *C. macrostachyus* and *Teclea nobilis*. Askunabo forest comprised eight species, namely *D. kilimandscharica*, *R. neglecta*, *A. gummifera*, *Prunus africana*, *Justicia schimperiana*, *E. trichogyne*, *C. macrostachyus* and *A. schimperiana* with densities 100 stems ha⁻¹ and above. In Kidamaja forest, *Discopodium penninervium* had the highest density, followed by *R. neglecta*, *Ehretia cymosa*, *V. dainellii*, *M. ferruginea* and *R. urcelliformis*. Six species, namely *B. abyssinica*, *M. arbutifolia*, *Canthium oligocarpum*, *M. lanceolata*, *T. nobilis* and *Maytenus obscura* had the highest densities in Khatasa forest. Generally, the highest density was for *C. spinarum* in Ambiqi forest.

4.2.3 Basal area and dominance of woody species

The total basal area and dominance of woody species with DBH ≥ 2.5 cm in the study area was 41.2 and 23.1 m² ha⁻¹, respectively (Appendix 4). Generally, 11 species such as *Albizia schimperiana*, *Prunus africana*, *A. gummifera*, *Apodytes dimidiata*, *Croton macrostachyus* and *Ekebergia capensis* scored a basal area of 1.0 m² ha⁻¹ and above, which were among the top dominant species. Ambiqi forest had the highest basal area (57.4 m² ha⁻¹), followed by Askunabo (43 m² ha⁻¹), Khatasa (40.5 m² ha⁻¹), Bradi (37 m² ha⁻¹), Kidamaja (35 m² ha⁻¹) and Degera (34.5 m² ha⁻¹) forests. In terms of dominance, Khatasa forest had the highest dominance (28.7 m² ha⁻¹), followed by Ambiqi (28 m² ha⁻¹), Askunabo (26 m² ha⁻¹), Kidamaja (25.3 m² ha⁻¹), Bradi (23.5 m² ha⁻¹) and Degera (20.8 m² ha⁻¹).

In each forest patch, few species had basal area of above 1.0 m² ha⁻¹. In Ambiqi forest, *P. africana*, *A. gummifera*, *A. schimperiana*, *C. macrostachyus*, *Celtis africana*, *Carissa spinarum*, *Allophylus abyssinicus*, *A. dimidiata*, *Ficus sur* and *F. thonningii* were the most dominant species. In Askunabo forest, *A. gummifera* was the most dominant followed by *E. capensis*, *P. africana*, *D. kilimandscharica*, *A. schimperiana*, *C. macrostachyus*, *A. dimidiata*, *Acacia abyssinica* and *F. thonningii*. In Bradi forest, *A. schimperiana* dominated, while *P. africana*, *E. capensis*, *A. gummifera*, *Vepris dainellii*, *C. africana*, *Dracaena steudneri*, *Rothmania urcelliformis*, *Croton macrostachyus*, *Millettia ferruginea* were among the dominant species. Degera forest had few dominant species such as *P. africana*, *A. dimidiata*, *C. africana*, *Croton macrostachyus*, *R. urcelliformis*, *A. schimperiana*, *Mimusops kummel*, *A. abyssinicus* and *V. dainellii*. Khatasa forest had a number of species in the dominant list, namely *A. dimidiata*, *Juniperus procera*, *P. africana*, *Canthium oligocarpum*, *Nuxia congesta*, *Maesa lanceolata*, *A. abyssinicus*, *Schefflera abyssinica*, *Bersama abyssinica*, *C. macrostachyus*, *F. sur* and *A.*

schimperiana. The fewest dominant species were recorded in Kidamaja forest including *A. schimperiana*, *A. gummifera*, *V. dainellii*, *E. cymosa*, *D. steudneri*, *M. ferruginea* and *C. macrostachyus*. Nevertheless, the highest basal area of a species was documented in Kidamaja forest (*A. schimperiana*, 13 m² ha⁻¹), followed by Khatasa (*A. dimidiata*, 11.2 m² ha⁻¹), Ambiqi (*P. africana*, 10.8 m² ha⁻¹), Askunabo (*A. gummifera*, 8.2 m² ha⁻¹), Bradi (*A. schimperiana*, 7.6 m² ha⁻¹) and Degera (*P. africana*, 7.5 m² ha⁻¹) forests.

4.2.4 Importance value index of woody species

The importance value index of woody species in the study area ranged from 0.05 to 16.8 (Appendix 4). The highest IVI was documented for *Rytigynia neglecta*. Species such as *Albizia gummifera*, *A. schimperiana*, *Prunus africana*, *Croton macrostachyus*, *Rothmania urcelliformis* and *Apodytes dimidiata* were among the most important species. Generally, 50.5% of the species had IVI of below one, 12% IVI of one and 37.5% above one.

The IVI of species in the forest patches moderately varied. For example, the highest IVI of species was in Kidamaja forest (*A. schimperiana*, 47.1), followed by Khatasa (*A. dimidiata*, 38.4), Askunabo (*D. kilimandascharica*, 37.2), Degera (*R. urcelliformis*, 33.8), Ambiqi (*C. spinarum*, 32.7) and Bradi (*R. urcelliformis*, 25.2). Generally, 14 woody species had IVI values of 20 and above, while the majority had below 20 in the forest patches. The species having IVI values of 20 and above include: in Ambiqi - *Carissa spinarum*, *Croton macrostachyus*, *Prunus africana* and *R. neglecta*; in Kidamaja - *A. schimperiana*, *Ehretia cymosa* and *V. dainellii*; in Khatasa - *Apodytes dimidiata*, *Bersama abyssinica* and *Canthium oligocarpum*; in Degera - *Rothmania urcelliformis* and *Prunus africana*; in Bradi - *R. urcelliformis*, *A. schimperiana* and

V. dainellii and in Askunabo - *Deinbollia kilimandscharica*, *A. gummifera*, *R. neglecta* and *Ekebergia capensis*.

4.2.5 Population structure of forests and woody species

4.2.5.1 Diameter and height class profile of forests

The DBH and height class distribution of woody species density in the study area showed an *Inverted-J* shaped structure (Fig. 7A). All DBH classes were represented by at least some individuals even though the highest density was concentrated in DBH classes below 12.5 cm. The highest DBH was recorded for one individual of *Ekebergia capensis* (270 cm). Twenty-four individuals of seven species, namely *Ekebergia capensis*, *Prunus africana*, *Schefflera abyssinica*, *Albizia gummifera*, *A. schimperiana*, *Juniperus procera* and *Apodytes dimidiata* had a DBH of 100 cm and above. The height class distribution showed more or less similar pattern to DBH classes. The majority of individuals were accumulated at the lower height classes (< 10 m) (Fig. 7B).

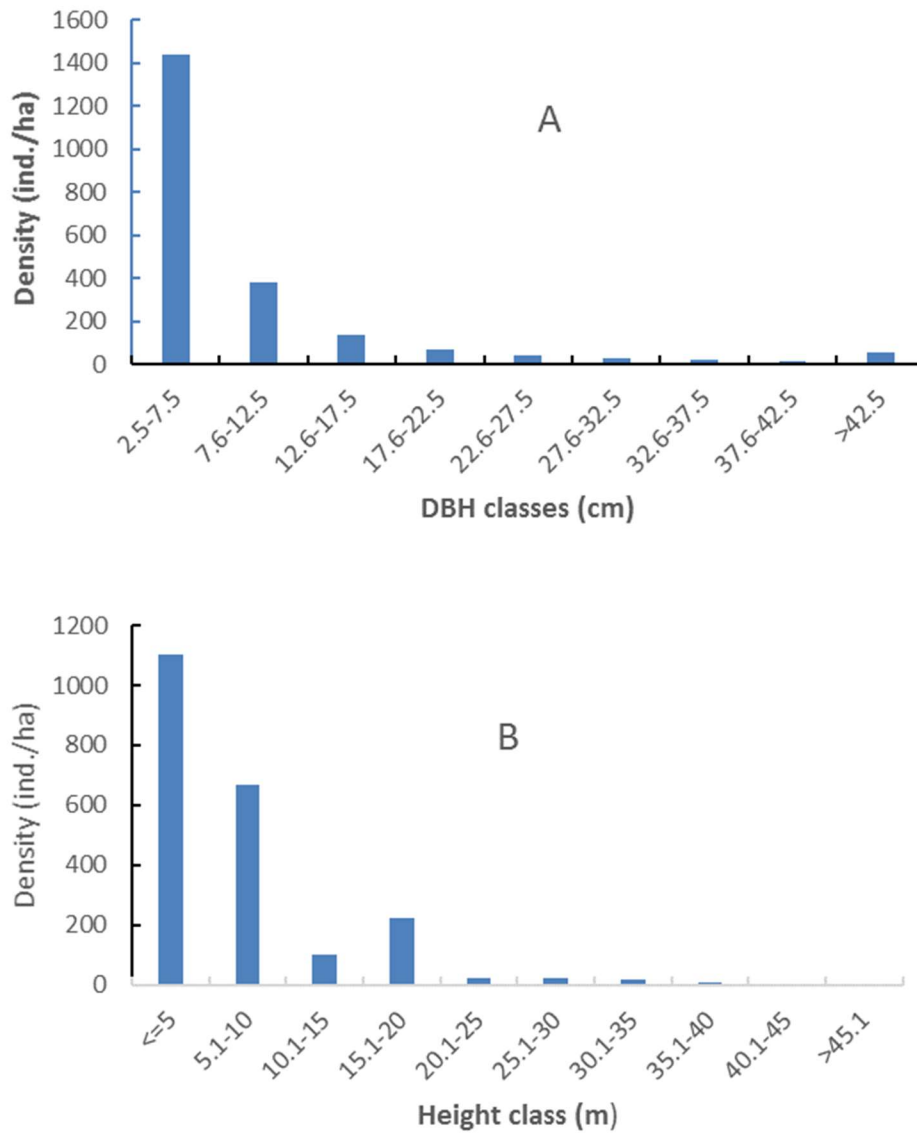


Figure 7. Distribution of population densities (number of individuals per hectare) in DBH (A) and height (B) classes in the study area.

Ten species, namely *Ekebergia capensis*, *P. africana*, *S. abyssinica*, *A. gummiifera*, *A. schimperiana*, *J. procera*, *A. dimidiata*, *C. macrostachyus*, *Ficus sur* and *Celtis africana* had 68 individuals with heights above 40 m, the tallest being *E. capensis* (46 m). The population structure of each forest patch was generally similar to the study area. In each forest patch, most individuals were accumulated in lower DBH or height classes (Fig. 8A & B).

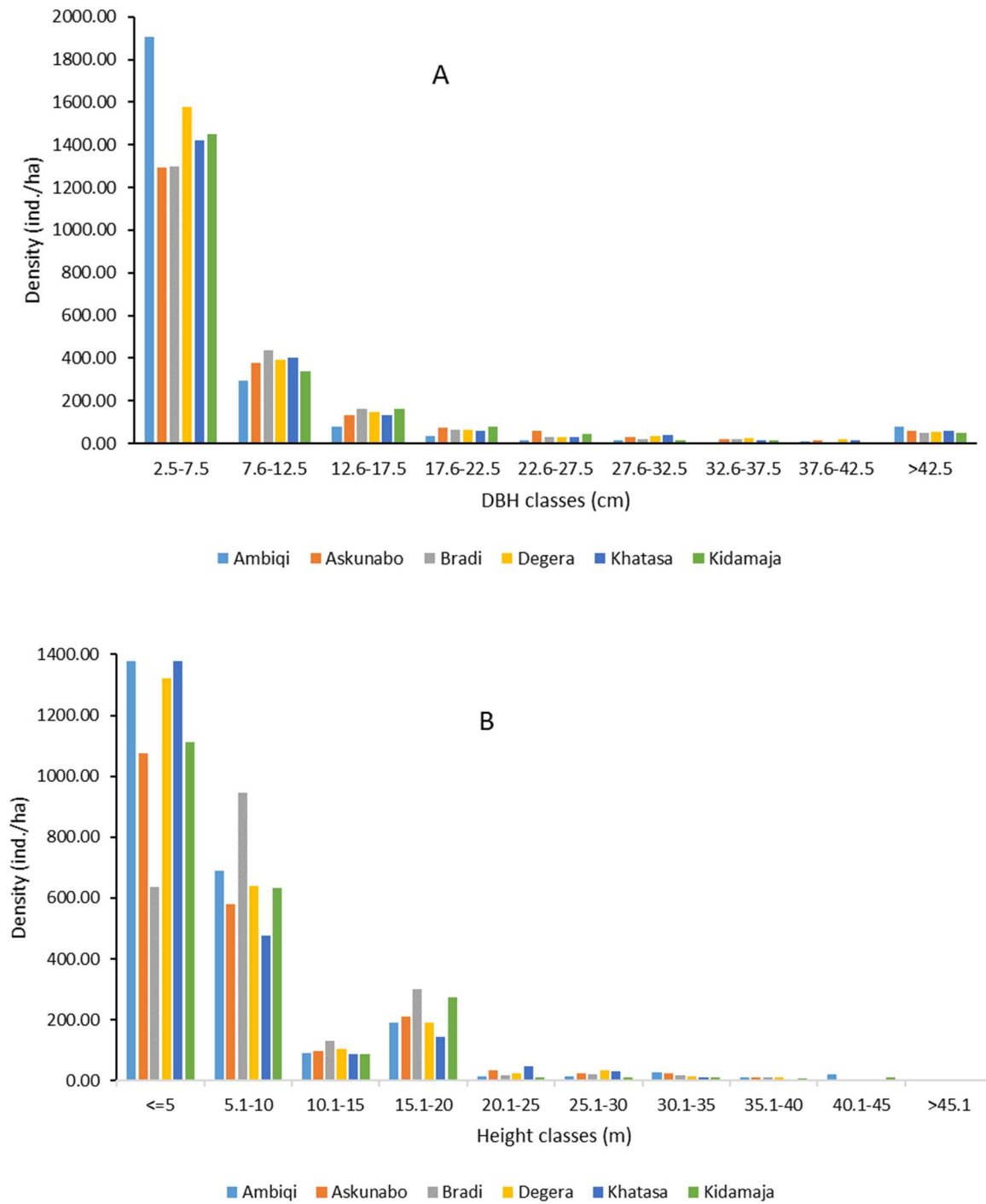


Figure 8. Distribution of population densities (number of individuals per hectare) in DBH (A) and height (B) classes for each forest patch.

4.2.5.2 Population structure of tree species

The analysis of population structure of 28 selected tree species in nine DBH classes revealed five population structure patterns (Fig. 9). The first pattern was an *Inverted-J* shaped in which the highest number of individuals were present in lower DBH classes and their presence decreased towards higher classes. Tree species in this category were *Albizia schimperiana*, *A. gummifera*, *Celtis africana*, *Prunus africana*, *Allophylus abyssinicus*, *Croton macrostachyus*, *Euphorbia abyssinica*, *Ficus sur*, *Maytenus obscura* and *Mimusops kummel*. The second pattern was *unimodal/bell* shaped in which a higher proportion of species were present in intermediate DBH classes and the trend decreased in both directions (lower and higher DBH classes). The species in this category were *Dracaena steudneri*, *Stereospermum kunthianum* and *Acacia abyssinica*.

The third pattern was *J* shaped in which a higher proportion of individuals were present at higher DBH classes and the trend decreased towards lower DBH classes. This pattern was exhibited by *Apodytes dimidiata*. The fourth pattern was a *Broken Inverted-J* shaped where individuals were absent at intermediate or higher DBH classes. *Ehretia cymossa*, *Ficus thonningii*, *Lepidotrichilia volkensii*, *Olea capensis subsp. macrocarpa*, *Pittosporum viridiflorum*, *Ritchiea albersii*, *Millettia ferruginea* and *Cordia africana* were in this category. The fifth pattern lacked individuals at lower and intermediate DBH classes and some mature individuals were present at the highest DBH classes. Trees such as *Juniperus procera*, *Ekebergia capensis*, *Euphorbia ampliphylla*, *Polyscias fulva*, *Schefflera abyssinica* and *Syzygium guineense* exhibited this pattern.

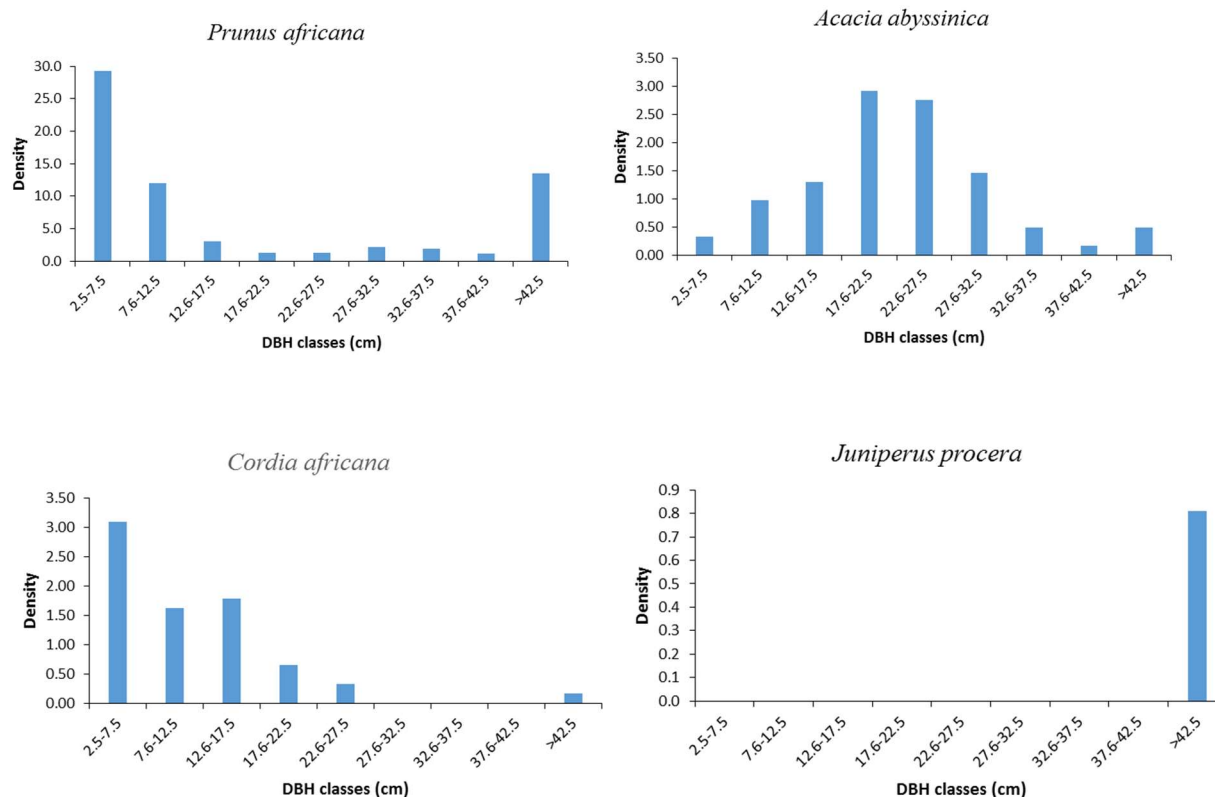


Figure 9. Representative population structure patterns of each tree species in the study area

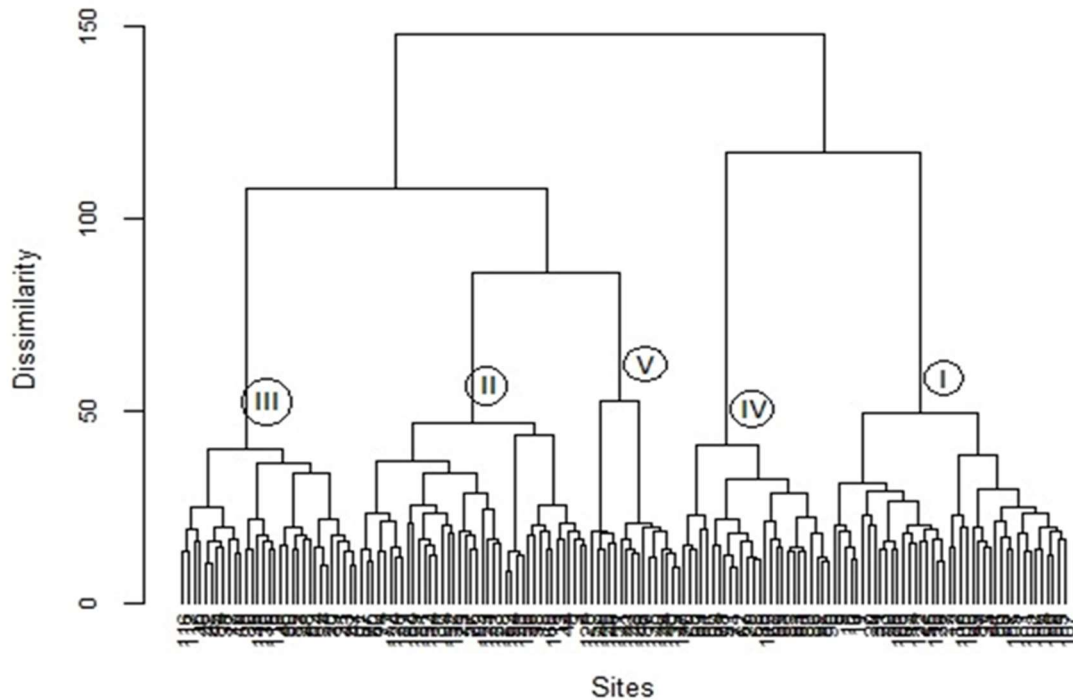
4.2.6 Seedling density of woody species

Ninety-two woody species had seedlings of variable density (Appendix 5). The total seedling density was 1607.1 individuals ha⁻¹. The density for each species ranged between 0.16 and 316 individuals ha⁻¹. The highest seedling density was exhibited by *Maytenus arbutifolia*, followed by *Landolphia buechananii*, *Albizia gummifera* and *Justicia schimperiana*. Thirty-one taxa had the least seedling density, which was less than one. Some of them were *Pterolobium stellatum*, *Nuxia congesta*, *Combretum aculeatum*, *Ficus thonningii*, *Ficus sur*, *Dracaena steudneri*, *Cordia africana*, *Ehretia cymosa*, *Salix subserrata*, *Dalbergia lactea*, *Lobelia gibberoa*, *Olea capensis* subsp. *macrocarpa*, *Dovyalis verrucosa*, *Buddleja polystachya*, *Maytenus obscura*, *Pittosporum viridiflorum*, *Vernonia amygdalina*, *Rhus glutinosa* subsp. *glutinosa* and *Rosa abyssinica*. The

remaining 30 species (24.6% of total woody species) lacked seedlings. Among them were trees such as *Juniperus procera*, *Syzygium guineense*, *Hagenia abyssinica*, *Polyscias fulva*, *Stereospermum kunthianum* and *Ekebergia capensis*.

4.3 Vegetation Classification (Plant Communities)

The hierarchical classification analysis resulted in five plant community types in the study area (Fig. 10), which were named after two or more indicator species (Table 9; Appendix 6). Consequently, the communities are *Millettia ferruginea* - *Vepris dainellii* - *Ehretia cymosa* community (C₁), *Vernonia auriculifera* - *Croton macrostachyus* community (C₂), *Celtis africana* - *Rothmania urcelliformis* community (C₃), *Deinbollia kilimandscharica* - *Hippocratea goetzei* community (C₄) and *Canthium oligocarpum* - *Buddleja polystachya* - *Embelia schimperi* community (C₅). Three classification levels were detected in the dendrogram: in the first hierarchy, C₁ and C₄ were separated from C₂, C₃ and C₅; in the second hierarchy C₁ and C₄ were separated from each other; and C₃ was separated from C₂ and C₅; in the third hierarchy C₂ was separated from C₅. The description of each community type about their altitudinal ranges, indicator species, dominant species and examples of other species in different vegetation layers (tree, shrub and herb); similarity between the five communities and richness, diversity and evenness of each community is dealt with in the following subsections.



- C₁:** 1, 2, 6, 7, 8, 9, 10, 11, 12, 14, 15, 20, 22, 23, 26, 27, 28, 29, 31, 33, 37, 41, 49, 56, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 122;
C₂: 3, 4, 5, 13, 18, 36, 44, 57, 58, 60, 73, 74, 75, 76, 77, 80, 84, 87, 93, 94, 113, 120, 121, 123, 124, 125, 126, 127, 128, 129, 131, 132, 133, 134, 135, 136, 153, 154, 155, 156;
C₃: 16, 17, 19, 21, 24, 25, 30, 32, 35, 38, 39, 40, 42, 43, 44, 45, 46, 47, 48, 50, 51, 52, 53, 54, 55, 115, 116, 117, 118, 119, 130;
C₄: 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 78, 79, 81, 82, 83, 85, 86, 88, 89, 90, 91, 92, 112;
C₅: 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152.

Figure 10. Dendrogram of sampling plots (Plant communities) at dissimilarity level of 50 in the study area

4.3.1 Description of plant communities

C₁: *Millettia ferruginea* - *Vepris dainellii* - *Ehretia cymosa* community: this community occurred at altitudes between 1830 and 2043 m asl, which was relatively at the lower margin of the study area. The highest number of sampling plots (41) and about 108 species were harbored by this community. Some of the indicator species are *M. ferruginea*, *V. dainellii*, *Ehretia cymosa*, *Hippocratea pallens* and *Ritchiea albersii* ($P < 0.01$). The tree layer was dominated by

Ekebergia capensis, *Schefflera abyssinica*, *Albizia schimperiana* and *Ficus sur* while the shrub layer was dominated by *Carissa spinarum*, *Justicia schimperiana* and *Rothmania urcelliformis*. The endemic species, namely *Tiliacora troupinii* was the most dominant in the liana category, followed by *Hippocratea pallens*, *H. goetzei*, *H. africana*, *Landolphia buchannanii* and *Gouania longispicata*. The herb layer included some species such as *Achyranthes aspera*, *Carduus leptacanthus*, *Cardamine africana* and *Achyrospermum schimperi*.

C₂: *Vernonia auriculifera* - *Croton macrostachyus* community: this community type occurred between altitudes 1878 and 2346 m asl. It consisted of 40 sampling plots and 158 species, being the richest in number of species among the five community types. The indicator species are *V. auriculifera* and *C. macrostachyus* ($P < 0.01$). The tree layer was dominated by *Euphorbia abyssinica*, *Acacia abyssinica*, *Albizia gummifera*, *Apodytes dimidiata*, *Schefflera abyssinica* and *Prunus africana*. The shrub layer consisted of *Carissa spinarum*, *Protea gaugudi* and *Deinbollia kilimandscharica*. Some of the liana species include *Jasminum abyssinicum*, *Combretum paniculatum*, *H. goetzei*, *H. pallens* and *Urera hypselodendron*. The herb layer was dominated by species such as *Girardinia bullosa*, *A. schimperi*, *Pycnostachys meyeri* and *Achyranthes aspera*. Epiphytic ferns such as *Pteris catoptera*, *Lepisorus schraderi* and *Asplenium aethiopicum* were also present.

C₃: *Celtis africana* - *Rothmania urcelliformis* community: this community was located at altitudes 1867 to 2106 m asl. Thirty-one sampling plots and 91 species occurred in this community. The indicator species are *C. africana*, *R. urcelliformis* and *Mimusops kummel* ($P < 0.01$). The tree layer was dominated by *Prunus africana*, *Ekebergia capensis*, *Apodytes dimidiata* and *Croton macrostachyus*. The most dominant species in the shrub layer include *Carissa spinarum* and *Vepris dainellii*. Lianas such as *T. troupinii*, *U. hypselodendron*, *L. buchannanii* and

H. goetzelii were dominant. The herb layer was dominated by *G. bullosa*, *Hypoestes triflora*, *Drymaria cordata* and *Justicia diclipteroides*. Epiphytic fern, namely *Drynaria volkensii* was also present.

C4: *Deinbollia kilimandscharica* - *Hippocratea goetzelii* community: This community occurred between altitudes 2068 and 2348 m asl. Twenty-six sampling plots and 78 species belonged to this community. The least species richness is found here. The indicator species are *D. kilimandscharica* and *H. goetzelii* ($P < 0.01$). The most dominant species in the tree layer was *E. capensis*, followed by *A. gummifera*, *F. sur*, *P. africana*, *A. abyssinicus*, *M. ferruginea*, *A. dimidiata* and *Dracaena steudneri*. The shrub layer contained species such as *Oxyanthus speciosus*, *Ehretia cymosa* and *Justicia schimperiana*. Lianas such as *Combretum panniculatum*, *C. aculeatum*, *U. hypselodendron*, *H. pallens*, *Sericostachys scandens* and *L. buchannani* highly dominated. Species such as *H. triflora*, *D. cordata*, *Justicia diclipteroides* and *Kalanchoe citrina* were present in the herb layer. Epiphytic ferns, namely *D. volkensii* and *A. aethiopicum* were present.

C5: *Canthium oligocarpum* - *Buddleja polystachya* - *Embelia schimperi* community: This community occurred at the highest elevational locations between 2359 and 2660 m asl. The least number of plots (16) and about 95 species belonged here. Some of the indicator species are *C. oligocarpum*, *B. polystachya*, *E. schimperi*, *Impatiens ethiopica*, *Drynaria volkensii*, *Lepisorus schraderi*, *Bersama abyssinica*, *Teclea nobilis* and *Nuxia congesta* ($P < 0.01$). The dominant species in the tree layer include *Schefflera abyssinica*, *Croton macrostachyus*, *Ficus sur*, *Juniperus procera*, *Maytenus obscura* and *Apodytes dimidiata*. The shrub layer comprised of *Maesa lanceolata*, *Teclea nobilis*, *N. congesta* and *M. arbutifolia*. Lianas such as *Urera hypselodendron* and *Embelia schimperi* were highly dominant. Species such as *J. ladanoides*,

Urtica simensis and *K. citrina* were abundant at the herb layer. Epiphytic ferns such as *P. catoptera*, *L. schraderi* and *D. volkensii* were also present.

Table 9. Synoptic and indicator values of species in each community type (C₁ - C₅) and their significance ($P < 0.01$).

Species	Synoptic Values*					Indicator Values (%)**					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₁	C ₂	C ₃	C ₄	C ₅	P value
<i>Millettia ferruginea</i>	3.7	0.6	0.0	1.2	0.0	67	0	0	0	0	0.001
<i>Ehretia cymosa</i>	3.4	0.7	0.1	2.0	0.0	62	0	0	0	0	0.001
<i>Vepris dainellii</i>	5.5	1.2	3.9	3.3	0.3	62	0	0	0	0	0.001
<i>Vernonia auriculifera</i>	0.1	2.1	0.6	0.4	0.7	0	58	0	0	0	0.001
<i>Croton macrostachyus</i>	3.7	5.1	3.5	2.2	0.4	0	57	0	0	0	0.001
<i>Celtis africana</i>	0.1	0.4	3.8	0.2	0.0	0	0	78	0	0	0.001
<i>Rothmannia urcelliformis</i>	4.9	0.5	5.5	0.1	0.0	0	0	70	0	0	0.001
<i>Deinbollia kilimandscharica</i>	0.4	1.6	0.0	6.0	0.0	0	0	0	85	0	0.001
<i>Hippocratea goetzei</i>	2.1	0.5	0.2	4.8	0.3	0	0	0	75	0	0.001
<i>Canthium oligocarpum</i>	0.0	0.5	0.0	0.0	3.6	0	0	0	0	81	0.001
<i>Buddleja polystachya</i>	0.0	0.3	0.4	0.0	2.8	0	0	0	0	67	0.001
<i>Embelia schimperi</i>	0.1	0.2	0.0	0.0	2.4	0	0	0	0	67	0.001

* The mean values of the species cover-abundance in each community.

** The product of the relative frequency and relative cover-abundance values in each community.

4.3.2 Diversity and evenness of plant communities

The diversity and evenness indices of plant communities were generally comparable (Table 10).

The highest alpha and beta diversity indices were in community II (C₂), which also had the highest species richness. Community IV (C₄) had also the highest beta diversity index even though the alpha diversity and evenness indices and species richness were the least among the plant communities.

Table 10. Diversity and evenness of plant communities in the study area

Community	Altitudinal Ranges (m)	Shannon Diversity	Shannon Evenness	Beta Diversity
C ₁	1830 - 2043	3.3	0.8	4.8
C ₂	1878 - 2346	3.4	0.8	6.1
C ₃	1867 - 2106	3.1	0.8	5.3
C ₄	2068 - 2348	2.8	0.7	6.1
C ₅	2359 - 2660	3.0	0.8	6.0

4.3.3 Similarities between plant communities

The similarities between plant communities were generally strong ($QS \geq 0.5$). The highest similarity was between C₁ and C₂, C₁ and C₃ as well as C₁ and C₄ (Table 11). The least similarity was between C₁ and C₅. The number of species shared between C₁ and communities C₂, C₃, C₄ and C₅ was 92, 73, 64 and 55, respectively.

Table 11. Similarity indices of plant communities (C₁ - C₅) in the study area.

	C ₁	C ₂	C ₃	C ₄
C ₂	0.70	-		
C ₃	0.70	0.65	-	
C ₄	0.70	0.60	0.68	-
C ₅	0.50	0.56	0.52	0.57

4.4 Vegetation-Environment Relationship (Ordination)

Among the 17 environmental variables, only eight variables (47% of total), namely Electrical conductivity, Potassium, Calcium, Sand, Slope, pH, Grazing and Altitude significantly affected species compositions of communities and their distributions ($P < 0.05$) and these variables were

used in the ordination analysis. The values of pH, EC, CEC, soil minerals, OM and N are summarized in Table 12. The soil pH had mean value of 5.7, while EC and CEC had 0.3 and 51.9, respectively. The mean values for Ca, Mg, Na, K, P and N were 30.2, 10.4, 0.1, 1.3, 10.3 and 0.5, respectively.

Table 12. Values of pH, EC, CEC, soil minerals, organic matter and nitrogen in the study area.

	pH	EC	CEC	Ca	Mg	Na	K	P	OM	N
Minimum	4.9	0.0	34.4	11.3	1.0	0.0	0.3	0.6	2.3	0.3
Maximum	6.8	0.7	80.1	74.0	47.1	0.3	3.5	49.9	8.8	3.0
Mean	5.7	0.3	51.9	30.2	10.4	0.1	1.3	10.3	6.1	0.5
Standard error	0.02	0.01	0.68	0.76	0.54	0.00	0.05	0.85	0.10	0.02

Altitude had strong and positive correlations with the first CCA axis ($r = 0.96$; $P < 0.05$); whereas EC had negative and strong correlation with the first CCA axis ($r = -0.52$; $P < 0.05$). pH was strongly and negatively correlated with the second CCA axis ($r = -0.88$; $P < 0.05$). Slope ($r = -0.7$) and grazing ($r = 0.6$), and Calcium ($r = -0.5$) and sand ($r = -0.78$) were strongly correlated with the third and fourth CCA axes, respectively ($P < 0.01$ for all correlations). Generally, the Eigen values for the constrained axes were 0.32, 0.14, 0.11 and 0.1 for the first, second, third and fourth axes, respectively. The first CCA axis was mainly explained by altitude and separated communities at high altitudes (community 2, 4 and 5) and low altitudes (communities 1 and 3) on the right and left side of the ordination axis, respectively (Fig. 11). The second CCA axis was mainly explained by pH which separated communities at low - medium and high pH areas above and below the ordination axis, respectively.

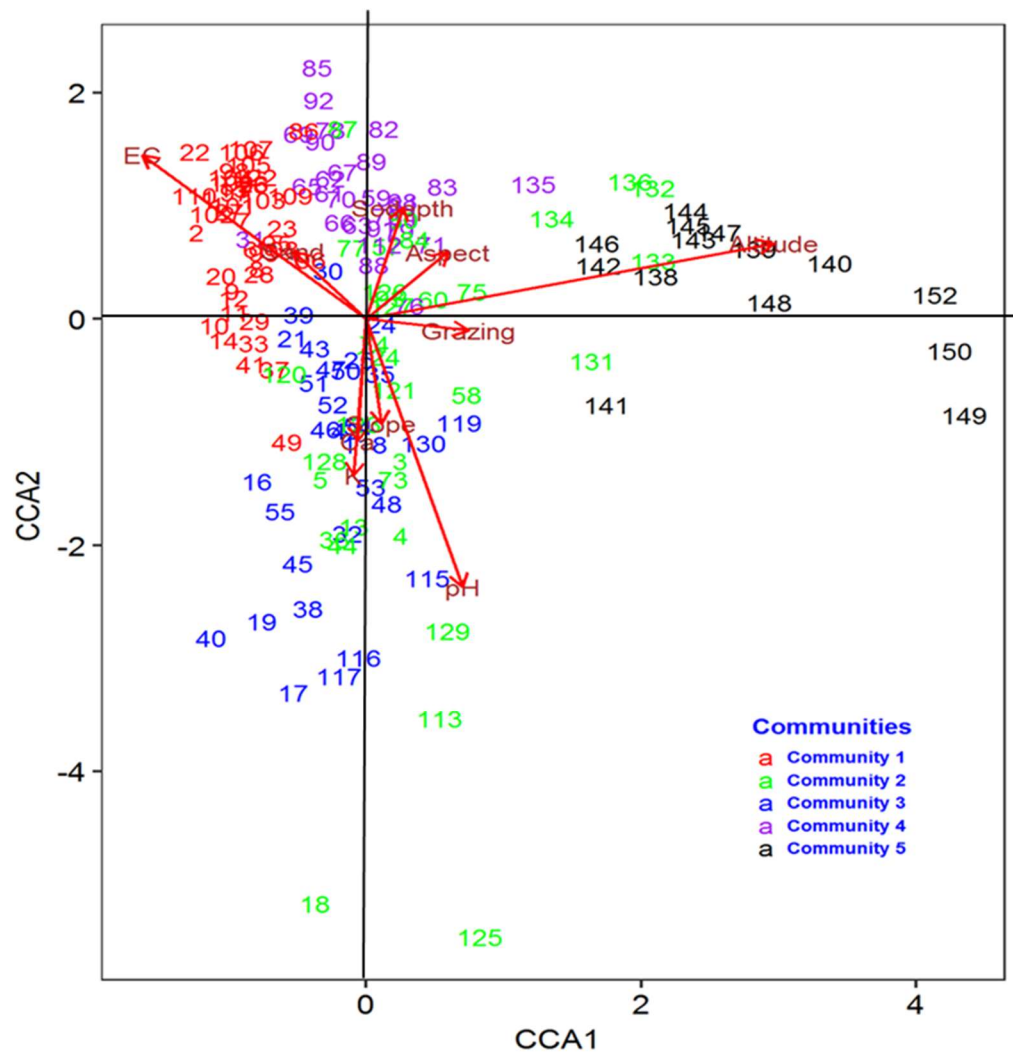


Figure 11. CCA biplot of environmental variables and sampling plots (communities)

4.5 Vegetation Distribution Modelling

4.5.1 Contribution of environmental variables

The stepwise selection of environmental variables revealed that eight bioclimatic variables (42% of total) and 10 soil variables (21% of total) contributed for the MaxEnt distribution model. The climatic variables are Precipitation of wettest month, Precipitation of wettest quarter, Isothermality, Minimum temperature of coldest month, Maximum temperature of warmest

month, Precipitation of driest quarter, Annual precipitation and Precipitation of Driest Month; while the soil variables are Bulk density (B & C), pH (B, C, D & F), CEC (D), Organic Carbon (A) and Clay (B & F). The highest contribution was from Precipitation of wettest month (56%), followed by soil bulk density (13%), Isothermality (11%) and CEC (4%). The least variable contribution was from Annual Precipitation, pH (F), Clay (B & F) and Precipitation of Driest Month. On the other hand, elevation, 11 bioclimatic variables (58% of total) and 38 soil variables (79% of total) performed poorly to the MaxEnt model with zero percent contribution. Generally, bioclimatic variables contributed 75%; while soil variables contributed the remaining 25% to the MaxEnt model.

4.5.2 Vegetation distribution and coverage

The most favorable areas for the distribution of the new vegetation type were found to be in Gojam Floristic Region (Fig. 12) - West Gojam Zone (Bahirdar Zuria, Zege Peninsula), Awi Zone (most parts of Awi) and Metekel Zone (eastern Wenbera, Dangur, Bullen and Madura); and Gondar Floristic Region - South Gondar Zone (south of Lake Tana, Western Farta) in Ethiopia. Some of the areas previously mapped as *Combretum-Terminalia* woodland and wooded grassland, Moist evergreen Afromontane forest and Dry evergreen Afromontane forest and grassland complex were reclassified as a new vegetation type (Fig. 13). The majority of the new vegetation type was previously mapped as DAF.

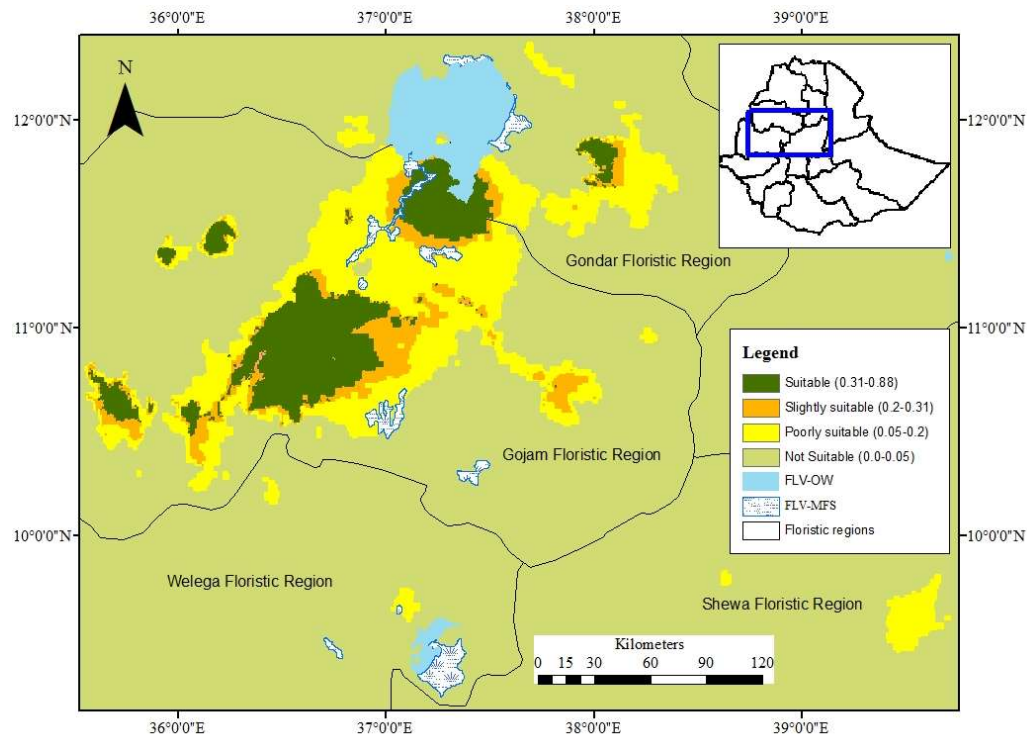


Figure 12. Predicted habitat suitability for the potential distribution of the new vegetation type in Ethiopia (Note – most of the unsuitable areas to IAF are clipped from the map).

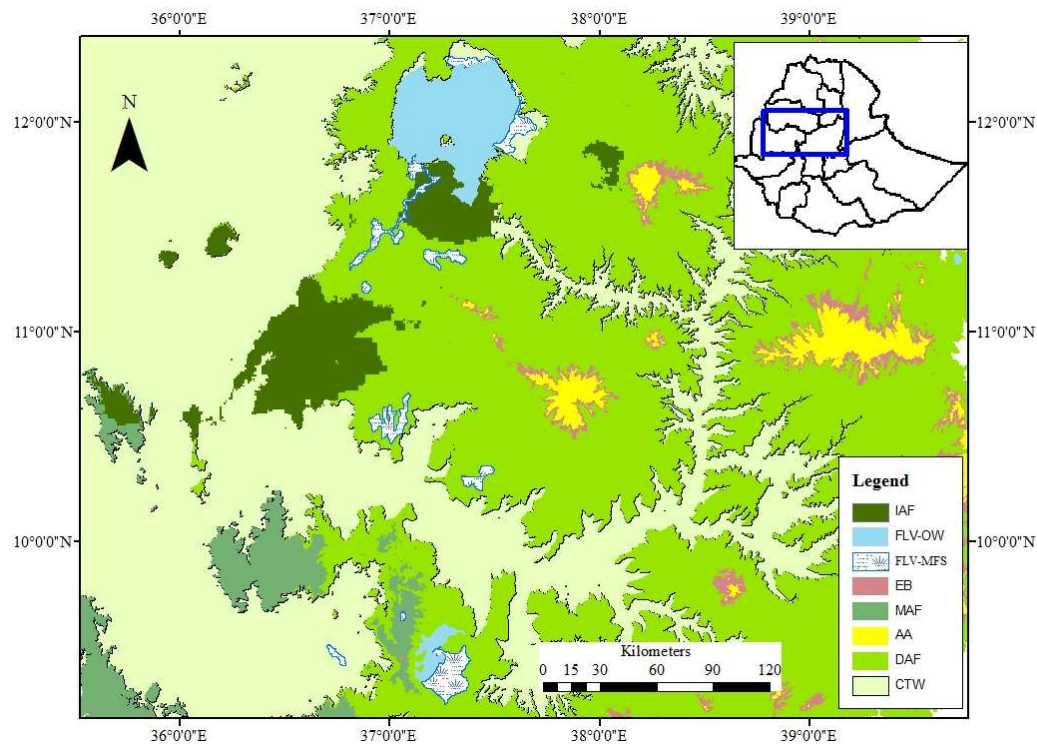


Figure 13. The potential distribution map of the new vegetation type (IAF) and other vegetation types in Ethiopia (note – other areas are clipped to clearly show the distribution of IAF).

In terms of area coverage, suitable areas for the distribution of the new vegetation type covered 6,915 km² with altitudinal ranges of between 1,500 and 2,800 m asl (Fig 14). Slightly and poorly suitable areas covered 4,045 km² and 16,739 km², respectively. The elevations of slightly suitable and poorly suitable areas extended to Afroalpine vegetations and lowland vegetations such as *Combretum-Terminalia* woodland and wooded grassland in Gojam and Gondar Floristic Regions.

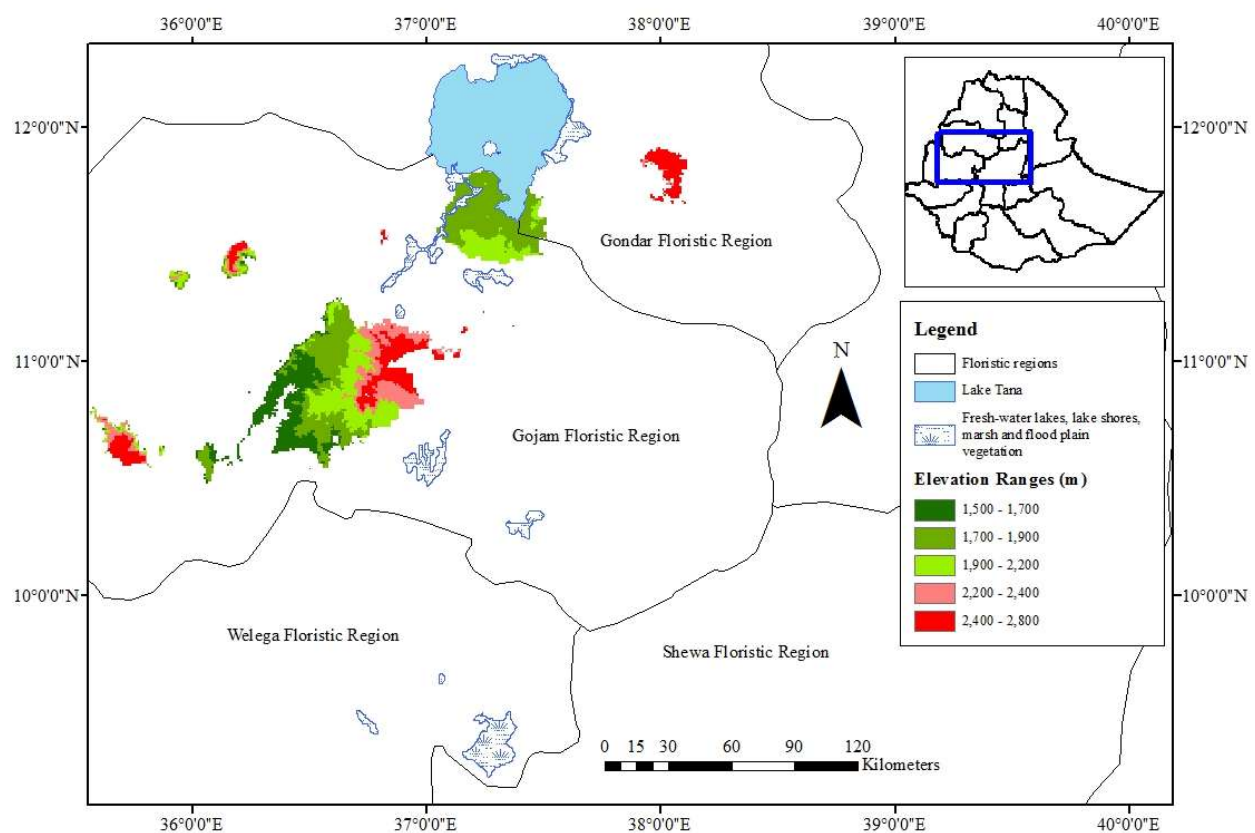


Figure 14. Elevational ranges of suitable areas for the potential distribution of Intermediate evergreen Afromontane forest (IAF) in Gojam and Gondar Floristic Regions.

4.6 Land use/cover Change

4.6.1 Accuracy assessment of Land use/cover classification

The overall accuracy level and Kappa coefficient were above 85% and 0.8, respectively for all study years. The lowest and highest accuracy and Kappa coefficient were obtained for 2001 and 1987 images, respectively. Consequently, the overall classification accuracy of the 1973, 1987, 2001 and 2014 images were 94, 96, 87 and 93%, respectively; while the Kappa coefficients were 0.92, 0.95, 0.83 and 0.88, respectively (Table 13). The producer's accuracy ranged from 87 to 97% for all study periods. The highest accuracy was for the primary forest and the lowest was for secondary forest/scrub. The User's accuracy was generally above 91%, the lowest and the highest being for primary forest and agriculture, respectively.

Table 13. Classification accuracy of the 1973 image in the study area

	Land Use/ Cover type	Reference Data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified Data	Primary forest	67	6	0	0	73	91.8
	Scrub	2	58	2	0	62	93.6
	Grassland	0	1	84	3	88	95.5
	Agriculture	0	1	2	66	69	95.7
Total		69	66	88	69	292	-
Producer's accuracy		97.1	87.9	95.5	95.7	-	-
Overall accuracy		94.2	-	-	-	-	-
Kappa coefficient		0.92	-	-	-	-	-

The 1987 image was classified with the highest accuracy among the periods, which is also true for the Producer and User's accuracy (Table 14). The User's accuracy was 98% for grassland, 97.7% for primary forest, 97.6% for agriculture and 90.6% for secondary forest/scrub. The Producer's accuracy was 98% for grassland, 97.6% for agriculture, 94.4% for primary forest and

94% for secondary forest/scrub. The Kappa coefficient and overall accuracy were generally the highest for the 1987 image.

Table 14. Classification accuracy of the 1987 image in the study area

	Land Use/ Cover type	Reference Data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified Data	Primary forest	84	2	0	0	86	97.7
	Scrub	5	77	1	2	85	90.6
	Grassland	0	2	99	0	101	98.0
	Agriculture	0	1	1	82	84	97.6
Total		89	82	101	84	356	-
Producer's accuracy		94.4	93.9	98.0	97.6	-	-
Overall accuracy		96.1	-	-	-	-	-
Kappa coefficient		0.95	-	-	-	-	-

The lowest classification accuracy among the years was for the 2001 image (Table 15). Accordingly, the User's accuracy was 77% for secondary forest, 97.6% for grassland, 81.3 for agriculture and 100% for primary forest. The Producer's accuracy was 98.3% for secondary forest/scrub, 89% for primary forest, 84% for agriculture and 77% for grassland. The overall accuracy and Kappa coefficient were 87% and 0.83, respectively.

Table 15. Classification accuracy of the 2001 image in the study area

	Land Use/ Cover types	Reference Data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified Data	Primary forest	56	0	0	0	56	100.0
	Scrub	7	59	0	10	76	77.6
	Grassland	0	1	40	0	41	97.6
	Agriculture	0	0	12	52	64	81.3
Total		63	60	52	62	237	-
Producer's accuracy		89.0	98.3	77.0	84.0	-	-
Overall accuracy		87.3	-	-	-	-	-
Kappa coefficient		0.83	-	-	-	-	-

The 2014 image was classified with high accuracy except some overlaps between agriculture and grassland, and primary forest and secondary forest (Table 16). The User's accuracy was 89% for agriculture, 93% for primary forest, 94% for secondary forest and 100% for Grassland. The Producer's accuracy was 87% for Grassland, 90% for secondary forest, 96% for primary forest and 97% for agriculture. The overall accuracy was one of the highest (93%) with high Kappa coefficient (0.88).

Table 16. Classification accuracy of the 2014 image in the study area

	Land Use/ Cover types	Reference Data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified Data	Primary forest	49	4	0	0	53	92.5
	Scrub	2	64	0	2	68	94.1
	Grassland	0	0	35	0	35	100.0
	Agriculture	0	3	5	66	74	89.2
Total		51	71	40	68	230	-
Producer's accuracy		96.1	90.1	87.5	97.1	-	-
Overall accuracy		93.0	-	-	-	-	-
Kappa coefficient		0.88	-	-	-	-	-

4.6.2 Land use/cover classification

The supervised classification clearly identified the four Land use/cover classes in the study periods (Fig. 15, 16). In 1973, the primary forest and agriculture covered 79% of the study area; while grassland and secondary forest/scrub covered only 21%. The largest proportion (40%) was covered by primary forest, followed by agriculture (39%), grassland (12%) and secondary forest (9%). In 1987, the largest proportion of the study area was covered by agriculture (46%), followed by primary forest (29%), grassland (14%) and secondary forest (11%). In 2001, agriculture took the significant portion of the land cover (50%), followed by secondary forest (27%), primary forest (16%) and grassland (7%). In 2014, agriculture covered the largest

proportion (45%), followed by secondary forest (29%), grassland (17%) and primary forest (9%). The most significant negative and positive changes were observed for primary forest and secondary forest, respectively in the whole study period.

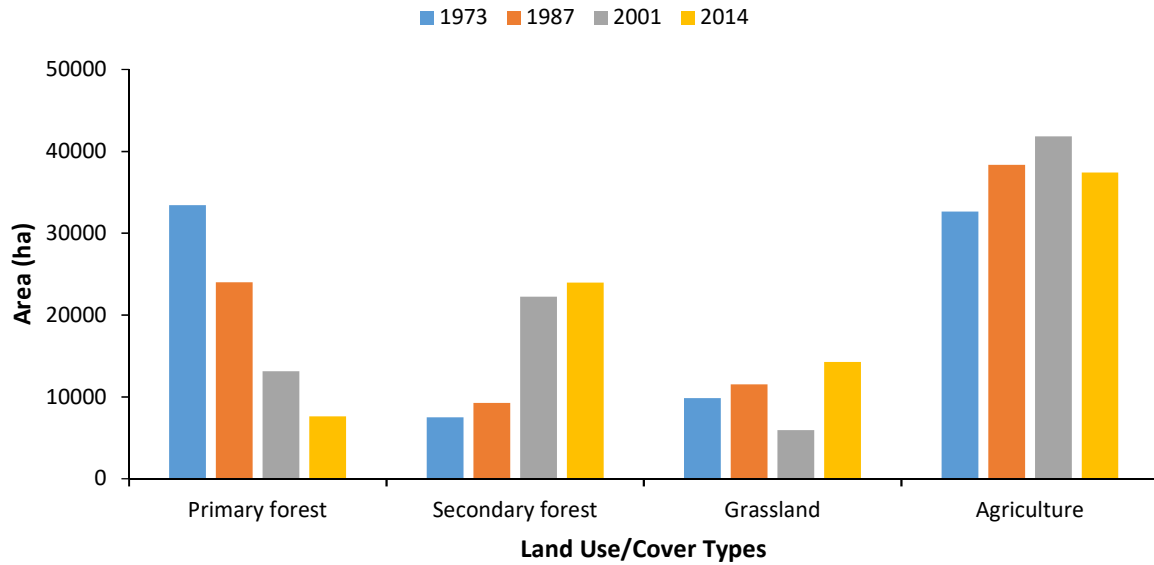


Figure 15. Proportion of Land use/cover classes (ha) in the study periods (1973-2014) in the study area.

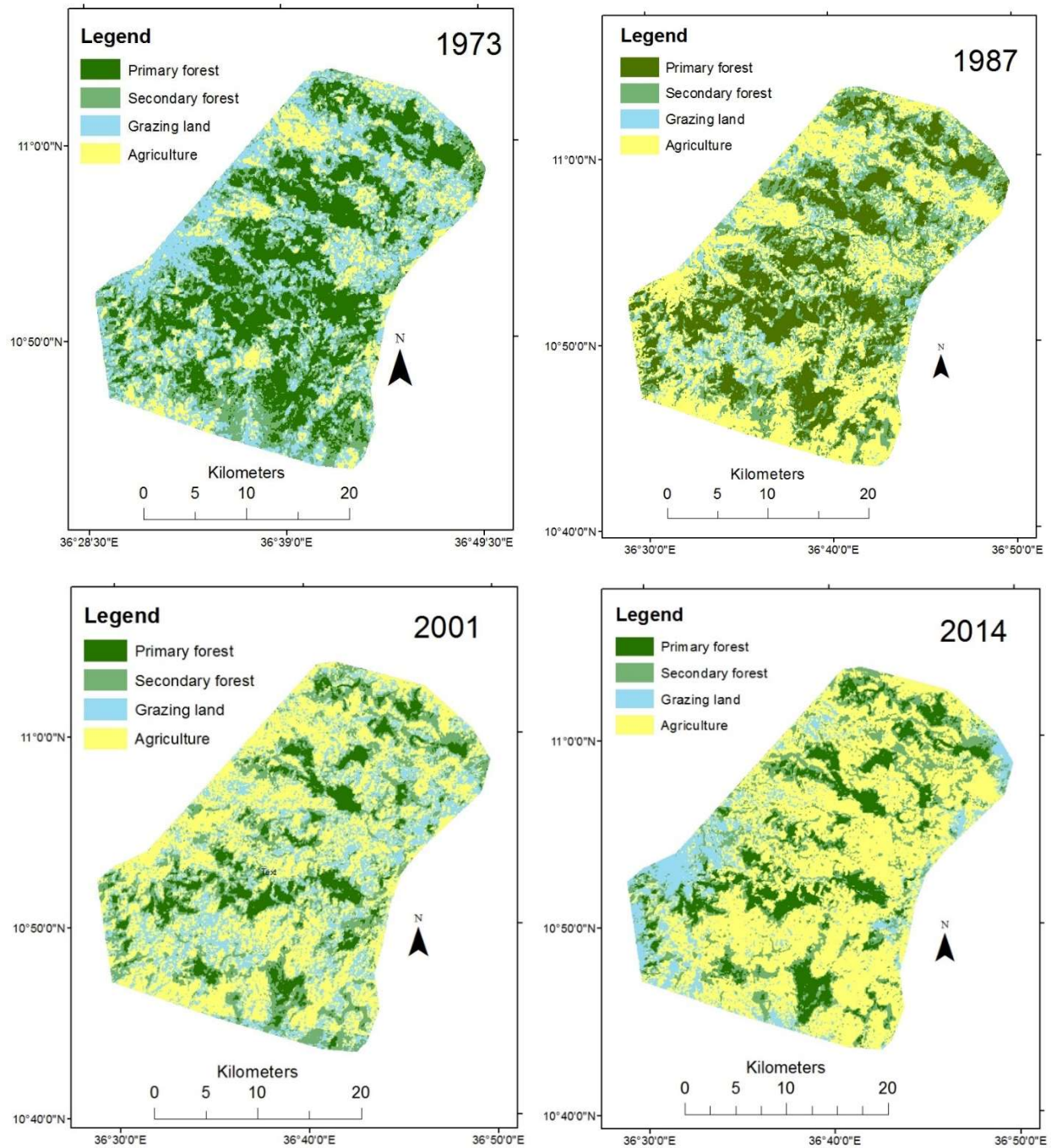


Figure 16. Land use/cover classification map of the years 1973, 1987, 2001 and 2014 images in the study area

4.6.3 Change detection and extent and rate of changes

The land use pattern showed a marked variation from 1973 to 2014. The primary forest cover declined from 40% in 1973 to only 9% in 2014; whereas secondary forest or scrub, grassland/grazing land and agriculture increased from 9, 12 and 39% to 29, 17 and 45%, respectively (Table 17; Fig. 17 - 20). Most Land use/cover changes, except the primary forest, were positive that is they increased in extent from 1973 to 2014, although grassland and agriculture showed a decrease in some of the periods. The primary forest cover change was consistently negative throughout the four study periods. The changes were mainly from primary forest to secondary forest/scrub and to agricultural land as well as grassland to agricultural land. For example, the primary forest cover was converted to agriculture (37%), secondary forest (36%) and grassland (9%) in 42 years. A significant proportion of grassland (49%) was also converted to agricultural land in similar years.

Table 17. Land use/cover changes (ha) from 1973 to 2014 in the study area.

Land Use/ cover Class		Initial State (1973)				Class Total ²
		Primary Forest	Scrub	Grassland	Agriculture	
Final state (2014)	Primary forest	6165.7	1063.1	54.3	405.8	7689
	Scrub	12041.1	3478.5	1506.0	6900.1	23926
	Grassland	2864.3	773.5	3418.9	7185.9	14243
	Agriculture	12301.4	2162.8	4825.2	18012.2	37302
	Class Total ¹	33373	7478	9804	32504	-
	Class Changes ³	27206.8	3999.4	6385.5	14491.8	-
	Difference ⁴	-25684.0	+16448.0	+4438.0	+4798.0	-

Note: ¹total area in each initial state class (1973); ²total area in each final state class (2014); ³total area of initial state pixels that changed classes; ⁴the difference in the total area of equivalently classed pixels in the two states (2014 and 1973) (Row Class Total - Column Class Total).

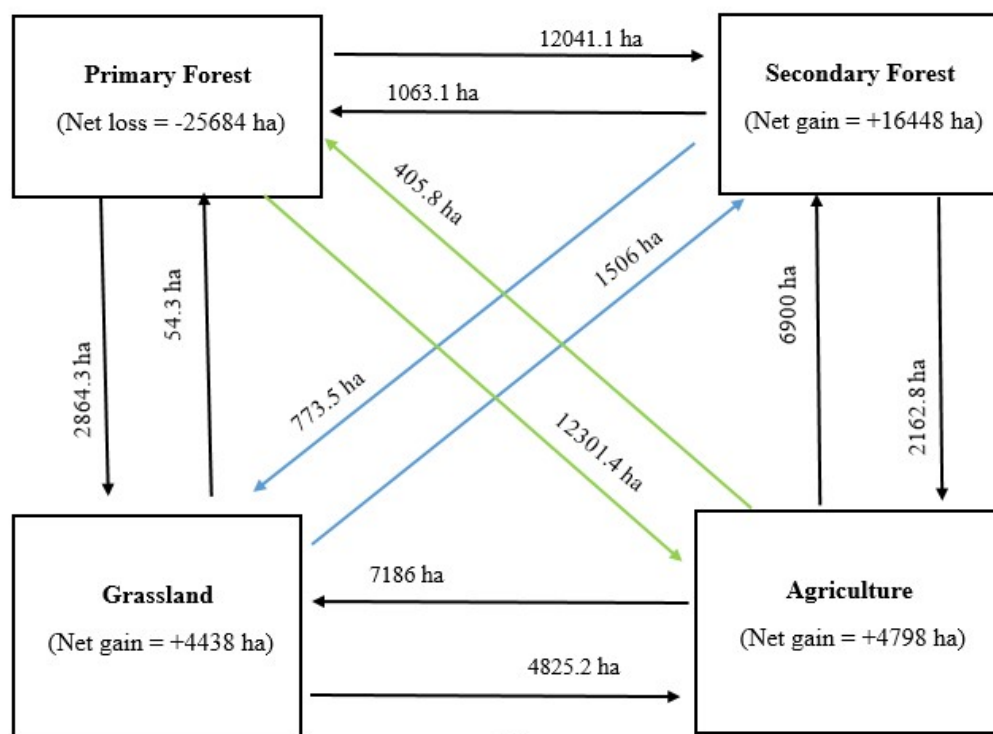


Figure 17. Land use/cover dynamics between 1973 and 2014 and direction of changes

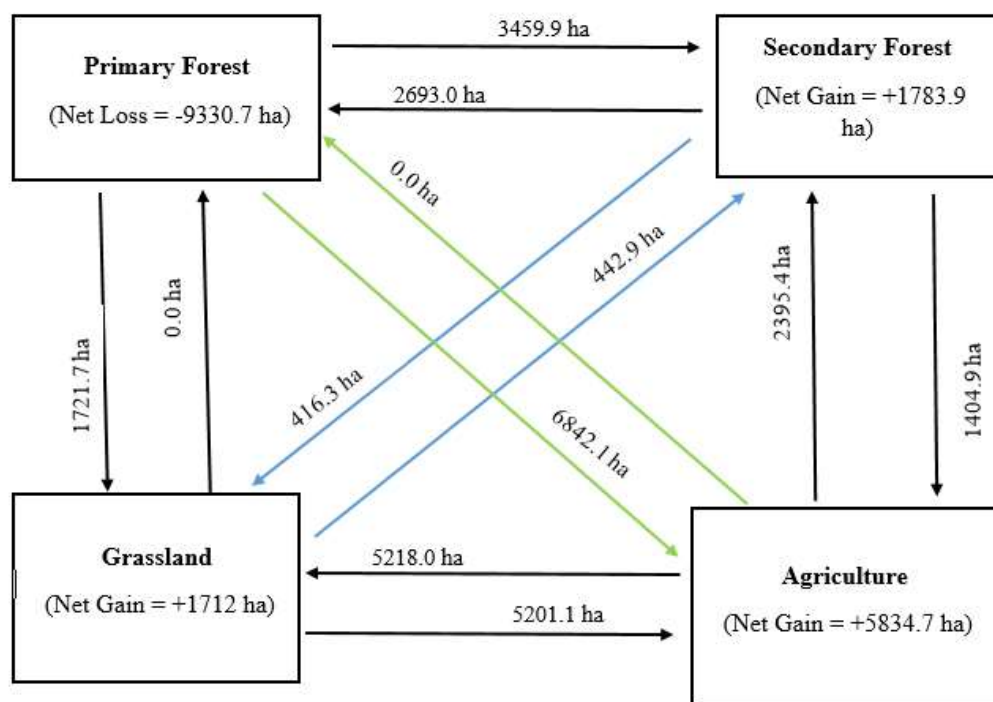


Figure 18. Land use/cover dynamics between 1973 and 1987 and direction of changes

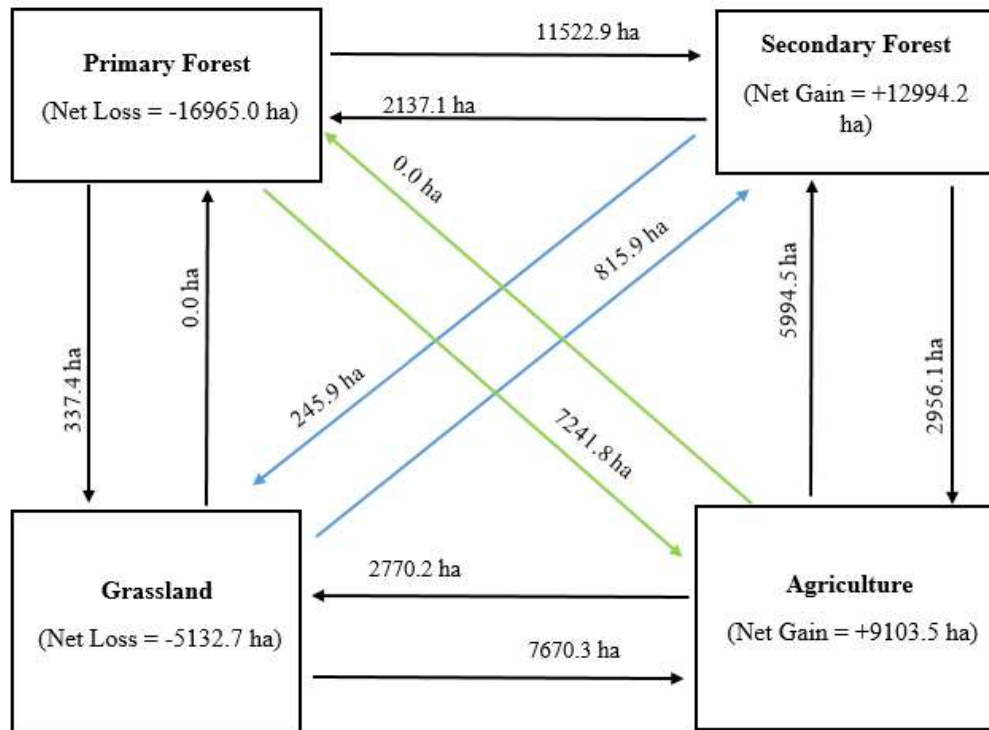


Figure 19. Land use/cover dynamics between 1987 and 2001 and direction of changes

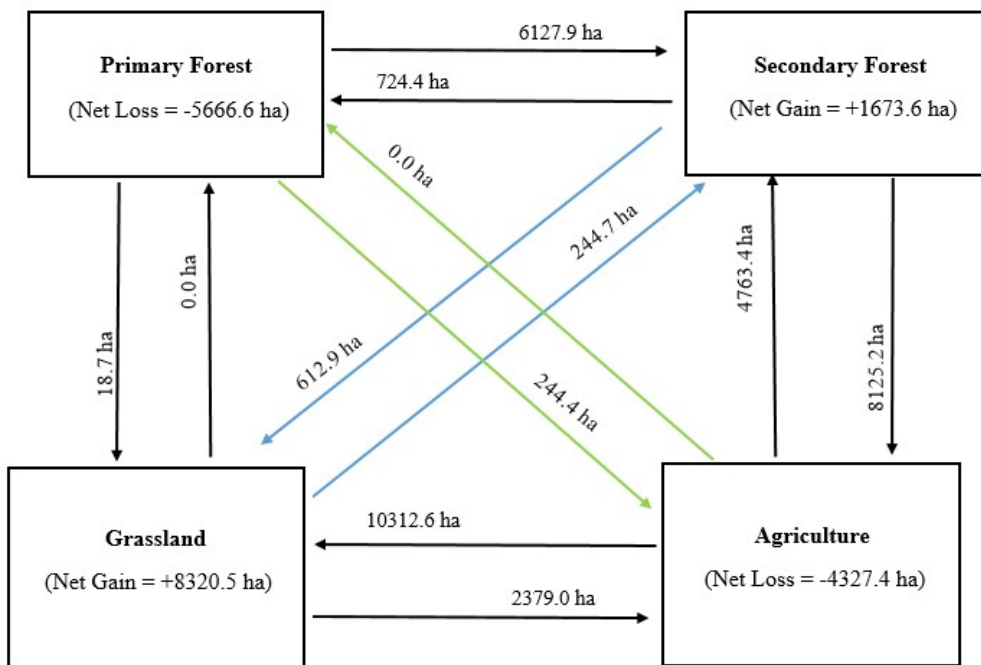


Figure 20. Land use/cover dynamics between 2001 and 2014 and direction of changes

Moreover, a portion of the secondary forest/scrub cover was converted to agriculture (29%) and grassland (10%). On the other hand, only insignificant proportion of the primary forest cover (18%) remained in its initial state; whereas a significant share of other land use types i.e. agriculture (57%), secondary forest (47%) and grassland (35%) remained in similar state. Extent and rate of changes in Land use/cover were variable for the classes considered in the whole study period. The primary forest has gone through consistent negative changes, at a rate of -1.8% in the whole study period (Table 18); that is 490 ha of primary forest has been converted to other land use types annually.

Table 18. Land use/cover changes (ha), extent and rate of change (%) from 1973 to 2014

Land Use/ Cover Class	1973-2014		
	Change	Extent	Rate
Primary forest	-25684.0	-77.0	-1.8
Scrub	+16448.0	220.0	+5.2
Grassland	+4438.0	45.0	+1.1
Agriculture	+4798.0	15.0	+0.4

The highest destruction occurred in the second study period at a rate of -3.8%. The change had been slowing in the first study period with minimum rate of -1.9% compared to the other periods. Generally, the highest destruction took place in the second study period, followed by the third and first study periods (Table 19). The extent of secondary forest cover was more than double at the end of the whole study period, the highest increasing rate being in the second study period. Consequently, the rate of secondary forest cover change was 5.2% in the whole study period. That is 208 ha of land was converted into secondary forest each year in the study area. On the other hand, grassland cover showed a wave like pattern, increasing in the first study period,

decreasing in the second study period and finally increasing in the third study period. Consequently, at the end of the study period the area covered by grassland increased by 45%.

Table 19. Land use/cover changes (ha), extent and rate of change (%) in the three periods

Land Use/ Cover Class	1973-1987			1987-2001			2001-2014		
	Change	Extent	Rate	Change	Extent	Rate	Change	Extent	Rate
Primary forest	-9330.7	-28.0	-1.9	-16965.0	-56.4	-3.8	-5666.6	-42.6	-3.0
Scrub	1783.9	23.9	1.6	12994.2	140.4	9.4	1673.6	7.5	0.5
Grassland	1712.1	17.5	1.2	-5132.7	-46.3	-3.1	8320.6	140.3	10.0
Agriculture	5834.7	18.0	1.2	9103.5	27.8	1.9	-4327.6	-10.4	-0.7

5. DISCUSSION

5.1 Floristic Composition and Diversity

The number of woody species recorded in this study (122 species) is higher than similar studies conducted in the Dry evergreen Afromontane forest such as Zege Peninsula forest (Alemnew Aleign *et al.*, 2007), central plateau of Shewa (Tamrat Bekele, 1993), Adelle and Boditi forests (Haile Yineger *et al.*, 2008), Amba Mariam forest (Abiyot Tilahun *et al.*, 2011), Tara Gedam and Abebaye forests (Haileab Zegeye *et al.*, 2011), Zengena forest (Desalegn Tadele *et al.*, 20013), Dense forest (Ermias Lulekal, 2014) and Kuandisha forest (Abiyot Berhanu *et al.*, 2017) in Ethiopia. This could be partially attributed to the size of the present study area, which covers wide altitudinal ranges (1830 - 2660 m). It has been long known that altitude plays paramount role in plant distribution and richness/diversity and the underlying direct causes such as climate, air pressure and soil properties are directly related to altitude (Brown & Lomolino, 1998; Barry, 2008). However, the present study area is not as much of some of similar study areas such as central plateau of Shewa (Jibat forest) in terms of altitudinal coverage (Tamrat Bekele, 1993). Thus, the most important justification for such variations could be climate variability (Schmitt *et al.*, 2013) and forest disturbance (Økland, 1990). The present study area is found in the intermediate zone between moist and dry climates and harbours a diverse assemblage of both the dry and moist evergreen Afromontane forest species (see sections 5.3.3 and 5.6). In forests of central plateau of Shewa, a very severe disturbance (forest clearing and selective logging) was reported as the most serious impact (Tamrat Bekele, 1993). Although disturbance is present in some of the forest patches in the present study area, the forests are relatively well protected, which contributed in conserving many of economically and ecologically useful canopy species such as *Celtis africana*, *Prunus africana*, *Apodytes dimidiata*, *Albizia schimperiana* and *A.*

gummifera. On the other hand, in terms of herbaceous species, less number of species (90 species) were recorded than other study areas (Haile Yineger *et al.*, 2008; Abiyot Tilahun *et al.*, 2011). The low number of herbaceous species richness may be attributed to the closed canopy cover of the forest patches in the study area. According to Friis (1986) and Murphy and Lugo (1986), herbaceous species cover is usually inversely proportional to canopy cover. That is closed canopy sites of forests have poor herbaceous cover and vice versa.

The order of families in terms of species richness is in accordance with other studies in that Asteraceae is reported to be the richest family elsewhere (Haile Yineger *et al.*, 2008; Abiyot Tilahun *et al.*, 2011; Ermias Lulekal, 2014) and in this study (18 species). On the other hand, Abiyot Berhanu *et al.* (2016) documented that the family Fabaceae was the richest family followed by Euphorbiaceae and Asteraceae in Kuandisha dry evergreen Afromontane forest fragment. Fabaceae is also known to be the richest family in species composition in the Flora Area followed by Poaceae, Asteraceae and Euphorbiaceae (Ensermu Kelbessa & Sebsebe Demissew, 2014).

The Shannon diversity index was high ($H' = 3.7$), and except one forest patch (Ambiqi) which was the least among the forest patches ($H'=2.9$), the values were between 3.1 and 3.8 for all forest patches. The least diversity index in Ambiqi forest could have been mainly resulted from severe disturbance such as selective logging and grazing (Maguran, 1988). The high diversity index in other forest patches may be attributed to the relatively less disturbance and high evenness values. The correlation between Shannon diversity index and evenness values was positive and strong ($r = 0.9$; $P < 0.05$) in the study area. Species diversity increases when the populations have more even abundances and vice versa (Maguran, 1988; Lean & Maclaurin, 2016). In other words, many of the species were rare and the distributions of individuals of the

species were even ($J \geq 0.7$). Shannon diversity index is sensitive to the presence of rare species and high evenness values (Maguran, 1988; Schmitt *et al.*, 2010). Consequently, the diversity index was higher than other forests in the DAF such as Tara Gedam and Abebaye forests (Haileab Zegeye *et al.*, 2011), Amba Mariam forest (Abiyot Tilahun *et al.*, 2011) and Zengena forest (Desalegn Tadele *et al.*, 2013). The beta diversity index was also high ($\beta = 5.6$), which was strongly and positively correlated with richness of forest patches ($r = 0.7$, $P < 0.05$) and strongly and negatively correlated with evenness of forest patches ($r = -0.7$, $P < 0.05$). According to Zerihun Woldu (2014), a beta diversity index higher than five can be considered as high value and this indicates a high turnover in and among the forest patches.

5.2 Conservation Status of Endemic Species

The number of endemic species (23 species) harbored in the forests of the study area is higher compared to moist evergreen Afromontane forests such as Hareenna forest, Berhane-Kontir forest, Bonga forest and Yayu forest (Feyera Senbeta, 2006; Ensermu Kelbessa & Teshome Soromessa, 2008) and Dry evergreen Afromontane forests such as Amba Mariam forest, Tara Gedam forest and Kuandisha forest (Abiyot Tilahun *et al.*, 2011; Haileab Zegeye *et al.*, 2011; Abiyot Berhanu *et al.*, 2017). According to Friis (2009), low endemism is a common phenomenon in the moist evergreen Afromontane forests of southwestern Ethiopia. The high endemics in the present study area may be due to the fact that the forests of the study area are found in the intermediate zone between MAF and DAF, which comprises a number of endemic species from both vegetation types. Consequently, 64% of the endemic species in this study were also documented from the forests in the MAF; while 45.5% of the species were documented in the DAF (Friis *et al.*, 2010).

Asteraceae is the largest family having endemic species in this study (5 species) and elsewhere in Ethiopia and in the Flora area (Feyera Senbeta, 2006; Abiyou Tilahun *et al.*, 2011; Ensermu Kelbessa & Sebsebe Demissew, 2014). For example, Asteraceae contributed 16% of the endemic species in the Flora area, followed by Fabaceae (11%) and Euphorbiaceae (7%) (Ensermu Kelbessa & Sebsebe Demissew, 2014). Similarly, Abiyou Tilahun *et al.* (2011) reported Asteraceae to have the highest endemic species, followed by Lamiaceae in Menagesha Amba Mariam Forest (Egdu forest) in central Shewa, Ethiopia.

Among the endemic woody species 13% of them, namely *Acanthus sennii*, *Crotalaria rosenii* and *Maytenus addat* are near threatened; and 17.4% of them, namely *Otostegia tomentosa* subsp. *tomentosa*, *Phyllanthus limmuensis*, *Tiliacora troupinii* and *Rhus glutinosa* subsp. *glutinosa* are vulnerable (Vivero *et al.*, 2005). About 48% of species such as *Erythrina brucei*, *Millettia ferruginea*, *Solanecio gigas*, *Vepris dainellii* and *Bothriocline schimperi* are least concern. Among the endemic herbaceous species, *Justicia diclipteroides* subsp. *aethiopica* is near threatened; *Brillantaisia grotanellii* and *Echinops kebericho* are vulnerable; while *Urtica simensis* and *Guizotia abyssinica* are least concern (Ensermu Kelbessa *et al.*, 1992).

5.3 Floristic Affinities to Vegetations in Ethiopia and Africa

5.3.1 Floristic similarities between the forest patches

The similarity of the forest patches was generally strong with some exceptions of Kuandisha forest at elevations above 2300 m. The similarity index between sites below 2300 m, namely Ambiqi, Bradi, Degera, Kidamaja and Askunabo was the highest whereas Khatasa forest exhibited relatively less similarity with all of the forest patches. The five forest patches generally have equivalent elevational ranges and the rainfall and temperature patterns are also similar,

which may have contributed for the highest similarity between them (Friis *et al.*, 2010; Schmitt *et al.*, 2013). The most dominant canopy species, namely *Prunus africana*, *Albizia schimperiana*, *A. gummifera*, *Ekebergia capensis*, *Croton macrostachus* and *Celtis africana* are also similarly found in most of the five forest patches with minor differences with respect to their dominance values. Moreover, some of the forests patches such as Bradi and Degera forests are found in close proximity disconnected by agricultural, grazing and settlement areas. Thus, gene flow is expected between the two forests through seed dispersal agents such as birds and domestic and wild animals (Lambert & Garber, 1998; Norconk *et al.*, 1998). For example, in addition to domestic animals, wild animals such as monkeys, bush pigs and warthogs, which are reported as dispersal agents elsewhere (Lambert & Garber, 1998), were observed crossing through the agricultural and grazing fields from Bradi forest to Degera forest and vice versa (pers. obs.). On the other hand, Khatasa forest is situated at the highest elevations which is highly isolated from the other forest patches and has slightly different climatic conditions. This has contributed to the formation of slightly different vegetation which is relatively similar to the DAF. The dominant canopy species such as *Apodytes dimidiata*, *Juniperus procera* and *Olea capensis* subsp. *macrocarpa* are some examples, which strengthen this assumption (Friis *et al.*, 2010).

5.3.2 Floristic similarities to other study areas in Ethiopia

Comparison of the species composition of the current study area to other study areas in the DAF and MAF of Ethiopia revealed a range of similarity indices (Table 20). The highest similarity index was to the Bonga forest (Schmitt *et al.*, 2010) and Kuandisha forest (Abiyot Berhanu *et al.*, 2017), followed by Tara Gedam forest (Haileab Zegeye *et al.*, 2011) and Zege Peninsula forest (Alemnew Alelign *et al.*, 2007). The least similarity was revealed with Hugumburda forest (Ermias Aynekulu, 2011) and Menagesha and Jibat forests (Tamrat Bekele, 1993). Bonga and

Jibat forests are part of the moist evergreen Afromontane forests of Ethiopia (Tamrat Bekele, 1993; Friis *et al.*, 2010). On the other hand, Kundisha, Tara Gedam, Zege Peninsula, Hugumburda and Menagesha Suba forests are part of the dry evergreen Afromontane forest and grassland complex. Factors such as climate (Friis *et al.*, 2010; Schmitt *et al.*, 2013), ecological distance (Mueller-Dombois and Ellenberg, 1974) and disturbance (Økland, 1990; Tamrat Bekele, 1993) may play important roles for the major differences between the forests of the present study area and other study areas.

Table 20. Woody species similarities between the study area and other study areas in Ethiopia.

Areas	Richness	Altitude (m)	Study area (Awi)
Study area (Awi)	122	1830-2660	-
Bonga	110	1600-2300	0.6
Hugumburda	63	1860-2700	0.3
Jibat	53	2000-2950	0.4
Kuandisha	67	2132-2365	0.6
Menagesha	98	2200-3385	0.4
Tara Gedam	96	2142-2484	0.5
Zege Peninsula	96	1770-1975	0.5

According to Schmitt *et al.* (2013), regional climate has paramount role in differences for species distribution patterns in tropical montane forests, especially in those with highly diverse topography. For example, Hugumburda forest is broadly categorized as Dry single-dominant Afromontane forest with *Juniperus procera* in the canopy and *Olea europaea* subsp. *cuspidata* as dominant tree species and the area receives annual rainfall of less than 1000 mm (Ermias Aynekulu, 2011). Whereas the present study area is mainly of an intermediate forest between moist and dry evergreen Afromontane forests with annual precipitation ranging between 1600

and 1800 mm. Ecological distance between any two areas has also been noted to play important part for the difference in species composition as well (Mueller-Dombois and Ellenberg, 1974). Disturbance also plays key role for such differences. For example, as stated in Tamirat Bekele (1993), the Menagesha Suba and Jibat forests have been severely exploited for lumber production and domestic consumption for firewood and construction purposes.

5.3.3 Floristic similarities to vegetation types in Ethiopia

The woody species of the study area were found to have affinities to nine out of the twelve vegetation types (75%) in Ethiopia (Table 21). Consequently, the woody vegetation showed strong affinity to the DAF and MAF vegetation types. A significant number of species were shared with the DAF, followed by MAF and RV. Accordingly, the three vegetation types, namely DAF, MAF and RV were represented by 88%, 59% and 33% of woody species, respectively. The proportion of tree species alone shared with the DAF, MAF and RV was 87%, 76% and 29%, respectively. This is different from the findings elsewhere in the Tropics, where the degree to which tree species are shared between wet and dry forests appears to be low (Murphy & Lugo, 1986). Moreover, the study area harboured 22 woody species that were considered in Friis *et al.* (2010) as unique to the DAF (19 species), MAF (two species) and CTW (one species). The high similarity with the DAF and MAF appears to be the location of the study area in the intermediate zone from moist climates of southwestern Ethiopia to dry climates of northeastern and central Ethiopia. However, none of the key primary elements of the MAF (e.g. *Pouteria adolfi-friedericii*, *Macaranga capensis*, *Cyathea manniana* and *Olea welwitschii*) and DAF (e.g. *Olea europaea* subsp. *cuspidata*) were documented in the study area. *Juniperus procera* was an exception at Khatasa forest, which was the fifth most important species with no regeneration and no individuals below 90 cm DBH. DSS and AA were poorly represented; while

ACB, CTW, EB and TRF were moderately represented. The CTW is found bordering the study area at the northwestern, western, southwestern and southern side even though the highland vegetation (study area) and lowland vegetation (CTW) are sharply separated by elevational drops. ACB, EB and TRF do neither border the study area nor are found in close proximity. Consequently, the higher number of woody species shared with those vegetation types than the CTW may be because of those species that are linking species or ecological transgressors of those vegetation types (Tamrat Bekele, 1993; Friis *et al.*, 2010).

Table 21. Comparison of woody species composition of the study area to vegetation types in Ethiopia.

Vegetation type	Unique species ¹	Shared species ²	Total species ³	Percent Total ⁴
ACB	0	12	12	10
CTW	1	9	10	8
DAF	19	88	107	88
DSS	0	1	1	1
MAF	2	70	72	59
RV	0	40	40	33
TRF	0	17	17	14
EB	0	15	15	12
AA	0	4	4	3

¹ Reported in Friis *et al.* (2010) as largely restricted to that vegetation type; ² Commonly found in the study area and that vegetation type but not unique to it; ³ Sum of unique and shared species; ⁴ Percentage proportion of Total species to the total number of woody species in the study area.

The majority of woody species in the study area within DAF were shared with the Undifferentiated Afromontane forest (61 species), followed by Afromontane woodland, wooded grassland and grassland (48 species) and Dry single dominant Afromontane forest of the

Ethiopian highlands subtypes (25 species) (Friis *et al.*, 2010). Only three species were shared with the Transition between Afromontane vegetation and *Acacia-Comiphora* bushland on the eastern escarpment subtype; which is now considered by van Breugel *et al.* (2016) as a new vegetation type named Transitional semi-evergreen bushland vegetation. The least number of species shared with this vegetation type could be attributed to location and climate of the TSEB, which is restricted to the eastern and southeastern escarpments of Ethiopia with dry climate and highly influenced by anthropogenic factors (Friis *et al.*, 2010; van Breugel *et al.*, 2016). A significant portion of species within the MAF were shared with the Primary or mature secondary moist evergreen Afromontane forest (54 species) and Edges of moist evergreen Afromontane forest, bushland and wooded grassland (33 species) subtypes.

5.3.4 Floristic similarities to other vegetations in Africa

Comparison of the species composition of the the study area with the Flora of Northern and Southern Africa and Madagascar confirmed wide distributional ranges of many of the species (88%) outside the Tropics (Ethiopia). Accordingly, 86 species (41% of total) were also recorded to occur in the flora of Southern Africa (Germishuizen & Meyer, 2003), 49 species (23% of total) in the Flora of Madagascar (Phillipson *et al.*, 2006) and 29 species (14% of total) in the Flora of Northern Africa (Dobignard & Chatelain, 2010-2013). The remaining 48 species (22% of total) were restricted to the Tropics (Lebrun & Stork, 1991-2015). Among all species, only 13 species were cosmopolitan (found in all regions), 45 species in three regions and 100 species in two regions. The only woody species which were recorded to occur in all regions were *Carissa spinarum* and *Senna septemtrionalis*. The remaining are herbaceous species, such as *Achyranthes aspera*, *Galinsoga parviflora* and *Tagetes minuta*. Trees such as *Prunus africana*, *Pittosporum viridiflorum*, *Cordia africana*, *Apodytes dimidiata* and *Olea capensis* were shared with

Madagascar and Southern Africa. Three tree species, namely *Albizia gummifera*, *Croton macrostachyus* and *Ehretia cymosa* were shared with only Madagascar. A number of tree species such as *Ficus sur*, *F. thonningii*, *Celtis africana*, *Ekebergia capensis*, *Sapium ellipticum* and *Syzygium guineense* were shared with only Southern Africa. *Salix subserrata* was the only tree species shared with Northern Africa.

5.4 Vegetation Structure

5.4.1 Frequency of species

A significant portion of the species were rare in the study area. For example, about 33% of the species each occurred in a single plot. The most frequent species were pioneer species such as *Croton macrostachyus* and *Bersama abyssinica* (Tamrat Bekele, 1993) and the common weed *Achyranthes aspera* (Townsend, 2000), which are also common in the disturbed forests and forest edges of the DAF and MAF elsewhere (Townsend, 2000; Friis *et al.*, 2010). *Vepris dainellii* is an endemic species, which was common in most (61%) of the sampling plots. According to Gilbert (1989), the species occurs in the understory of moist montane forests, often with *Podocarpus falcatus* or *Pouteria adolfi-frederici*, less often at forest margin or in secondary growth. Tamrat Bekele (1993) reported similar results about the species in Jibat forest. The other most frequent species, namely *B. abyssinica* and *Maytenus arbutifolia* are common species in disturbed and secondary forests with early developmental stage in the DAF and MAF and they are usually strongly associated with overgrazing (Getachew Tesfaye & Abiyot Berhanu, 2006; Abiyot Berhanu *et al.*, 2017).

Canopy trees such as *Albizia schimperiana* and *A. gummifera* are also dominant species in the Afromontane forests between altitudes 1600 and 2600 m and they are widely distributed in

eastern Tropical Africa (Thulin, 1989; Friis *et al.*, 2010). *A. gummifera* and *C. macrostachyus* have also been reported to be the most frequent species in Tara Gedam and Abebaye forests, respectively (Haileab Zegeye *et al.*, 2011). On the other hand, the liana species *Landolphia buchananii*, which was also highly frequent in the study area, is mainly of a lowland species in gallery forests, woodlands, often on or near rocks between 1300 and 1550 m (Leeuwenberg, 2003). Hence, its high presence above 1550 m (up to 2100 m) in the study area is unusual. The species has also been reported to be the second most dominant species next to *Coffea arabica* in moist evergreen Afromontane forests of southwestern Ethiopia (Feyera Senbeta, 2006). Thus, its high presence in the study area may be attributed to the transitional climate from moist to dry climates. Generally, except few variations, many of the most frequent species in the study area were also the most frequent in each forest patch.

5.4.2 Density of woody species

The overall density of woody species with DBH ≥ 2.5 cm was considerably lower than other forests such as Zege Peninsula, Tara Gedam and Kuandisha forests in the DAF (Alemnew Alelign *et al.*, 2007; Haileab Zegeye *et al.*, 2011; Abiyot Berhanu *et al.*, 2017) and moist evergreen Afromontane forests of southwestern Ethiopia (Feyera Senbeta, 2006). The composition of the top most abundant species was also different from such forests except *Rytigynia neglecta*, *Croton macrostachyus*, *Maytenus arbutifolia* and *Bersama abyssinica* that are gap fillers and pioneer woody species in disturbed sites, secondary forests and forest edges (Tamrat Bekele, 1993; Gemedo Dalle & Masresha Fetene, 2004; Azene Bekele, 2007; Abiyot Berhanu *et al.*, 2017). Some climax tree species such as *Albizia gummifera* and *Millettia ferruginea* were also reported as having the highest density in Tara Gedam and Zege Peninsula forests, respectively (Alemnew Alelign *et al.*, 2007; Haileab Zegeye *et al.*, 2011). On the other

hand, no significant variations of the mean densities of woody species were found among the forest patches in the study area ($P > 0.05$).

Generally, 6.6% of the species, namely *Rytigynia neglecta*, *Rothmania urcelliformis*, *Deinbollia kilimandscharica*, *Albizia gummifera*, *Croton macrostachyus*, *Bersama abyssinica*, *Vepris dainellii* and *Maytenus arbutifolia* accounted for 53% of the total stem density in the study area. Those species had also the largest density of seedlings. For example, *M. arbutifolia*, *Landolphia buchananii*, *A. gummifera*, *Justicia schimperiana* and *Hippocratea pallens* were among the five top woody species with the highest seedling density. This has partly to do with disturbance as species such as *M. arbutifolia* and *J. schimperiana* favor disturbance and sudden openings of forests for their growth and establishment (Gemedo Dalle & Masresha Fetene, 2004; Getachew Tesfaye & Abiyot Berhanu, 2006; Abiyot Berhanu *et al.*, 2017). Moreover, seedlings of *A. gummifera* and *A. schimperiana* were abundant in openings near mother trees where the sites were relatively undisturbed. According to Muhanguzi *et al.* (2002), *A. gummifera* has a very high rate of seed germination under shade or light conditions, which is an escape mechanism from mortality factors.

The absence of seedlings of some of the canopy trees such as *Juniperus procera* and *Syzygium guineense* is highly attributed to disturbance (trampling and seedling removal), seed predation, habitat unsuitability and life history strategy. Disturbance and seed predation have been noted to play their own role in reducing the seedling population of woody species (Demel Teketay, 2005b; Alemayehu Wassie *et al.*, 2009). Destructive collection of seedlings of economically and socially important species such as *J. procera* and *Olea capensis* subsp. *macrocarpa* from growing sites and transferring to settlement areas and church compounds is a common practice in

Khatasa forest (pers. com.). However, no seedlings of *J. procera* were encountered in the study area (Khatasa forest) during the study period, which is in contrast to the reports from the local people. Similarly, no or poor regeneration of *J. procera* under natural conditions have been reported elsewhere in Ethiopia (Hailu Sharew, 1994; Ermias Aynekulu *et al.*, 2009) and Saudi Arabia (El-Juhany *et al.*, 2008). Consequently, it has been noted that *J. procera* will not regenerate in its own shade and its presence as a forest tree is largely dependent on fire, either natural or man-made, which removes the deep layer of humus and exposes the soil mineral for seed germination, seedling growth and survival (White, 1983; Hailu Sharew, 1994; Orwa *et al.*, 2009).

5.4.3 Basal area and dominance of woody species

The total basal area of woody species in the study area with DBH ≥ 2.5 cm ranged between 34 and 57 m² ha⁻¹ even though there were no significant variations among the forest patches ($P > 0.05$). The total basal area of woody species (ha⁻¹) is generally in the range provided for tropical and subtropical dry and wet forests of the world (Murphy & Lugo, 1986). Moreover, the range of the total basal area of woody species in the forest patches of the study area was comparable to that of Moist evergreen Afromontane forests of southwestern Ethiopia (Feyera Senbeta, 2006) and Dry evergreen Afromontane forests of central Ethiopia (Ermias Lulekal, 2014). The lower and higher DBH classes contributed most to the total basal area, which was also supported by other studies (Tamrat Bekele, 1993; Feyera Senbeta, 2006; Desalegn Tadele *et al.*, 2013; Ermias Lulekal, 2014; Abiyot Berhanu *et al.*, 2017). For example, the majority of individuals in Moist evergreen Afromontane forests of southwestern Ethiopia were in the lower DBH classes (Feyera Senbeta, 2006).

Eleven species, namely *Albizia schimperiana*, *A. gummifera*, *Prunus africana*, *Apodytes dimidiata*, *Ekebergia capensis*, *Croton macrostachyus*, *Celtis africana*, *Vepris dainellii*, *Ficus sur*, *Deinbollia kilimandscharica* and *Rothmania urcelliformis* contributed 71% of the total basal area. The first three species alone, namely *A. schimperiana*, *P. africana* and *A. gummifera* were the most dominant species contributing 37% of the total basal area. The basal area and dominance value of woody species was higher than some forests such as Zengena forest (Desalegn Tadele *et al.*, 2013), Kuandisha forest (Abiyot Berhanu *et al.*, 2017), Hugumburda forest (Ermias Aynekulu, 2011) and Adele and Boditi forests (Haile Yineger *et al.*, 2008). On the other hand, the basal area of woody species reported from Tara Gedam is higher than the present study area (Haileab Zegeye *et al.*, 2011). The most appealing reason is that Tara Gedam forest has old-aged and big trees, which have long been protected by the church. Moreover, according to Alemayehu Wassie *et al.* (2005), churches and monasteries harbour many of the forests with the oldest and large-sized individuals of trees in north Gondar.

5.4.4 Vertical structure of forests

The International Union of Forest Research Organizations (IUFRO) classification scheme classifies vertical structure of forests into three layers/storeys based on mean heights of canopy tree species (Lampercht, 1989). This classification is entirely related to woody species (trees and shrubs). Lianas were excluded from this analysis as their heights were not measured. The upper storey consists of woody species with heights above 2/3rd of the tallest trees, 46 m in this study. Accordingly, 32 individuals (ha⁻¹) of 11 tree species were in this storey (> 30.7 m). The upper storey species were *Croton macrostachyus*, *Ekebergia capensis*, *Prunus africana*, *Allophylus abyssinicus*, *Albizia schimperiana*, *A. gummifera*, *Euphorbia abyssinica*, *Ficus sur*, *Celtis*

africana, *Juniperus procera* and *Apodytes dimidiata*. *Prunus africana* has also been designated as canopy (upper canopy) species whereas *A. abyssinicus* and *A. dimidiata* as subcanopy (middle canopy) species in the Bonga moist evergreen Afromontane forest, southwestern Ethiopia (Ensermu Kelbessa & Teshome Soromessa, 2008). The mean heights of canopy trees of the study area were comparable to that of moist evergreen Afromontane forests of southwestern Ethiopia (Feyera Senbeta, 2006; Ensermu Kelbessa & Teshome Soromessa, 2008). The middle storey includes individuals with heights between 1/3rd and 2/3rd of the tallest tree (15.3 m - 30.7 m). Hence, 82 individuals (ha⁻¹) of 32 woody species were in the middle storey. Some of the most common middle storey species were *Bersama abyssinica*, *Buddleja polystachya*, *Vepris dainellii*, *Ficus thonningii*, *Millettia ferruginea*, *Canthium oligocarpum*, *Syzygium guineense*, *Mimusops kummel*, *Acacia abyssinica* and *Nuxia congesta*. The lower storey comprises individuals with heights below 1/3rd of the tallest trees (< 15.3 m). The majority of individuals that is 1864 individuals (ha⁻¹) of 88 woody species were in the lower storey. Some of the most common lower storey species are *Deinbollia kilimandscharica*, *Carissa spinarum*, *Maytenus arbutifolia*, *Rothmania urcelliformis*, *Vernonia auriculifera*, *Calpurnia aurea*, *Paveta abyssinica* and *Teclea nobilis*. Most of the shrubs were in this category. According to White (1983), this layer is mixed and the shrub layer is poorly differentiated from the lower tree layer.

5.4.5 Importance value index of woody species

The importance value index (IVI) of woody species in the study area was generally lower compared to other forests in the DAF (Haileab Zegeye *et al.*, 2011; Desalegn Tadele *et al.*, 2013; Ermias Lulekal, 2014; Abiyot Berhanu *et al.*, 2017). The majority of woody species (62.5%) had IVI value of one and lower which places them in the rarest list. Some of the species with the least

IVI values were *Pittosporum viridiflorum*, *Rhus glutinosa*, *Otostegia tomentosa* subsp. *tomentosa*, *Oxyanthus speciosus*, *Polyscias fulva* and *Steganotaenia araliacea*. Species with high IVI values, such as *Rytigynia neglecta*, *Albizia gummifera*, *A. schimperiana*, *Prunus africana*, *Croton macrostachyus*, *Rothmania urcelliformis* and *Apodytes dimidiata* were also the most abundant, dominant and frequent species in the study area.

The variability of IVI values of species among the forest patches is partly attributed to the conservation status of some of the highly dominant species in those forests. *Albizia schimperiana* and *A. gummifera*, for example, which are highly valued for their shade for livestock and humans and protected by the community (pers. com.), were the most abundant and dominant species with the highest IVI values in Ambiqi, Kidamaja and Bradi forest patches. Habitat suitability also plays its own part. For instance, *Carissa spinarum* and *Croton macrostachyus* were the most important species in the highly disturbed Ambiqi forest, which are usually indicators of degraded or seriously disturbed forests (Tamrat Bekele, 1993; Friis *et al.*, 2010; Abiyot Berhanu *et al.*, 2017). On the other hand, some of the least important species in the forests of the study area such as *Syzygium guineense* and *Salix subserrata* are usually important species in the Riverine vegetation, beside streams and lake shores; occasionally also transgressing into humid secondary evergreen bushland and woodland (Meikle, 1989; Friis, 1995; Friis *et al.*, 2010). Moreover, least important species in the study area such as *Steganotaenia araliacea* and *Stereospermum kunthianum* are usually found in open woodlands and savanna (Hedberg & Hedberg, 2003; Bidgood, 2006) and their presence in the study area may be for similar reasons. On the other hand, *Rhus glutinosa* subsp. *glutinosa* had been excessively exploited for its high-quality wood for traditional house construction as it is resistant to termites (pers. com.) and its use for

firewood, farm tools and tool handles in the study area and elsewhere (Azene Bekele, 2007). Thus, its status in the study area is very poor having the least IVI value with rare presence.

5.4.6 Population structure of forest patches and tree species

The population structural patterns of all forests of the study area and individual forest patches generally indicated a healthy status of those forests; which was *Inverted-J* shaped. Similar findings have been reported elsewhere in Ethiopia (Feyera Senbeta, 2006; Dinkissa Beche, 2011; Desalegn tadele *et al.*, 2013; Abiyot Berhanu *et al.*, 2017). However, that was contrary to the fact that is clearly seen from population structure of each tree species. Consequently, an investigation of the population structure of many of the tree species revealed that they lacked individuals at various DBH or height classes. Moreover, a highly skewed *Inverted-J* shaped population pattern may to some extent indicate abnormal distribution of population densities in the forests undergoing secondary development after forest clearance or disturbance such as selective logging of individuals having higher DBH classes (Friis, 1986; Tamrat Bekele, 1993). And under such circumstances, it is usually difficult to generalize based on the shape of the population pattern of the whole forest alone as indicator of forest health. Consequently, the *Inverted-J* shaped distribution pattern of forest patches should be interpreted with caution (Westphal *et al.*, 2006; Ducey, 2010). The pertinent reason, which was observed from population patterns of forest patches, was the “compensatory effect;” where populations of one species compensate for the missing populations of another species in various DBH and height classes. Hence, the population pattern of each tree species was found to be comparatively useful as forest health indicator in the study area as population absences and presences for each tree species were clearly detected in various DBH or height classes.

Different population patterns of tree species are usually caused by various factors such as selective cutting, disturbance, shade-intolerance and life history strategy (Demel Teketay, 2005a; Bin *et al.*, 2012). The five population patterns revealed in this study are attributed to those factors. The first pattern, which is *Inverted-J* shaped is usually an indicator of healthy population status of a species (Demel Teketay, 2005a; Feyera Senbeta, 2006; Alemnew Alelign *et al.*, 2007; Desalegn tadele *et al.*, 2013; Abiyot Berhanu *et al.*, 2017) even though the density of individuals in various DBH or height classes slightly varied among studied forest patches.

The second pattern, which is *unimodal* or *bell-shaped*, is highly attributed to poor regeneration and selective removal of individuals with lower and higher DBH classes; while populations in the middle classes are left. This pattern has rarely been reported in the DAF (Desalegn tadele *et al.*, 2013; Ermias Lulekal, 2014) and MAF (Feyera Senbeta, 2006; Ensermu Kelbessa & Teshome Soromessa, 2008).

The third pattern, which was a *J* shaped distribution, is an indicator of a highly-disturbed forest with poor reproduction and selective removal of individuals with lower DBH classes (Tamrat Bekele, 1993; Feyera Senbeta, 2006). That is intermediate and mature individuals are usually left in the population whereas lower dbh classes are removed for various uses such as firewood, construction and farm implements (pers. obs.).

The fourth pattern with *Broken Inverted-J* shaped structure lacked individuals at intermediate or higher DBH classes (Feyera Senbeta, 2006). This pattern is caused by selective removal of mature individuals for construction purposes (Alemnew Alelign *et al.*, 2007).

The fifth pattern lacked all of the individuals except the highest dbh class (>42.5 cm). This pattern is an indicator of lack of regeneration and establishment of populations of a species after

a major disturbance such as clear-cutting for agriculture, grazing land or settlement, leaving few mature individuals as shade trees (Friis, 1986) or a life history strategy where mother trees negatively influence the germination of seeds and establishment of seedlings under their canopies (White, 1983; Bin *et al.*, 2012). This pattern has rarely been reported for tree species, namely *Juniperus procera* and *Erythrina brucei* in the highly-disturbed forests of the DAF (Tamrat Bekele, 1993; Desalegn tadele *et al.*, 2013).

5.5 Plant Communities and their Relationship with the Environment

5.5.1 Relationship between environmental variables

The mean of all environmental variables, except aspect, cutting, Magnesium and Sodium, significantly varied among the five community types ($P < 0.05$). However, only 47% of the environmental variables, namely Altitude, Electrical Conductivity (EC), Potassium (K), Calcium (Ca), Sand, Slope, pH and Grazing significantly explained the variations in species composition of the plant communities ($P < 0.05$). Thus, the remaining environmental variables were either collinear (significantly correlated to explanatory variables) (ter Braak, 1987; Zerihun Woldu, 2014; Oksanen, 2015) or their effects on species composition of plant communities were insignificant (ter Braak, 1987; Ashcroft, 2011). Similar to the present findings, altitude, EC and Potassium were found to have significant effects on species compositions of plant communities in Benishangul Gumuz Region (Tesfaye Awas, 2007); while only altitude in moist evergreen Afromontane forests of southwestern Ethiopia (Feyera Senbeta, 2006).

The positive and highly significant correlation between pH and Calcium ($r = 0.4$; $P < 0.01$) is predictable as the increase in the availability of cations increases pH and vice versa (Wilkey, 1979; Horneck *et al.*, 2011). The correlation between many of the environmental variables,

which have significant effects on species composition of plant communities, was weak (Table 22). On the other hand, some of them, namely grazing and slope; altitude and EC; grazing and Ca; pH and EC, Ca and K; EC and Sand; and Ca and K were strong ($P < 0.05$).

The Pearson correlation matrix of all environmental variables and their significance (P values) is provided in Appendix 7. Positive and strong correlation was observed between soil Organic matter (OM) and Ca ($r = 0.3$; $P < 0.05$). According to Krull *et al.* (2001), the presence of multivalent cations such as Ca in soils leads to accumulations of OM in comparison to other soil with low Ca.

Table 22. Pearson correlation coefficients between selected environmental variables (below diagonal) and their significance values (above diagonal).

	Altitude	Slope	Grazing	pH	EC	Ca	K	Sand
Altitude	-	0.27	0.15	0.69	0.00*	0.77	0.12	0.99
Slope	0.09	-	0.03**	0.21	0.37	0.13	0.12	0.44
Grazing	0.12	-0.18	-	0.81	0.42	0.01**	0.93	0.62
pH	0.03	-0.10	-0.02	-	0.00*	0.00*	0.00*	0.64
EC	-0.34	-0.07	-0.07	-0.29	-	0.25	0.07	0.00*
Calcium	-0.02	0.13	-0.21	0.39	0.10	-	0.00*	0.19
Potassium	-0.13	0.13	0.01	0.37	-0.15	0.31	-	0.38
Sand	0.00	-0.06	-0.04	-0.04	0.24	0.11	-0.07	-

Note: Correlations are significant at: * $P < 0.01$; ** $P < 0.05$.

Moreover, Cation Exchange Capacity (CEC) was positively and strongly correlated with Ca, Magnesium (Mg), K, Na, Phosphorus (P), Nitrogen (N), Sand and OM; but negatively with clay ($P < 0.05$). CEC is a measure of a soil's capacity to retain and release elements such as Ca, K, Mg and Na (Horneck *et al.*, 2011). Negative and strong correlations were observed between sand and clay ($r = -0.7$; $P < 0.05$) and sand and silt ($r = -0.6$; $P < 0.05$). Similar results were found in Bibita forest (Gura Ferda) (Dereje Denu, 2006). Whereas positive and strong correlations were observed between K and P ($r = 0.6$; $P < 0.05$) and P and Ca ($r = 0.5$; $P < 0.05$). OM was

negatively and weakly correlated with soil pH ($P > 0.05$), which can be a sign of low levels of biological activity due to acidity and water logging (Horneck *et al.*, 2011).

On the other hand, a strong and negative correlation between OM and pH was reported elsewhere (Mueller *et al.*, 2012). According to Mueller *et al.* (2012), a nearly two-fold increase in acidity (decrease in pH) was associated with a more than two-fold increase of organic matter at a common garden experiment. Grazing negatively and weakly affected the availability of soil minerals (Mg, Na and K), pH and OM ($P > 0.05$).

The correlation between grazing and Ca and grazing and P was positive and significant ($P < 0.05$). Overgrazing leads to the removal of the above ground biomass (forage) by domestic and other animals, which subsequently reduces the accumulation of OM in the soil (Assmann *et al.*, 2014; An & Li, 2015; Mligo, 2015). The correlation between grazing and soil Nitrogen was positive and weak ($P > 0.05$). This is usually caused by the accumulation of waste products in the soil such as dung and urine by grazing and browsing animals, which raises the nitrogen level in the soil (Franzluebbers, 2010; Assmann *et al.*, 2014; Moses *et al.*, 2015).

5.5.2 Relationship between elevation and other environmental variables

Negative and weak correlations between elevation, and Phosphorus, Sodium and Potassium were revealed in the study area ($P > 0.05$). However, the correlation between elevation and EC was negative and strong ($P < 0.05$); which is also confirmed in the ordination diagram where the arrows of the two variables were almost in opposite directions. In contrast to this result, Saeed *et al.* (2014) found negative and weak correlation between elevation and EC in Takatu mountain range of Pakistan. A negative correlation was also reported between elevation and Calcium, EC

and Sodium in Benishangul Gumuz Region (Tesfaye Awas, 2007). OM and Nitrogen showed positive and significant correlation with elevation ($P < 0.05$); whereas soil pH showed very weak and positive correlation ($P > 0.05$) as also confirmed in the ordination diagram. According to Griffiths *et al.* (2009), reduced temperatures and increased moisture are probably factors responsible for reduced decomposition rates and thus the accumulation of OM at higher elevations. Similarly, positive and significant correlations were reported between elevation and OM, nitrogen and electrical conductivity in the moist evergreen Afromontane forests of southwestern Ethiopia (Kumelachew Yeshitela & Tamrat Bekele, 2002). Moreover, a study in the northern Ethiopian highlands showed that OM and nitrogen were significantly and positively correlated with altitude, whereas soil pH did not (Abreha Kidanemariam *et al.*, 2012). Similarly, Tesfaye Awas (2007) reported a positive correlation between altitude and CEC, Magnesium, OM and Nitrogen in Benishangul Gumuz Region in Ethiopia. Soil pH showed a weak positive correlation with elevation; whereas organic matter was negatively correlated with elevation in Takatu mountain range of Pakistan (Saeed *et al.*, 2014).

5.5.3 Relationship between plant communities and the environment

In terms of floristic composition, the five plant communities described in this study were different from the plant communities described in the dry and moist evergreen Afromontane forests of Ethiopia. Moreover, a unique association (combination) of indicator species were revealed in the study area, which was one of the basis for modelling and description of a new vegetation type (see sections 3.3.8 & 5.6). Nevertheless, some of the individual indicator species in this study such as *Croton macrostachyus*, *Vepris dainellii*, *Millettia ferruginea*, *Vernonia auriculifera* and *Rothmania urcelliformis* were also reported as indicator species elsewhere in the DAF and MAF vegetation types in Ethiopia (Tamrat Bekele, 1993; Dereje Denu, 2006; Mamo

Kebede *et al.*, 2013; Abreham Assefa, 2013; Fekadu Gurmessa *et al.*, 2013; Abiyot Berhanu *et al.*, 2017).

The *Vernonia auriculifera* - *Croton macrostachyus* community (C₂) could be understood as a community in secondary stage of development; which may have developed after a major disturbance regime such as forest clearance for agriculture with few remnant tree species or intermediate disturbance regime such as selective cutting of canopy tree species for various purposes (Tamrat Bekele, 1993; Abiyot Berhanu *et al.*, 2017). The presence of climax canopy tree species in this community such as *Albizia gummifera*, *Apodytes dimidiata*, *Schefflera abyssinica* and *Prunus africana* strengthens this assumption. This community was the richest in species composition (158 species) and had the highest alpha diversity ($H' = 3.4$) and beta diversity ($\beta = 6.1$) indices among all communities. The most pertinent reason could be the highest altitudinal ranges enclosed within this community (1878 - 2346 m) that included sampling plots and species from lower and mid-altitude forest patches. In this study, species richness was strongly and positively correlated to altitudinal ranges ($r = 0.8$; $P < 0.05$). Intermediate disturbance is also known to enhance the regeneration of light demanding or shade-intolerant woody species following formation of forest canopy gaps thereby increasing the floristic richness and diversity of forests (Wilkinson, 1999; Catford *et al.*, 2012).

The forest patches were not exclusively loyal to the plant communities described in this study. Nevertheless, some of the forest patches particularly Khatasa forest contained more of one community type than others and had comparatively less similarity with other plant communities. The relatively less similarity between community V (C₅) and other communities is mainly attributed to altitudinal differences, as the former was located at the highest elevations (> 2300 m) and ecologically isolated from the others by agricultural and grazing lands and settlement;

while the altitudinal locations of other plant communities overlap to some extent. Moreover, the climate of this forest patch (Khatasa forest) where community V (C_5) was described is to some extent different from the other communities in that the area gets rain almost 12 months a year. It has been long known that climate varies with the variation in altitude, which subsequently affects the distribution of species along altitudinal gradients (White, 1983; Friis *et al.*, 2010; Schmitt *et al.*, 2013; Abiyot Berhanu *et al.*, 2016). According to Mueller-Dombois and Ellenberg (1974), no two stands (forest patches) are exactly alike, owing to chance events of dispersal, disturbance, extinction and history. And this type of dissimilarity is more noticeable when the distance (isolation) between any two forest patches is elevated. Community V (Khatasa forest) is also found as a transition forest from the newly described forest (Intermediate evergreen Afromontane forest - IAF) to the Dry evergreen Afromontane forest and grassland complex in the northern and northeastern part of the study area. As a result, one of the characteristic species of community V (C_5), namely *Juniperus procera* was restricted to this community being the fifth most important species; though much of the forest is devoid of *J. procera* because of selective cutting for construction purposes (pers. obs.). The species had one of the least relative frequencies and relative densities in Khatasa forest and the high importance value of the species is primarily attributed to its high DBH (≥ 90 cm).

Altitude, EC and pH had the longest arrows in the ordination diagram and this indicated their strong influence on species composition of plant communities and their distribution (ter Braak, 1987; Zerihun Woldu, 2014; Oksanen, 2015). Moreover, the beta diversity of each community was high (see section 4.3) indicating the presence of long environmental gradients and a high turnover in the five community types (Zerihun Woldu, 2014). The correlation between the first ordination axis and altitude was positive and strong ($r = 0.96$; $P < 0.05$); whereas negative and

strong with EC ($r = -0.52$; $P < 0.05$). The second ordination axis was negatively and strongly correlated with pH ($r = -0.88$; $P < 0.05$). According to ter Braak (1987), environmental variables with long arrows are more strongly correlated with the ordination axes than those with short arrows and so more closely related to the pattern of community variation shown in the ordination diagram. Consequently, most of the plots and species at lower altitudes (e.g. Community I) were positively and strongly correlated with Electrical Conductivity (EC). Species such as *Senna septemtrionalis*, *Acanthus pubescens*, *Protea gaguedi*, *Rhus natalensis*, *Kalanchoe densiflora*, *Carissa spinarum* and *Phyllanthus rotundifolius* were strongly and positively correlated with pH and they were located in high pH areas.

A number of plots and species belonging to community V were located at areas of highest elevations, where disturbance was prevalent. This is profoundly attributed to forest clearance for grazing land, settlement, fuel wood and agriculture at mid and higher elevations (Tesfaye Awas, 2007). According to Friis (1986), Ethiopian Afromontane vegetation is mostly very deeply influenced by anthropogenic impacts. Species such as *Rumex nepalensis*, *Vernonia myriantha*, *Sida ternata*, *Juniperus procera*, *Embelia schimperi*, *Nuxia congesta*, *Justicia ladanoides*, *Polystachya caduca*, *Cissus petiolata* and *Ensete ventricosum* were strongly and positively correlated with altitude and they were located at high elevations. On the other hand, species such as *Celosia anthelminthica*, *Phyllanthus limmuensis*, *P. ovalifolius*, *Momordica foetida*, *Celtis africana*, *Otostegia tomentosa* and *Solanum giganteum* favored lower elevations.

5.6 Vegetation Distribution Modelling and Description

5.6.1 Model performance and distribution of the new vegetation type

The selected climate and soil variables predicted the distribution of the new vegetation type in Ethiopia and clearly showed that Gojam and Gondar Floristic Regions were the most suitable areas. Bioclimatic extremes played the most important role in predicting the distribution of the new vegetation type. According to White (1983), climatic extremes are often more important for plants than the means, and for agriculture and forestry, in particular, it is important to know how often such extremes may occur. The model predicted the distribution of the new vegetation type with high certainty (AUC, 0.31 - 0.88) in (central and northeastern) Gojam and (southern) Gondar Floristic Regions. However, the AUC values below 0.31 did not clearly separate the new vegetation type from existing vegetation types such as Ericaceous belt, Afroalpine vegetation and *Combretum-Terminalia* woodland and wooded grassland vegetation types in Gojam and Gondar Floristic Regions. These vegetation types were predicted as slightly and poorly suitable for the new vegetation type. Thus, the areas between 1500 and 2800 m in Gojam and Gondar floristic regions, as clearly delineated by the model (AUC, 0.31 - 0.88), are highly suitable habitats for the distribution of the new vegetation type, covering the areas of doubtful position between MAF and DAF, as discussed by Friis *et al.* (2010).

However, the new vegetation type did not extend to Welega Floristic Region as hypothesized by Friis *et al.* (2010); except few modelled areas predicted as poorly suitable for the new vegetation type (AUC, 0.05 - 0.2) in northern and northeastern part. These areas overlap with the Moist evergreen Afromontane forest (MAF) (Fekadu Gurmessa *et al.*, 2013). Moreover, areas modelled as poorly suitable areas in (northern) Shewa Floristic Region overlap with the Dry evergreen

Afromontane forest and grassland complex (Friis *et al.*, 2010). Areas in central, northern and northeastern Wenbera (Gojam Floristic Region), which have been classified as MAF in Friis *et al.* (2010) were modelled in this study as IAF, which is also confirmed from field notes of Sebsebe Demissew and Friis (unpublished data). Consequently, these forest patches were briefly discussed in Friis *et al.* (2010), where it was concluded that they represented the northernmost examples of MAF, but in the light of the model predictions they represent a form of the new vegetation type. And the Wembera plateau agrees with the southwestern outpost of the habitats marked as suitable (AUC, 0.31 - 0.88) by the Model (Sebsbe Demissew & Friis, unpublished data).

5.6.2 Description of the new vegetation type

The results of this work indicated that those forests in the study area (Awi forests), Zege Peninsula and nearby forests, which were included in the DAF and MAF with some uncertainties, are rather part of a new vegetation type known hereafter as “Intermediate evergreen Afromontane forest (IAF)”. The following evidences were considered for the establishment of the new vegetation type. First, primary elements of the DAF (e.g. *Juniperus procera*, *Podocarpus falcatus* and *Olea europaea* subsp. *cuspidata*) and the MAF (e.g. *Pouteria adolfi-friederici*, *Macaranga capensis*, *Ocotea kenyensis*, *Psychotria orophila* and *Cyathea manniana*) were not found in the IAF. Second, there exists comparable high similarity in species composition of IAF in comparison with both DAF and MAF (see sections 5.3.2 & 5.3.3). Third, IAF is intermediate in terms of climate as it is located in the transition zone from high rainfall areas of southwestern Ethiopia in Welega Floristic Region to low rainfall areas in Gojam and Gondar Floristic Regions. Fourth, the predicted areas which are suitable for the distribution of the new vegetation type have unique indicator species associations (combinations). Fifth, the

model outputs clearly showed the distribution of the IAF with high certainty (AUC, 0.31-0.88) in Gojam and Gondar Floristic Regions including those areas (e.g. Zege Peninsula) hitherto hypothesized as part of a unique vegetation type which resembles the moist forests of southwestern Ethiopia by Friis *et al.* (2010).

The forests below 1500 m at the southern, southwestern, western and northwestern part of the area of IAF in Awi are bordered with the *Combretum-Terminalia* woodland and wooded grassland (CTW), which separates small patches of MAF in northern and northeastern Welega floristic regions from the IAF. The CTW also divides the IAF in Wenbera from Awi. On the other hand, at the northeastern side of IAF above 2800 m in Awi is bordered by the Dry evergreen Afromontane forest and grassland complex (DAF), which extends to the IAF in the northern, northwestern and western parts of Zege Peninsula and the southern surroundings of Lake Tana. The northern outpost of the IAF in Awi Zone is found in Khatasa forest which could be regarded as a transition between IAF and DAF. Thus, the forests between elevations 1500 and 2800 m as specified by the model are part of an intermediate type of vegetation which includes a significant number of species from the Moist evergreen Afromontane forests of southwestern Ethiopia (Welega Floristic Region) and the Dry evergreen Afromontane forests and grassland complex of central and northeastern Ethiopia (Gojam and Gondar Floristic Regions).

5.6.3 Diversity and floristic overlap with other vegetation types

The Intermediate evergreen Afromontane forest (IAF) is fifth only after *Combretum-Terminalia* woodland and wooded grassland (CTW) in terms of woody taxa richness. A total of 169 woody taxa have been recorded to occur in the IAF (Appendix 8), and none of these has been recorded to occur from this vegetation type alone. A total of 145 taxa have been recorded from both this

vegetation type and the adjacent vegetation type Dry evergreen Afromontane forest and grassland complex (DAF). A total of 90 taxa have been recorded from both this vegetation type and the adjacent vegetation type Moist evergreen Afromontane forest (MAF). A total of 56 taxa have been recorded from both this vegetation type and the adjacent vegetation type Riverine vegetation (RV). A total of 22 taxa have been recorded from both this vegetation type and the adjacent vegetation type *Combretum-Terminalia* woodland and wooded grassland (CTW), while 19 have been recorded from both this vegetation type and the non-adjacent vegetation type *Acacia-Comiphora* woodland and bushland (ACB). Only 20 taxa have been recorded from both this vegetation type and the non-adjacent vegetation type Transitional rain forest (TRF), while four have been recorded from both this vegetation type and the non-adjacent vegetation type Afroalpine belt (AA), and only one has been recorded from both this vegetation type and the non-adjacent vegetation type Desert and semi-desert scrubland (DSS). The highest number of woody taxa are shared with the three vegetation types Dry evergreen Afromontane forest and grassland complex (DAF), Moist evergreen Afromontane forest (MAF) and Riverine vegetation (RV).

5.6.4 Characteristic species of Intermediate evergreen Afromontane forest (IAF)

The IAF predominantly contains broad-leaved evergreen species in the two-three layered canopy. *Olea europaea* subsp. *cuspidata* may occur in the Zege Peninsula, but it is rare having a frequency and density of 0.7% and 0.2 individuals ha⁻¹, respectively (Alemnew Alelign *et al.*, 2007). Moreover, *Juniperus procera* was recorded to occur in “Khatasa forest”, at the northern part of Awi forests being the fifth most important species in this forest patch, which was as a result of its high DBH values. However, the relative frequency and relative density of the species were 0.94% and 0.26%, respectively with no regeneration, saplings or any other DBH classes

except the biggest individuals with DBH ≥ 90 cm. *J. Procera* is completely absent in the Guangua-Illala forests of Awi Zone. On the other hand, *Albizia schimperiana*, *A. gummifera*, *Celtis africana* and *Prunus africana* are the most dominant canopy trees in IAF.

About 62 tree taxa (37% of total) have been recorded to occur in this vegetation type. The canopy of the IAF consists of species such as *A. schimperiana*, *A. gummifera*, *A. grandibracteata*, *Celtis africana*, *Prunus africana*, *Ekebergia capensis*, *Sapium ellipticum*, *Croton macrostachyus*, *Euphorbia abyssinica*, *E. ampliphylla*, *Polyscias fulva*, *Schefflera abyssinica* and *Cordia africana*. *E. ampliphylla* and *C. macrostachyus* are usually seen in clearings and secondary forests (Friis *et al.*, 2010). The sub-canopy includes trees with heights below 30 m such as *Mimusops kummel*, *Apodytes dimidiata*, *Cassipourea malosana*, *Allophylus abyssinicus*, *Deinbollia kilimandascharica*, *Bersama abyssinica*, *Brucea antidysenterica*, *Millettia ferruginea*, *Rothmania urcelliformis*, *Oxyanthus speciosus*, *Vepris dainellii*, *Dracaena steudneri*, *Ehretia cymosa*, *Lepidotrichilia volkensii*, *Lobelia giberroa*, *Nuxia congesta*, *Pittosporum viridiflorum* and *Solanecio gigas*.

About 82 shrub taxa (48% of total) have been recorded to occur in this vegetation type. The shrub layer includes species such as *Clausena anisata*, *Teclea nobilis*, *Justicia schimperiana*, *Acanthus eminens*, *A. polystachius*, *A. pubescens*, *A. sennii*, *Carissa spinarum*, *Vernonia amygdalina*, *V. auriculifera*, *Maytenus arbutifolia*, *Clutia abyssinica*, *Erythrococca trichogyne*, *Phyllanthus limmuensis*, *Calpurnia aurea*, *Otostegia tomentosa* subsp. *tomentosa*, *Satureja abyssinica* subsp. *abyssinica*, *Rosa abyssinica* and *Galiniera saxifraga*. Introduced and cultivated *Coffea arabica* is a dominant shrub species in the Zege Peninsula (Alemnew Aleign *et al.*, 2007).

Lianas are also common and about 25 taxa (15% of total) have been recorded to occur in this vegetation type. Some of the most common lianas in this vegetation type include *Capparis tomentosa*, *Dalbergia lactea*, *Clematis longicauda*, *C. simensis*, *Combretum aculeatum*, *C. paniculatum*, *Embelia schimperi*, *Gouania longispicata*, *Hippocratea africana*, *H. goetzei*, *H. pallens*, *Jasminum abyssinicum*, *Landolphia buchananii*, *Phyllanthus ovalifolius*, *Phytolacca dodecandra*, *Pterollobium stellatum*, *Tiliacora troupinii* and *Urera hypselodendron*.

Epiphytes are also common and about 12 species have been recorded to occur in this vegetation type, namely *Adiantum poiretii*, *Aerangis brachycarpa*, *Polystachya caduca*, *P. cultriformis*, *Asplenium aethiopicum*, *A. erecta*, *Canarina eminii*, *Drynaria volkensii*, *Lepisorus schraderi*, *Huperzia dacrydioides*, *Peperomia tetraphylla* and *Selaginella goudotiana*.

The ground layer of IAF usually consists of herbaceous species, grasses and terrestrial ferns. About 80 herbaceous species have been recorded to occur from the ground layer of this vegetation type. This figure does not include ground layer species in the Zege Peninsula, Islands of Lake Tana and other predicted areas as there are no studies available on herbaceous flora to date in those areas. The ground layer is usually dominated by *Girardinia bullosa*, *Urtica simensis*, *Achyranthes aspera*, *Hypoestes triflora*, *Justicia ladanoides*, *Asplenium aethiopicum*, *A. erectum* and *Pteris catoptera*. The ferns *A. aethiopicum* and *A. erectum* have also epiphytic or epilithic nature (Roux, 2009).

5.7 Land use/cover Changes with Emphasis to Vegetation Cover

5.7.1 Accuracy assessment of Land use/cover classifications

It is impossible to produce a land use/cover map that is completely accurate and satisfies the needs of all (Brown *et al.*, 1999; Strahler *et al.*, 2006). Moreover, there is no one universal “best”

method of accuracy assessment, but rather a suite of methods of varying value and applicability for any given map and purpose (Strahler *et al.*, 2006). Hence, although there is no set standard, it is recommended that the minimum level of interpretation accuracy in the identification of Land use/cover categories from remote sensor data be at least 80-85 percent (Anderson *et al.*, 1976; Foody, 2002; Olson, 2008). This has also been employed in the study of Land use/cover changes in Ethiopia and elsewhere (Addis Getnet, 2009; Mengistie Kindu *et al.*, 2013). In view of that, the Producer and User's accuracies, overall accuracy as well as the Kappa coefficient of this study were above the recommended level. Nevertheless, some confusions were detected in the classification results, which were caused by the miss-classification of some pixels of primary forest and secondary forest as well as grassland and agriculture. The primary forest and secondary forest are usually found side by side or in close proximity and sometimes mixed in areas of major disturbance such as forest clearing in the study area (pers. obs.). However, both errors were insignificant and it was generally concluded that the classification results were highly accurate and acceptable.

5.7.2 Land use/cover changes

The primary forest cover of the study area has been severely affected by conversion to secondary forests, agricultural lands and grazing lands in the past four decades. In similar periods, the number of domestic animals and the human population gradually increased which exerted huge pressure on primary forests, secondary forests and grasslands (CSA, 2013a & b). The highest proportion of land cover at the beginning of the study period was shared by primary forest (40%), which was eventually converted to other land use types. There are various justifications for the forest destruction, the most important being population growth, which requires space for settlement and agricultural and grazing lands (Alemu Mekonnen and Bluffstone, 2007; Sisay

Nune, 2007; Abyot Yismaw *et al.*, 2014). Policy, though it does not contribute directly, is believed to influence Land use/cover changes in rural areas (Samuel Gebreselassie, 2006). For example, the enforced displacement of farmers from their agricultural fields (steep slopes and hillsides) for afforestation purposes in the 1980s disrupted afforestation programmes and protection of forests (Sisay Nune, 2007). Thus, the most significant decrease in primary forest cover and grassland cover in the second study period (1987 – 2001) is mainly attributed to government change (downfall of DERG regime) that led to the illegal destruction and proprietorship of protected forests and grasslands for agriculture by farmers (Abiyot Berhanu *et al.*, 2017). In particular, the highest destruction of forest resources occurred between 1991 and 1997 in the study area (pers. com.). Consequently, the rate of forest cover conversion (-3.8%) to other land use types in the second study period was one of the highest in the country (Belay Tegene, 2002; Eyayu Molla *et al.*, 2010; Abiy Wogderes, 2014).

Elsewhere in Ethiopia, similar trends were revealed in that the primary forest cover and woodlands were converted to mainly agricultural lands (Efrem Garedew, 2010; Eyayu Molla *et al.*, 2010; Mengistie Kindu *et al.*, 2013). Similarly, the conversion of forests to agricultural lands and settlements was reported elsewhere in the world (Critchley & Bruijnzeel, 1996; Houghton & Goodale, 2004; Dittrich *et al.*, 2010). In 1997, land was legally redistributed to farmers in the study area, which also contributed to the decrease of grasslands (pers. com.).

5.7.3 Change detection and direction of changes

The decrease in primary forest cover was accompanied by an increase in secondary forest cover and agriculture in the study area. The most significant increase in the extent of secondary forest cover (220%) was mainly caused by various factors, revision and enforcement of forest laws and

area closure being the most important. Forest laws were revised and reinforced which prohibited illegal forest destruction and introduced penalties on the wrong doers (Alemu Mekonnen and Bluffstone, 2007; Sisay Nune, 2007). Consequently, the farmlands that were illegally owned by clearing the primary forest were abandoned and allowed to regenerate, which eventually developed to grasslands and subsequently to secondary forest/scrub. Moreover, area closures were introduced in some areas to enhance the recovery of abandoned fields and steep slopes (BoA, 2012; Amogne Asfaw, 2014).

Nevertheless, coupled with agricultural expansion, protection of forests and legal enforcements resulted in the scarcity of grazing areas, construction materials and firewood that inflicted heavy pressure on secondary forests and edges of primary forests (pers. com.). Thus, selective cutting of woody plants (Abiyot Berhanu *et al.*, 2017) and illegal conversion of secondary forests to grasslands was a common phenomenon in similar periods (1973-2014). Although insignificant, the hillsides and steep slopes were also planted with introduced species such as *Eucalyptus* sp., *Acacia* sp. and *Sesbania sesban* (Sisay Nune, 2007; BoA, 2012; Amogne Asfaw, 2014). This was highly practical starting in the 1980s and onwards (Amogne Asfaw, 2014). The change from grassland into secondary forest/scrub is predictable as pioneer species and some native nitrogen fixing woody plants such as *Acacia* species often establish themselves following disturbance, overgrazing and abandonment (Brown & Archer, 1989; Polley *et al.*, 2002; Myster, 2012; Liu *et al.*, 2013). Generally, the Land use/cover changes during the whole study period and the three study periods (1973-1987, 1987-2001 and 2001-2014) were multidirectional. That is one land use type (e.g. secondary forest) was converted or developed into other land use types (e.g. grassland) and vice versa. Those changes were highly noticeable except that of the changes from grassland and agriculture into primary forest, which were nonexistent for the three periods. The

most visible changes in the whole study periods were from grassland to agriculture (49%), followed by primary forest to agriculture (37%) and primary forest to secondary forest (36%).

Even though agriculture received the largest percentage conversions from grassland and primary forest, it eventually lost 43% of its cover to: grassland (22%) and secondary forest (21%). An insignificant portion of agricultural (1.2%) and grazing lands (0.6%) developed into primary forest in the whole study period (42 years); probably because of subsequent changes through development of agriculture and grassland to secondary forest and finally to primary forest (Mengistie Kindu *et al.*, 2013; Adedeji *et al.*, 2015). According to Cole *et al.* (2013), Tropical forests disturbed by anthropogenic impact such as logging and burning for agriculture recover very slowly depending on management activities. This may most likely be due to lack of seed sources such as soil seedbanks, which are sources for woody species regeneration, as they are usually depleted in the course of time. For example, Mulugeta Lemenih and Demel Teketay (2006) found out that there was a general tendency of disappearance of native woody species from the soil seed banks with increasing period of soil cultivation. On the other hand, a portion of secondary forest (14%) developed into primary forest. This was highly visible in the first study period (1973-1987); when deforestation was relatively less practical in the study area (pers. com.).

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusions

1. The study area comprised of high floristic richness, diversity, evenness and endemism. A high floristic composition similarity to the DAF, MAF and RV was also documented. The highest similarity was to the southwestern and northwestern Ethiopian forests such as the Bonga, Kuandisha, Tara Gedam and Zege Peninsula forests. The least similarity was to the central and northeastern Ethiopian forests such as Menagesha Suba and Hugumburda forests.
2. The population density patterns of the forests of the study area and each forest patch in DBH and height classes revealed that the study area and the forest patches were in healthy status (*Inverted-J* shaped). This was highly different from the population density patterns of each tree species; where four additional patterns were discovered that indicated the absence of populations in various DBH classes. Generally, five population density patterns were evident for 28 tree species investigated, namely *Inverted-J* shaped, *J* shaped, *Broken Inverted-J* shaped, unimodal/bell-shaped and a fifth pattern where only mature individuals were represented. The later four patterns indicated unhealthy status of tree species in various stages of development.
3. The hierarchical classification revealed five plant communities in the study area, which were influenced by disturbance, elevation, edaphic factors and climate. The four communities (C₁ - C₄) had to some extent overlapping altitudinal ranges and they were found to have strong affinities to each other; whereas community V was found at high elevations isolated from the others and with relatively less similarity. A significant number of environmental variables explained the distribution of species and plant communities in the study area. Among the eight environmental variables which significantly affected plant distributions, altitude, EC

and pH had the longest arrows and they were highly correlated with the first and second ordination axes, respectively. Accordingly, the two ordination axes separated communities which favoured high altitude or low pH areas from low altitude or high pH areas.

4. The forests of the study area belonged to the same vegetation type - the newly described vegetation type between 1500 and 2800 m elevations. Differing from hypothesis I, there were no significant differences in terms of floristic richness and structure (density, basal area and dominance) of the forest patches. Furthermore, the list of the most dominant canopy species of the five forest patches, namely Ambiqi, Bradi, Degera, Kidamaja and Askunabo were similar, with minor differences in their level of dominance. Thus, it is highly likely that the forests of the forest patches were once connected somehow before the advent of agriculture and settlement.
5. As suggested in hypothesis II, the forests of the study area were found to be unique and they were proposed as a new vegetation type “Intermediate evergreen Afromontane forest (IAF)” for Ethiopia. The strong similarity to both vegetation types (MAF and DAF), the transitional rainfall pattern between the moist and dry climate, the absence of primary elements of the forest canopies of DAF and MAF and the model prediction of the distribution of the new vegetation type with high certainty all contributed to its uniqueness. This has paramount importance for the conservation and sustainable utilization of those and related forests.
6. As stated in hypothesis III, a significant number of endemic and other species and forest patches were threatened. The majority of species had IVI values below one in each forest patch and in the study area in general. Moreover, the population structure of tree species, except naturally rare plants, confirmed the absence of individuals in various DBH classes that contributed to the low IVI values. Similarly, the three sites (forest patches) – Ambiqi,

Khatasa and Kidamaja forests have been relatively highly influenced by agricultural activities in that the bulk of those forests were cleared, which is one of the worst threats to the species.

7. As indicated in hypothesis IV, a significant conversion of primary forest to other land use types such as secondary forests, agriculture and grazing land occurred in the study area and this is a concrete evidence for the decline of forest patches. Moreover, the rate of conversion of the primary forest cover to other land use types is highly alarming. It will not be far that all the primary forests will be gone if the trend is not reversed.

6.2 Recommendations

1. The high similarity between the forest patches (Ambiqi, Bradi, Degera, Kidamaja, Askunabo and Khatasa) in terms of species composition could be a basis for studying past forest connections and historical forest changes. Moreover, a study on the effects of climate change (past and future) on regeneration, growth and establishment of species and their resilience after disturbance is highly recommended.
2. Using population density patterns in various DBH and height classes to show the status of forests and individual tree species has been largely employed in Ethiopia and elsewhere. However, the use of such patterns particularly for forest patches was not that useful as realized in this study because of "compensatory" effects of individuals of species in various DBH classes. Thus, it is highly recommended to use population density patterns of each tree species instead and interpret the results with caution. Some tree species may show different patterns because of life strategy or other natural factors.

3. The floristic composition and diversity of many of the modelled forest fragments in the new vegetation type (IAF) are not investigated, yet. Thus, it is highly recommended to investigate those forests between elevations 1500 and 2800 m for developing complete list of woody and other species particularly in the Gojam Floristic Region (Awi and Metekel Zones) and Gondar Floristic Region (western Farta). The new vegetation type, being relatively small in area coverage in Ethiopia and under severe human and livestock pressure, should be considered for conservation priority area with full participation of local communities and/or needs strengthening the existing (National) Regional Forest Priority Areas (Guangua-Illala and Khatasa forests).
4. Degraded and threatened forests and species require maintenance and restoration activities, enrichment planting in suitable areas, protection of sites and introducing appropriate management interventions. The list of threatened and endemic species compiled herewith could be used as an input for maintenance and restoration activities. Moreover, studies on soil seedbanks of woody species in general and regeneration capabilities of threatened species in particular is highly recommended. Special emphasis should also be given for the conservation of endemic plants.
5. Forest Land use/cover changes induced by humans are detrimental to floristic richness and diversity particularly endemic and rare plant species. Thus, it is highly recommended to reverse these changes by introducing appropriate forest land use planning. The future land cover changes of those forests should also be projected so that it will help to introduce appropriate conservation and management measures.

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8. APPENDIX

Appendix 1. Floristic composition of the study area (pooled data from all forest patches): habit, local name and collection number

Species	Family	Habit	Agaw Name	Collection No.
<i>Abutilon figarianum</i> Webb	Malvaceae	Herb	Tsarifucha	AB151
<i>Abutilon mauritianum</i> (Jack.) Medie.	Malvaceae	Herb	-	AB178
<i>Acacia abyssinica</i> Hochst. ex Benth.	Fabaceae	Tree	Tsatsi	-
<i>Acacia lahai</i> Steud. & Hochst. ex Benth.	Fabaceae	Shrub	Tsivi	-
<i>Acanthus eminens</i> C. B. Clarke	Acanthaceae	Shrub	Danduri	AB004
<i>Acanthus polystachius</i> Delile	Acanthaceae	Shrub	Danduri	AB143
<i>Acanthus pubescens</i> (Oliv.) Engl.	Acanthaceae	Shrub	Danduri	AB093
<i>Acanthus sennii</i> Chiv.	Acanthaceae	Shrub	Danduri	-
<i>Achyranthes aspera</i> L.	Amaranthaceae	Herb	-	-
<i>Achyrosperrum schimperi</i> (Hochst. ex Briq.) Perkins	Lamiaceae	Herb	-	AB033
<i>Adiantum poiretii</i> Wikstr.	Adiantaceae	Herb	-	AB140
<i>Aerangis brachycarpa</i> (A. Rich.) Th. Dur. & Schinz	Orchidaceae	Herb	-	AB097
<i>Albizia gummifera</i> (J. F. Gmel.) C. A. Sm.	Fabaceae	Tree	Kansikansi	AB076
<i>Albizia schimperiana</i> Oliv.	Fabaceae	Tree	Kansini	AB077
<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Sapindaceae	Tree	Entahtahign	AB086
<i>Apodytes dimidiata</i> E. Mey. ex Arn. var. <i>acutifolia</i> (Hochst. ex A. Rich.) Boutique	Icacinaceae	Tree	Zindi	AB064
<i>Arundinaria alpina</i> K. Schum.	Poaceae	Tree	-	-
<i>Asparagus africanus</i> Lam.	Asparagaceae	Liana	-	AB134
<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Aspleniaceae	Herb	-	AB100
<i>Asplenium erectum</i> Bory ex Willd.	Aspleniaceae	Herb	-	AB104
<i>Basella alba</i> L.	Basellaceae	Herb	-	AB201
<i>Bersama abyssinica</i> Fresen. subsp. <i>abyssinica</i>	Melanthaceae	Shrub	Dinkifi	-
<i>Bidens pillosa</i> L.	Asteraceae	Herb	-	AB171
<i>Bidens prestinaria</i> (Sch. Bip.) Cufod.	Asteraceae	Herb	-	AB075
<i>Bothriocline schimperi</i> Sch. Bip. ex Walp.	Asteraceae	Shrub	Tehla	AB150
<i>Brillantaisia grotanellii</i> Pic. Serm.	Acanthaceae	Herb	-	AB186
<i>Brucea antidysenterica</i> J. F. Mill.	Simaroubaceae	Shrub	Abali	-
<i>Buddleja polystachya</i> Fresen.	Loganiaceae	Shrub	Ashikori	AB116
<i>Calpurnia aurea</i> (Ait.) Benth.	Fabaceae	Shrub	Tintirasi	AB061
<i>Canarina eminii</i> Schweinf.	Campanulaceae	Herb	-	AB139
<i>Canthium oligocarpum</i> Hiern subsp. <i>oligocarpum</i>	Rubiaceae	Shrub	Chingursti	AB010
<i>Capparis tomentosa</i> Lam.	Capparidaceae	Liana	Hanguri	-
<i>Cardamine africana</i> L.	Brassicaceae	Herb	-	Ab022

Species	Family	Habit	Agaw Name	Collection No.
<i>Carduus leptacanthus</i> Fresen.	Asteraceae	Herb	-	AB034
<i>Carissa spinarum</i> L.	Apocynaceae	Shrub	Hetsiri	AB137
<i>Carum piovanii</i> Chiov.	Apiaceae	Herb	-	AB204
<i>Cassipourea malosana</i> (Baker) Alston	Rhizophoraceae	Shrub	Marqedi	AB016
<i>Cayratia ibuensis</i> (Hook, f.) Susseng.	Vitaceae	Herb	Sinkuy	AB019
<i>Celosia anthelminthica</i> Asch, in Schweinf.	Amaranthaceae	Herb	-	AB084
<i>Celtis africana</i> Burm. f.	Ulmaceae	Tree	Tsaringi	AB044
<i>Centella asiatica</i> (L.) Urban	Apiaceae	Herb	-	AB208
<i>Chloris gayana</i> Kunth	Poaceae	Herb	Achichi	AB183
<i>Chloris pycnothrix</i> Trin.	Poaceae	Herb	Serdo	AB005
<i>Cissus petiolata</i> Hook. f.	Vitaceae	Liana	Bokehera	AB187
<i>Clausena anisata</i> (Willd.) Benth.	Rutaceae	Shrub	Lumsi	AB108
<i>Clematis longicauda</i> Steud ex A. Rich.	Ranunculaceae	Liana	-	AB2011
<i>Clerodendrum myricoides</i> (Hochst.) Vatke	Lamiaceae	Herb	-	AB057
<i>Clutia abyssinica</i> Jaub. & Spach. var. <i>abyssinica</i>	Euphorbiaceae	Shrub	-	AB121
<i>Clutia lanceolata</i> Forssk. subsp. <i>lanceolata</i> Forssk.	Euphorbiaceae	Herb	-	AB011
<i>Combretum aculeatum</i> Vent.	Combretaceae	Liana	-	-
<i>Combretum paniculatum</i> Vent.	Combretaceae	Liana	Gori	AB132
<i>Commelina</i> sp.	Commelinaceae	Herb	-	-
<i>Cordia africana</i> Lam.	Boraginaceae	Tree	Bugtsi	-
<i>Crotalaria rosenii</i> (Pax) Milne-Redh. ex Polhill	Fabaceae	Shrub	Embiqi	AB001
<i>Croton macrostachyus</i> Del.	Euphorbiaceae	Tree	Asisi	-
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Herb	-	AB006
<i>Cynoglossum amplifolium</i> Hochst. ex A.DC in DC.	Boraginaceae	herb	Kesijua	AB007
<i>Cyperus metzii</i> (Steud.) Mattf. & Kuk.	Cyperaceae	Herb	-	AB207
<i>Cyphostemma cyphopetalum</i> (Fresen.) Desc. ex Wild & Drummond	Vitaceae	Herb	-	AB070
<i>Dalbergia lactea</i> Vatke	Fabaceae	Liana	-	AB135
<i>Deinbollia kilimandscharica</i> Taub.	Sapindaceae	Tree	-	AB115
<i>Dichondra repens</i> J. R. & G. Forst.	Convolvulaceae	Herb	-	AB066
<i>Dicliptera maculata</i> Nees	Acanthaceae	Herb	-	AB015
<i>Dicliptera verticillata</i> (Forssk.) C. Chr.	Acanthaceae	Herb	-	AB154
<i>Dicrocephala integrifolia</i> (L.F.) Kuntze subsp. <i>integrifolia</i>	Asteraceae	Herb	-	AB063
<i>Discopodium penninervium</i> Hochst.	Solanaceae	Tree	Zagrismi	AB039
<i>Dombeya quinqueseta</i> (Del.) Excell	Sterculiaceae	Tree	Sheksheki	AB092
<i>Dombeya rotundifolia</i> (Hochst.) Planch.	Sterculiaceae	Shrub	Tsari	AB046
<i>Dovyalis abyssinica</i> (A. Rich.) Warb.	Flacourtiaceae	Shrub	-	AB122
<i>Dovyalis verrucosa</i> (Hochst.) Warb.	Flacourtiaceae	Shrub	Agomi	AB014
<i>Dracaena steudneri</i> Engler	Dracaenaceae	Tree	Zagrim	-

Species	Family	Habit	Agaw Name	Collection No.
			emperpera	
<i>Drymaria cordata</i> (L.) Schultes	Caryophyllaceae	Herb	Bitin	AB155
<i>Drynaria volkensii</i> Hieron.	Polypodiaceae	Herb	-	AB098
<i>Dumasia villosa</i> DC.	Fabaceae	Herb	-	AB172
<i>Echinops kebericho</i> Mesfin	Asteraceae	Herb	-	-
<i>Ehretia cymosa</i> Thonn.	Boraginaceae	Tree	Cheabugtsi	AB020
<i>Ehrharta erecta</i> Lam. var. <i>abyssinica</i> (Hochst.) Pilg.	Poaceae	Herb	Santili	AB103
<i>Ekebergia capensis</i> Sparrm.	Meliaceae	Tree	Churi	AB053
<i>Eleusine indica</i> (L.) Gaertn.	Poaceae	Herb	-	AB059
<i>Embelia schimperi</i> Vatke	Myrsinaceae	Liana	-	AB055
<i>Englerina woodfordioides</i> (Schweinf.) M. Gilbert	Loranthaceae	Shrub	-	AB169
<i>Ensete ventricosum</i> (Welw.) Cheesman	Musaceae	Herb	Emperperi	AB072
<i>Erythrina brucei</i> Schweinf.	Fabaceae	Tree	-	-
<i>Erythrococca trichogyne</i> (Muell Arg.) Prain	Euphorbiaceae	Shrub	Shamli	AB173
<i>Eugenia bukobensis</i> Engl.	Myrtaceae	Shrub	Girni	AB182
<i>Euphorbia abyssinica</i> Gmel.	Euphorbiaceae	Tree	Kulkuli	-
<i>Euphorbia ampliphylla</i> Pax	Euphorbiaceae	Tree	Kulkuli	-
<i>Euphorbia schimperiana</i> Scheele	Euphorbiaceae	Herb	Enquach	AB062
<i>Ficus sur</i> Forssk.	Moraceae	Tree	Umi	AB041
<i>Ficus thonningii</i> Blume	Moraceae	Tree	Tsiwawi	AB079
<i>Flacourtia indica</i> (Burm. f.) Merr.	Flacourtiaceae	Shrub	Gerkadumi	AB090
<i>Galiniera saxifraga</i> (Hochst. Bridson	Rubiaceae	Shrub	-	AB024
<i>Galinsoga parviflora</i> Cav.	Asteraceae	Herb	-	AB037
<i>Girardinia bulbosa</i> (Stedudel) Wedd.	Urticaceae	Herb	Ababira	AB036
<i>Gongronema angolense</i> (N.E. Br.) Bullock	Asclepiadaceae	Liana	-	AB113
<i>Gouania longispicata</i> Engl.	Rhamnaceae	Liana	Maya Areg	AB048
<i>Grewia ferruginea</i> Hochst. ex A. Rich.	Tiliaceae	Shrub	Tsankuy	AB161
<i>Guizotia abyssinica</i> (L. f) Cass.	Asteraceae	Herb	-	AB002
<i>Habenaria macrantha</i> A. Rich.	Orchidaceae	Herb	-	AB094
<i>Hagenia abyssinica</i> (Brace) J. F. Gmel.	Rosaceae	Tree	Kosho	-
<i>Hibiscus macranthus</i> Hochst. ex A. Rich.	Malvaceae	Shrub	-	AB003
<i>Hippocratea africana</i> (Willd.) Loes.	Celastraceae	Liana	-	AB111
<i>Hippocratea goetzei</i> Loes.	Celastraceae	Liana	Gashini	AB017
<i>Hippocratea pallens</i> Planch ex Oliver	Celastraceae	Liana	Ankmahari	AB119
<i>Hyperzia dacrydioides</i> (Baker) Pic. Serm.	Lycopodiaceae	Herb	-	AB131
<i>Hygrophila schulli</i> (Hamilt.) M.R. & S.M. Almeida	Acanthaceae	Herb	-	AB091
<i>Hypericum revolutum</i> Vahl.	Guttiferae	Shrub	-	AB071
<i>Hypoestes triflora</i> (Forssk.) Roem & Shult.	Acanthaceae	Herb	-	AB080
<i>Impatiens ethiopica</i> Grey-Wilson	Balsaminaceae	Herb	-	AB168

Species	Family	Habit	Agaw Name	Collection No.
<i>Jasminum abyssinicum</i> Hochst. ex DC.	Oleaceae	Liana	Awiri	AB095
<i>Juniperus procera</i> Hochst. ex Endl.	Cupressaceae	Tree	Tsidi	AB043
<i>Justicia diclipteroides</i> Lindau	Acanthaceae	Herb	-	AB031
<i>Justicia ladanoides</i> Lam.	Acanthaceae	Herb	-	AB181
<i>Justicia schimperiana</i> (Hochst. Ex Nees) T. Anders	Acanthaceae	Shrub	Lili	-
<i>Justicia</i> sp.	Acanthaceae	Herb	-	AB112
<i>Kalanchoe citrina</i> Schweinf.	Crassulaceae	Herb	-	AB073
<i>Kalanchoe densiflora</i> Rolfe var. <i>subpilosa</i> Cufod.	Crassulaceae	Herb	-	AB185
<i>Laggera braunii</i> Vatke	Asteraceae	Herb	Liflif	AB152
<i>Landolphia buchananii</i> (Hall.f.) Stapf	Apocynaceae	Liana	Kefiy	AB018
<i>Lepidotrichia volkensii</i> (Gurke) Leroy	Meliaceae	Tree	Kiwan abali	AB114
<i>Lepisorus schraderi</i> (Mett.) Ching.	Polypodiaceae	Herb	-	AB099
<i>Leucas deflexa</i> Hook. f.	Lamiaceae	Herb	-	AB133
<i>Lippia adoensis</i> Hochst. ex Walp. var. <i>adoensis</i>	Verbenaceae	Shrub	-	AB143
<i>Lobelia giberroa</i> Hemsl.	Lobeliaceae	Shrub	Bambili	-
<i>Maesa lanceolata</i> Forssk.	Myrsinaceae	Shrub	Kimbi	AB109
<i>Malva verticillata</i> L.	Malvaceae	Herb	-	AB023
<i>Maytenus addat</i> (Loes.) Sebsebe	Celastraceae	Shrub	Antuy	AB027
<i>Maytenus arbutifolia</i> (A. Rich.) Wilczek	Celastraceae	Shrub	Antuy	AB008
<i>Maytenus obscura</i> (A. Rich.) Cuf.	Celastraceae	Tree	Duli	-
<i>Maytenus undata</i> (Thunb.) Blakelock	Celastraceae	Shrub	Gisegna duri	AB054
<i>Melanthera scandens</i> (Schumach. & Thonn.) Roberty subsp. <i>madagascariensis</i> (Bak.) Wild	Asteraceae	Herb	-	AB205
<i>Microglossa pyrifolia</i> (Lam.) Kuntze	Asteraceae	Shrub	-	AB088
<i>Millettia ferruginea</i> (Hochst.) Bak.	Fabaceae	Tree	Cheyekoi	AB013
<i>Mimusops kummel</i> A. DC.	Sapotaceae	Tree	Enkoy	AB125
<i>Momordica foetida</i> Schumach.	Cucurbitaceae	Herb	-	AB065
<i>Nuxia congesta</i> R. Br. ex Fresen.	Loganiaceae	Shrub	Masha ashkori	AB085
<i>Ocimum lamiifolium</i> Hochst. Ex Benth.	Lamiaceae	Shrub	-	AB078
<i>Olea capensis</i> L. subsp. <i>Macrocarpa</i> (C.A. Wright) Verdc.	Oleaceae	Tree	Wiri	AB009
<i>Oncinotis tenuiloba</i> Stapf.	Apocynaceae	Herb	-	AB176
<i>Oplismenus hirtellus</i> (L.) P. Beauv.	Poaceae	Herb	Sherfi	AB184
<i>Orobanche minor</i> Smit	Orobanchaceae	Herb	-	AB074
<i>Otostegia tomentosa</i> A. Rich. subsp. <i>tomentosa</i>	Lamiaceae	Shrub	-	AB129
<i>Oxyanthus speciosus</i> DC. subsp. <i>Stenocarpus</i> (K. Schum.) Bridson	Rubiaceae	Shrub	-	AB081
<i>Paveta abyssinica</i> Fresen. var. <i>abyssinica</i>	Rubiaceae	Shrub	Eshagimbi	AB130
<i>Peperomia tetraphylla</i> (Forster) Hook. & Arn.	Piperaceae	Herb	-	AB124
<i>Peponium</i> sp.	Cucurbitaceae	Herb	-	AB056
<i>Periploca linearifolia</i> Quart. -Dill. & A. Rich.	Asclepiadaceae	Liana	-	AB126

Species	Family	Habit	Agaw Name	Collection No.
<i>Phaulopsis imbricata</i> (Forssk.) Sweet	Acanthaceae	herb	Zimbila	AB060
<i>Phyllanthus limmuensis</i> Cufod.	Euphorbiaceae	Shrub	-	AB120
<i>Phyllanthus ovalifolius</i> Forssk.	Euphorbiaceae	Liana	-	AB131
<i>Phyllanthus rotundifolius</i> Willd.	Euphorbiaceae	Herb	-	AB159
<i>Phytolacca dodecandra</i> L 'Herit.	Phytolaccaceae	Liana	Sibiti	AB146
<i>Pittosporum viridiflorum</i> Sims	Pittosporaceae	Tree	Kanitkuana	AB097
<i>Plectranthus punctatus</i> (L.f.) L 'Her.	Lamiaceae	Herb	-	AB206
<i>Polyscias fulva</i> (Hiern) Harms	Araliaceae	Tree	-	AB136
<i>Polystachya caduca</i> Rehb.f.	Orchidaceae	Herb	-	AB106
<i>Polystachya cultriformis</i> (Thouars) Spreng.	Orchidaceae	Herb	-	AB096
<i>Protea gagedi</i> J. F. Gmel.	Proteaceae	Shrub	-	AB118
<i>Prunus africana</i> (Hook. f.) Kalkm.	Rosaceae	Tree	Demsi	AB128
<i>Pteris catoptera</i> Kunze var. <i>catoptera</i> Schelpe	Pteridaceae	Herb	-	AB101
<i>Pterolobium stellatum</i> (Forssk.) Brenan	Fabaceae	Liana	-	AB068
<i>Pycnostachys meyeri</i> Gurke	Lamiaceae	Herb	-	AB153
<i>Rhus glutinosa</i> A. Rich. subsp. <i>glutinosa</i>	Anacardiaceae	Shrub	Kumini	AB083
<i>Rhus natalensis</i> Krauss	Anacardiaceae	Shrub	Kumini	AB144
<i>Ricinus communis</i> L.	Euphorbiaceae	Shrub	-	AB069
<i>Ritchiea albersii</i> Gilg	Capparidaceae	Tree	Enkoy	AB045
<i>Rosa abyssinica</i> Lindley	Rosaceae	Shrub	Gimsi	-
<i>Rothmannia urcelliformis</i> (Hiern) Robyns	Rubiaceae	Shrub	Chemneknekey	AB038
<i>Rubus apetalus</i> Poir.	Rosaceae	Shrub	-	AB188
<i>Rumex abyssinicus</i> Jacq.	Polygonaceae	Herb	-	AB021
<i>Rumex nepalensis</i> Spreng.	Polygonaceae	Herb	-	-
<i>Rumex nervosus</i> Vahl	Polygonaceae	Shrub	-	AB050
<i>Rytigynia neglecta</i> (Hiern) Robyns	Rubiaceae	Shrub	Jakuti	AB110
<i>Salix subserrata</i> Willd.	Salicaceae	Tree	-	-
<i>Sanicula elata</i> Buch. -Ham. ex D. Don	Apiaceae	Herb	-	AB170
<i>Sapium ellipticum</i> (Krauss) Pax	Euphorbiaceae	Tree	-	-
<i>Satureja abyssinica</i> Benth. Briq. subsp. <i>abyssinica</i>	Lamiaceae	shrub	-	AB177
<i>Sauromatum venosum</i> (Ait.) Kunth	Araceae	Herb	Muriqa	AB149
<i>Schefflera abyssinica</i> (Hochst. ex A. Rich.) Harms	Araliaceae	Tree	Pinpini	-
<i>Selaginella caffrorum</i> (Milde) Hieron.	Selaginellaceae	Herb	-	AB200
<i>Selaginella goudotiana</i> Spring	Selaginellaceae	Herb	-	AB105
<i>Senna septemtrionalis</i> (Viv.) Irwin & Barneby	Fabaceae	Shrub	-	AB165
<i>Sericostachys scandens</i> Gilg & Lopr.	Amaranthaceae	Liana	-	AB147
<i>Sida rhombifolia</i> L.	Malvaceae	Shrub	-	AB127
<i>Sida ternata</i> L. f.	Malvaceae	Herb	-	AB179
<i>Sida urens</i> L.	Malvaceae	Herb	-	AB067

Species	Family	Habit	Agaw Name	Collection No.
<i>Solanecio gigas</i> (Vatke) C. Jeffrey	Asteraceae	Shrub	Bambili	-
<i>Solanum anguivi</i> Lam.	Solanaceae	Shrub	-	AB117
<i>Solanum giganteum</i> Jasq	Solanaceae	Shrub	-	-
<i>Solanum sinaicum</i> Boiss	Solanaceae	Herb	-	AB032
Sp. 137a (unidentified)	Asteraceae	Herb	-	AB209
Sp. 153a (unidentified)	Lamiaceae	Herb	-	AB2010
<i>Steganotaenia araliacea</i> Hochst. ex A. Rich.	Apiaceae	Shrub	Kanidemsa	AB056
<i>Stephania abyssinica</i> (Dillon & A. Rich.) Walp.	Menispermaceae	Herb	-	AB156
<i>Stereospermum kunthianum</i> Cham.	Bignoniaceae	Tree	Zana	AB089
<i>Swertia abyssinica</i> Hochst.	Gentianaceae	Herb	-	AB203
<i>Syzygium guineense</i> (Willd.) DC. subsp. <i>guineense</i>	Myrtaceae	Tree	Bahusti	AB138
<i>Tacazzea conferta</i> N.E. Br.	Asclepiadaceae	Liana	-	AB166
<i>Tagetes minuta</i> L.	Asteraceae	Herb	-	AB029
<i>Teclea nobilis</i> Del.	Rutaceae	Shrub	Sini	AB123
<i>Thalictrum rhynchocarpum</i> Dill. & A. Rich.	Ranunculaceae	Herb	Tehla	AB025
<i>Tiliacora troupinii</i> Cufod.	Menispermaceae	Liana	Efkuli	AB047
<i>Trifolium</i> sp.	Fabaceae	Herb	-	-
<i>Triumfetta annua</i> L.	Tiliaceae	Herb	-	AB160
<i>Urera hypselodendron</i> (A. Rich.) Wedd.	Urticaceae	Liana	Dungdungi	-
<i>Urtica simensis</i> Steudel	Urticaceae	Herb	Ababira	-
<i>Uvaria angolensis</i> Oliv.	Annonaceae	Liana	-	AB164
<i>Vepris dainellii</i> (Pich. Serm.) Kokwaro	Rutaceae	Shrub	Gimbiltini	-
<i>Vernonia amygdalina</i> Del.	Asteraceae	Shrub	Kukitsi	-
<i>Vernonia auriculifera</i> Hiern.	Asteraceae	Shrub	-	AB082
<i>Vernonia leopoldi</i> (Sch. Bip. ex Walp.) Vatke	Asteraceae	Shrub	-	AB156
<i>Vernonia myriantha</i> Hook.f.	Asteraceae	Shrub	-	AB107

Appendix 2. Floristic richness and Shannon diversity and evenness indices of plots in the study area. Plot codes: Bradi, 1-31 & 56; Degera, 32-55; Askunabo, 57-94 & 153-156; Kidamaja, 95-113; Ambiqi, 114-130; Khatasa, 132-152.

Plot	Total Richness	Woody taxa Richness	Herbaceous taxa Richness	Diversity (H)	Evenness (J)
1	26	18	8	2.60	0.90
2	32	15	17	2.46	0.91
3	27	20	7	2.54	0.85
4	18	12	6	2.05	0.82
5	16	10	6	1.67	0.73
6	21	16	5	2.42	0.87
7	27	22	5	2.87	0.93
8	29	19	10	2.39	0.81
9	32	19	13	2.38	0.81
10	26	12	14	2.20	0.89
11	24	14	10	2.27	0.86
12	27	12	15	2.02	0.81
13	35	17	18	1.90	0.67
14	33	18	15	2.34	0.81
15	22	16	6	1.97	0.71
16	22	11	11	1.85	0.77
17	19	12	7	2.22	0.89
18	29	17	12	2.51	0.89
19	14	11	3	1.81	0.75
20	19	15	4	2.20	0.81
21	26	21	5	2.54	0.84
22	26	23	3	2.56	0.82
23	17	11	6	2.09	0.87
24	18	15	3	2.21	0.82
25	21	17	4	2.40	0.85
26	20	14	6	2.04	0.77
27	19	16	3	2.25	0.81
28	15	14	1	2.17	0.82
29	14	11	3	1.94	0.81
30	20	17	3	2.29	0.81
31	22	19	3	2.63	0.89
32	32	23	9	2.73	0.87
33	23	19	4	2.38	0.81
34	19	17	2	1.98	0.70
35	21	17	4	2.40	0.85

Plot	Total Richness	Woody taxa Richness	Herbaceous taxa Richness	Diversity (H)	Evenness (J)
36	33	25	8	2.59	0.80
37	22	18	4	2.43	0.84
38	19	15	4	2.17	0.80
39	15	13	2	2.27	0.89
40	14	12	2	2.21	0.89
41	25	22	3	2.40	0.78
42	14	11	3	1.81	0.75
43	18	17	1	2.56	0.90
44	29	24	5	2.82	0.89
45	23	14	9	2.01	0.76
46	22	18	4	2.00	0.69
47	21	19	2	2.25	0.76
48	22	17	5	2.03	0.72
49	26	23	3	2.60	0.83
50	22	19	3	2.39	0.81
51	24	19	5	2.26	0.77
52	16	13	3	2.10	0.82
53	24	21	3	2.41	0.79
54	19	17	2	2.26	0.80
55	20	15	5	2.00	0.74
56	20	17	3	2.16	0.76
57	18	15	3	2.02	0.75
58	17	13	4	2.12	0.83
59	18	16	2	1.97	0.71
60	12	9	3	1.17	0.53
61	21	17	4	2.25	0.79
62	15	13	2	1.81	0.70
63	16	13	3	2.07	0.81
64	17	14	3	2.07	0.78
65	20	16	4	1.54	0.56
66	23	21	2	2.45	0.81
67	16	15	1	2.25	0.83
68	17	12	5	2.07	0.83
69	17	16	1	2.03	0.73
70	18	16	2	2.07	0.75
71	22	17	5	2.19	0.77
72	17	12	5	1.93	0.78
73	24	16	8	2.28	0.82
74	27	20	7	2.46	0.82

Plot	Total Richness	Woody taxa Richness	Herbaceous taxa Richness	Diversity (H)	Evenness (J)
75	17	13	4	2.26	0.88
76	18	12	6	1.91	0.77
77	21	17	4	2.47	0.87
78	19	15	4	2.27	0.84
79	15	11	4	1.95	0.81
80	13	9	4	1.97	0.90
81	16	11	5	1.61	0.67
82	12	9	3	1.41	0.64
83	17	14	3	1.93	0.73
84	22	17	5	2.03	0.72
85	17	13	4	2.10	0.82
86	24	18	6	2.34	0.81
87	19	14	5	2.17	0.82
88	16	11	5	1.91	0.80
89	16	12	4	1.82	0.73
90	16	12	4	1.67	0.67
91	20	17	3	2.08	0.73
92	20	12	8	1.93	0.78
93	16	12	4	1.68	0.68
94	26	15	11	2.13	0.78
95	23	19	4	2.53	0.86
96	22	21	1	2.61	0.86
97	21	19	2	2.47	0.84
98	19	12	7	1.79	0.72
99	21	16	5	2.50	0.90
100	25	21	4	2.47	0.81
101	19	16	3	2.24	0.81
102	23	19	4	2.49	0.84
103	17	14	3	2.14	0.81
104	19	17	2	2.38	0.84
105	21	17	4	2.48	0.88
106	23	19	4	1.79	0.61
107	21	17	4	2.44	0.86
108	21	18	3	2.60	0.90
109	22	19	3	2.29	0.78
110	19	16	3	2.40	0.86
112	23	15	8	2.14	0.79
113	23	14	9	1.72	0.65
115	29	18	11	1.80	0.62

Plot	Total Richness	Woody taxa Richness	Herbaceous taxa Richness	Diversity (H)	Evenness (J)
116	19	9	10	1.26	0.58
117	22	11	11	1.99	0.83
118	25	18	7	2.41	0.84
119	24	18	6	2.16	0.75
120	12	8	4	1.39	0.67
121	24	19	5	2.40	0.81
122	21	19	2	2.53	0.86
123	25	19	6	2.38	0.81
124	20	13	7	2.11	0.82
125	28	17	11	2.24	0.79
126	18	9	9	1.65	0.75
127	15	10	5	1.64	0.71
128	23	14	9	2.08	0.79
129	25	17	8	1.93	0.68
130	22	14	8	2.01	0.76
131	20	16	4	2.22	0.80
132	23	20	3	2.45	0.82
133	17	15	2	2.42	0.90
134	16	10	6	1.62	0.70
135	19	15	4	2.17	0.80
136	24	12	12	2.16	0.87
137	38	22	16	2.64	0.86
138	31	19	12	2.59	0.88
139	23	18	5	2.40	0.83
140	27	16	11	2.22	0.80
141	26	16	10	2.37	0.86
142	16	9	7	1.72	0.78
143	22	13	9	2.22	0.87
144	23	14	9	1.63	0.62
145	35	19	16	2.26	0.77
146	23	10	13	2.06	0.89
147	19	10	9	1.98	0.86
148	24	15	9	2.17	0.80
149	22	11	11	1.50	0.63
150	22	10	12	1.76	0.76
151	23	7	16	1.06	0.54
152	34	20	14	2.16	0.72
153	17	6	11	1.51	0.84
154	18	5	13	1.33	0.82

Plot	Total Richness	Woody taxa Richness	Herbaceous taxa Richness	Diversity (H)	Evenness (J)
155	24	11	13	1.80	0.75
156	24	10	14	1.67	0.72
Total	212	122	90	3.71	0.80

Appendix 3. Endemic species, their IUCN status and geographical distributions. LC, Least Concern; NT, Near Threatened; VU, Vulnerable.

Species	Family	Habit	IUCN Status	Altitude (m)*	Floristic Region*
<i>Acanthus sennii</i>	Acanthaceae	Shrub	NT	1700-3200	GD GJ WU SU AR WG KF GG SD BA HA
<i>Bothriocline schimperi</i>	Asteraceae	Shrub	LC	1300-2820	GD GJ SU AR WG IL KF GG SD BA
<i>Brillantaisia grotanellii</i>	Acanthaceae	Herb	VU	1000-2400	GD GJ WG IL KF GG SD
<i>Carum piovanii</i> * ¹	Apiaceae	Herb	LC	2000-2800	WU SU
<i>Clematis longicauda</i>	Ranunculaceae	Liana	LC	1350-3300	GD GJ SU WG KF IL SD
<i>Crotalaria rosenii</i> * ¹	Fabaceae	Shrub	NT	1350-2800	SU AR BA KF SD
<i>Echinops kebericho</i>	Asteraceae	Herb	VU	2300-2600	TU GJ SU
<i>Erythrina brucei</i>	Fabaceae	Tree	LC	1400-2600	WU WG GJ SU BA HA IL KF GD GG SD
<i>Guizotia abyssinica</i>	Asteraceae	Herb	LC	1500-2400	EW TU GD GJ WU SU AR WG KF GG SD BA HA
<i>Justicia diclipteroides</i> subsp. <i>aethiopica</i> * ¹	Acanthaceae	Herb	NT	1200-2300	SU IL WG AR KF GG SD
<i>Kalanchoe densiflora</i> var. <i>subpilosa</i> * ¹	Crassulaceae	Herb	LC	1300-2550	GD SU IL
<i>Lippia adoensis</i> var. <i>adoensis</i>	Verbenaceae	Shrub	LC	1600-3000	EE TU GD GJ WU SU AR WG KF GG SD HA
<i>Maytenus addat</i> * ¹	Celastraceae	Shrub	NT	2200-3000	SU AR SD GG
<i>Millettia ferruginea</i>	Fabaceae	Tree	LC	1000-2500	TU GD GJ SU WG HA IL
<i>Otostegia tomentosa</i> subsp. <i>tomentosa</i> * ¹	Lamiaceae	Shrub	VU	2000-3000	EW TU
<i>Phyllanthus limmuensis</i>	Euphorbiaceae	Shrub	VU	1050-2200	GD GJ WG IL KF
<i>Polystachya caduca</i> * ¹	Orchidaceae	Herb	LC	2400-2600	GD SU AR WG KF SD BA
<i>Rhus glutinosa</i> subsp. <i>glutinosa</i>	Anacardiaceae	Shrub	VU	1800-3300	EW TU GD GJ
<i>Solanecio gigas</i>	Asteraceae	Shrub	LC	1750--3350	GD GJ WU SU AR SD IL KF BA HA
<i>Tiliacora troupinii</i> * ¹	Menispermaceae	Liana	VU	1500-2100	SU IL KF SD
<i>Urtica simensis</i>	Urticaceae	Herb	LC	1500-3400	TU GD GJ SU AR BA SD
<i>Vepris dainellii</i>	Rutaceae	Tree	LC	1750-2500	GJ SU WG IL KF SD BA
<i>Vernonia leopoldi</i>	Asteraceae	Shrub	LC	1850-2850	TU GD GJ WU SU WG KF HA GG

* Source: Flora of Ethiopia and Eritrea Volumes (1-7); *¹ New records for GJ Floristic Region

Appendix 4. Structure (frequency, abundance, density, basal area, dominance and importance value index) of woody species in the study area (pooled data from the six forest patches)

Species	Frequency	Relative Frequency	Abundance	Density (ha ⁻¹)	Relative Density	Basal Area (m ² ha ⁻¹)	Dominance	Relative Dominance	IVI
<i>Acacia abyssinica</i>	4.55	0.3	67	10.88	0.5	0.55	0.48	2.07	2.86
<i>Acacia lahai</i>	1.3	0.08	6	0.97	0.04	0	0	0.01	0.14
<i>Acanthus pubescens</i>	3.9	0.25	11	1.79	0.08	0	0	0.01	0.34
<i>Albizia gummifera</i>	50	3.26	635	103.08	4.74	4.55	1.92	8.35	16.35
<i>Albizia schimperiana</i>	56.49	3.69	399	64.77	2.98	5.49	2.1	9.1	15.76
<i>Allophylus abyssinicus</i>	27.27	1.78	85	13.8	0.63	0.98	0.67	2.89	5.31
<i>Apodytes dimidiata</i>	35.06	2.29	155	25.16	1.16	3.08	2.05	8.89	12.34
<i>Bersama abyssinica</i>	53.9	3.52	575	93.34	4.29	0.39	0.25	1.07	8.89
<i>Brucea antidysentrica</i>	16.88	1.1	52	8.44	0.39	0.02	0.02	0.07	1.56
<i>Buddleja polystachya</i>	10.39	0.68	62	10.06	0.46	0.12	0.08	0.34	1.48
<i>Cissus petiolata</i>	3.25	0.21	5	0.81	0.04	0	0	0	0.25
<i>Calpurnia aurea</i>	6.49	0.42	153	24.84	1.14	0.07	0.04	0.18	1.75
<i>Canthium oligocarpum</i> <i>subsp. oligocarpum</i>	10.39	0.68	169	27.44	1.26	0.38	0.27	1.19	3.13
<i>Capparis tomentosa</i>	7.14	0.47	17	2.76	0.13	0.01	0	0.02	0.61
<i>Carissa spinarum</i>	8.44	0.55	378	61.36	2.82	0.34	0.13	0.55	3.92
<i>Cassipourea malosana</i>	16.88	1.1	58	9.42	0.43	0.03	0.02	0.08	1.62
<i>Celtis africana</i>	18.83	1.23	128	20.78	0.96	1.35	0.87	3.77	5.95
<i>Clausena anisata</i>	12.99	0.85	99	16.07	0.74	0.04	0.03	0.11	1.7
<i>Clematis longicauda</i>	3.9	0.25	11	1.79	0.08	0	0	0.01	0.34
<i>Clutia abyssinica</i>	1.95	0.13	4	0.65	0.03	0	0	0	0.16

Species	Frequency	Relative Frequency	Abundance	Density (ha ⁻¹)	Relative Density	Basal Area (m ² ha ⁻¹)	Dominance	Relative Dominance	IVI
<i>Combretum aculeatum</i>	5.19	0.34	18	2.92	0.13	0.01	0.01	0.03	0.5
<i>Combretum paniculatum</i>	40.91	2.67	204	33.12	1.52	0.06	0.05	0.2	4.39
<i>Cordia africana</i>	13.64	0.89	47	7.63	0.35	0.13	0.08	0.34	1.59
<i>Croton macrostachyus</i>	68.18	4.45	616	100	4.6	2.5	1.48	6.4	15.45
<i>Dalbergia lactea</i>	9.09	0.59	32	5.19	0.24	0.01	0.01	0.03	0.86
<i>Deinbollia kilimandscharica</i>	25.97	1.7	721	117.05	5.38	1.01	0.72	3.11	10.18
<i>Discopodium penninervium</i>	14.29	0.93	277	44.97	2.07	0.22	0.1	0.43	3.43
<i>Dombeya quinqueseta</i>	0.65	0.04	1	0.16	0.01	0.01	0.01	0.02	0.07
<i>Dombeya rotundifolia</i>	16.88	1.1	48	7.79	0.36	0.12	0.07	0.3	1.76
<i>Dovyalis abyssinica</i>	0.65	0.04	3	0.49	0.02	0.01	0	0.01	0.07
<i>Dovyalis verrucosa</i>	4.55	0.3	19	3.08	0.14	0.02	0.01	0.05	0.49
<i>Dracaena steudneri</i>	12.34	0.81	60	9.74	0.45	0.82	0.57	2.46	3.71
<i>Ehretia cymosa</i>	29.22	1.91	331	53.73	2.47	0.75	0.47	2.03	6.4
<i>Ekebergia capensis</i>	6.49	0.42	18	2.92	0.13	2.84	1.44	6.24	6.8
<i>Embelia schimperi</i>	7.14	0.47	51	8.28	0.38	0.01	0.01	0.03	0.88
<i>Erythrococca trichogyne</i>	53.9	3.52	337	54.71	2.52	0.16	0.12	0.51	6.55
<i>Eugenia bukobensis</i>	2.6	0.17	6	0.97	0.04	0.01	0	0.02	0.23
<i>Euphorbia abyssinica</i>	1.3	0.08	22	3.57	0.16	0.15	0.1	0.43	0.68
<i>Euphorbia ampliphylla</i>	5.84	0.38	25	4.06	0.19	0.17	0.09	0.4	0.97
<i>Ficus sur</i>	12.99	0.85	71	11.53	0.53	1.01	0.65	2.82	4.2
<i>Ficus thonningii</i>	6.49	0.42	29	4.71	0.22	0.18	0.11	0.47	1.11
<i>Flacourtia indica</i>	8.44	0.55	22	3.57	0.16	0.03	0.16	0.69	1.4
<i>Galiniera saxifraga</i>	0.65	0.04	3	0.49	0.02	0	0	0	0.07

Species	Frequency	Relative Frequency	Abundance	Density (ha ⁻¹)	Relative Density	Basal Area (m ² ha ⁻¹)	Dominance	Relative Dominance	IVI
<i>Grewia ferruginea</i>	9.09	0.59	42	6.82	0.31	0.05	0.02	0.09	1
<i>Gouania longispicata</i>	5.84	0.38	14	2.27	0.1	0	0	0.02	0.51
<i>Hypericum revolutum</i>	1.3	0.08	5	0.81	0.04	0	0	0.01	0.13
<i>Hippocratea goetzei</i>	29.22	1.91	145	23.54	1.08	0.05	0.04	0.18	3.17
<i>Hippocratea pallens</i>	24.03	1.57	121	19.64	0.9	0.07	0.05	0.21	2.68
<i>Jasminum abyssinicum</i>	3.9	0.25	10	1.62	0.07	0	0	0.01	0.34
<i>Juniperus procera</i>	1.95	0.13	5	0.81	0.04	0.56	0.56	2.42	2.59
<i>Justicia schimperiana</i>	23.38	1.53	241	39.12	1.8	0.06	0.03	0.13	3.45
<i>Landolphia buchananii</i>	50	3.26	280	45.45	2.09	0.11	0.09	0.39	5.74
<i>Lepidotrichilia volkensii</i>	29.22	1.91	228	37.01	1.7	0.26	0.21	0.93	4.54
<i>Lobelia giberola</i>	1.3	0.08	5	0.81	0.04	0	0	0	0.13
<i>Maesa lanceolata</i>	9.09	0.59	256	41.56	1.91	0.43	0.16	0.69	3.2
<i>Malva verticillata</i>	0.65	0.04	1	0.16	0.01	0	0	0	0.05
<i>Maytenus arbutifolia</i>	53.9	3.52	546	88.64	4.08	0.11	0.08	0.35	7.94
<i>Maytenus obscura</i>	11.69	0.76	159	25.81	1.19	0.27	0.01	0.03	1.98
<i>Maytenus undata</i>	6.49	0.42	22	3.57	0.16	0.01	0.01	0.04	0.62
<i>Millettia ferruginea</i>	25.97	1.7	355	57.63	2.65	0.64	0.47	2.03	6.38
<i>Mimusops kummel</i>	14.29	0.93	95	15.42	0.71	0.27	0.13	0.57	2.21
<i>Nuxia congesta</i>	6.49	0.42	68	11.04	0.51	0.39	0.2	0.88	1.81
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	14.29	0.93	55	8.93	0.41	0.16	0.08	0.35	1.69
<i>Otostegia tomentosa</i> subsp. <i>tomentosa</i>	2.6	0.17	15	2.44	0.11	0	0	0.02	0.3
<i>Oxyanthus speciosus</i> subsp.	0.65	0.04	28	4.55	0.21	0.01	0.01	0.04	0.29

Species	Frequency	Relative Frequency	Abundance	Density (ha ⁻¹)	Relative Density	Basal Area (m ² ha ⁻¹)	Dominance	Relative Dominance	IVI
<i>stenocarpus</i>									
<i>Paveta abyssinica</i> var. <i>abyssinica</i>	27.92	1.82	165	26.79	1.23	0.17	0.12	0.52	3.57
<i>Phyllanthus limmuensis</i>	0.65	0.04	1	0.16	0.01	0	0	0	0.05
<i>Phyllanthus ovalifolius</i>	3.9	0.25	17	2.76	0.13	0	0	0.01	0.4
<i>Phytolacca dodecandra</i>	16.23	1.06	58	9.42	0.43	0.03	0.02	0.1	1.59
<i>Pittosporum viridiflorum</i>	14.29	0.93	37	6	0.27	0.05	0.04	0.15	1.36
<i>Polyscias fulva</i>	1.3	0.08	2	0.32	0.01	0.03	0.03	0.13	0.23
<i>Protea gaguedi</i>	0.65	0.04	9	1.46	0.07	0	0	0.01	0.12
<i>Prunus africana</i>	44.81	2.92	385	62.5	2.87	5.2	2.27	9.84	15.64
<i>Pterolobium stellatum</i>	10.39	0.68	28	4.55	0.21	0.01	0.01	0.03	0.92
<i>Rhus glutinosa</i> subsp. <i>glutinosa</i>	5.84	0.38	26	4.22	0.19	0.03	0.01	0.05	0.62
<i>Ricinus communis</i>	1.3	0.08	2	0.32	0.01	0	0	0	0.1
<i>Ritchiea albersii</i>	18.18	1.19	69	11.2	0.52	0.1	0.07	0.31	2.01
<i>Rosa abyssinica</i>	5.19	0.34	23	3.73	0.17	0.02	0.01	0.04	0.55
<i>Rothmannia urcelliformis</i>	48.7	3.18	880	142.86	6.57	1.01	0.79	3.4	13.15
<i>Rubus apetalus</i>	0.65	0.04	1	0.16	0.01	0	0	0	0.05
<i>Rytigynia neglecta</i>	83.77	5.47	1341	217.69	10.01	0.5	0.3	1.3	16.78
<i>Salix subserrata</i>	0.65	0.04	5	0.81	0.04	0.01	0	0.02	0.1
<i>Schefflera abyssinica</i>	1.95	0.13	4	0.65	0.03	0.95	0.74	3.22	3.38
<i>Senna septemtrionalis</i>	0.65	0.04	2	0.32	0.01	0	0	0	0.06
<i>Solanecio gigas</i>	22.73	1.48	184	29.87	1.37	0.08	0.03	0.13	2.99
<i>Solanum giganteum</i>	10.39	0.67	45	7.3	0.33	0.01	0.01	0.04	1.06

Species	Frequency	Relative Frequency	Abundance	Density (ha ⁻¹)	Relative Density	Basal Area (m ² ha ⁻¹)	Dominance	Relative Dominance	IVI
<i>Steganotaenia araliacea</i>	0.65	0.04	4	0.65	0.03	0	0	0.01	0.08
<i>Stereospermum kunthianum</i>	1.95	0.13	11	1.79	0.08	0.06	0.04	0.19	0.4
<i>Syzygium guinense</i> subsp. <i>guineense</i>	3.9	0.25	13	2.11	0.1	0.13	0.06	0.25	0.6
<i>Teclea nobilis</i>	22.73	1.48	260	42.21	1.94	0.19	0.15	0.63	4.06
<i>Tiliacora troupinii</i>	5.19	0.34	13	2.11	0.1	0	0	0.01	0.45
<i>Cayratia ibuensis</i>	4.55	0.3	9	1.46	0.07	0	0	0.01	0.37
<i>Urera hypselodendron</i>	48.7	3.18	239	38.8	1.78	0.17	0.12	0.51	5.48
<i>Uvaria angolensis</i>	0.65	0.04	1	0.16	0.01	0	0	0	0.05
<i>Vepris dainellii</i>	61.04	3.98	556	90.26	4.15	1.16	0.82	3.54	11.67
<i>Vernonia amygdalina</i>	10.39	0.68	44	7.14	0.33	0.05	0.05	0.2	1.21
<i>Vernonia auriculifera</i>	26.62	1.74	224	36.36	1.67	0.06	0.04	0.19	3.6
<i>Vernonia myriantha</i>	2.6	0.17	10	1.62	0.07	0.01	0.01	0.03	0.28
Total	-	-	13380	2172.1	-	41.2	23.1	-	302.1

Appendix 5. Seedling density of woody species in the study area (pooled data from the six forest patches).

Species	Abundance	Density (ha ⁻¹)
<i>Acacia abyssinica</i>	13	2.1
<i>Acacia lahai</i>	18	2.9
<i>Acanthus pubescens</i>	38	6.2
<i>Albizia gummifera</i>	841	136.5
<i>Albizia schimperiana</i>	421	68.3
<i>Allophylus abyssinicus</i>	8	1.3
<i>Apodytes dimidiata</i>	48	7.8
<i>Bersama abyssinica</i>	115	18.7
<i>Brucea antidysenterica</i>	16	2.6
<i>Buddleja polystachya</i>	3	0.5
<i>Calpurnia aurea</i>	40	6.5
<i>Canthium oligocarpum</i> subsp. <i>oligocarpum</i>	12	1.9
<i>Capparis tomentosa</i>	83	13.5
<i>Carissa spinarum</i>	45	7.3
<i>Cassipourea malosana</i>	19	3.1
<i>Celtis africana</i>	75	12.2
<i>Clausena anisata</i>	156	25.3
<i>Clematis longicauda</i>	15	2.4
<i>Clutia abyssinica</i>	11	1.8
<i>Combretum aculeatum</i>	1	0.2
<i>Combretum paniculatum</i>	128	20.8
<i>Cordia africana</i>	6	1.0
<i>Croton macrostachyus</i>	73	11.9
<i>Dalbergia lactea</i>	4	0.6
<i>Deinbollia kilimandscharica</i>	340	55.2
<i>Discopodium penninervium</i>	22	3.6
<i>Dombeya quinqueseta</i>	0	0.0
<i>Dombeya rotundifolia</i>	21	3.4
<i>Dovyalis abyssinica</i>	0	0.0
<i>Dovyalis verrucosa</i>	3	0.5
<i>Dracaena steudneri</i>	6	1.0
<i>Ehretia cymosa</i>	5	0.8
<i>Ekebergia capensis</i>	0	0.0
<i>Rumex nervosus</i>	3	0.5
<i>Embelia schimperi</i>	44	7.1
<i>Erythrococca trichogyne</i>	261	42.4
<i>Eugenia bukobensis</i>	18	2.9

Species	Abundance	Density (ha ⁻¹)
<i>Euphorbia abyssinica</i>	0	0.0
<i>Euphorbia ampliphylla</i>	8	1.3
<i>Ficus sur</i>	5	0.8
<i>Ficus thonningii</i>	1	0.2
<i>Flacourtia indica</i>	0	0.0
<i>Galiniera saxifraga</i>	0	0.0
<i>Grewia ferruginea</i>	0	0.0
<i>Gouania longispicata</i>	16	2.6
<i>Hypericum revolutum</i>	2	0.3
<i>Hippocratea goetzei</i>	218	35.4
<i>Hippocratea pallens</i>	573	93.0
<i>Jasminum abyssinicum</i>	36	5.8
<i>Juniperus procera</i>	0	0.0
<i>Justicia schimperiana</i>	732	118.8
<i>Landolphia buchananii</i>	947	153.7
<i>Lepidotrichilia volkensii</i>	30	4.9
<i>Lobelia gibberoa</i>	4	0.6
<i>Maesa lanceolata</i>	26	4.2
<i>Malva verticillata</i>	0	0.0
<i>Maytenus arbutifolia</i>	1944	315.6
<i>Maytenus obscura</i>	101	16.4
<i>Maytenus undata</i>	2	0.3
<i>Millettia ferruginea</i>	47	7.6
<i>Mimusops kummel</i>	0	0.0
<i>Nuxia congesta</i>	1	0.2
<i>Olea capensis</i> susp. <i>macrocarpa</i>	4	0.6
<i>Otostegia tomentosa</i>	0	0.0
<i>Oxyanthus speciosus</i> subsp. <i>stenocarpus</i>	20	3.2
<i>Paveta abyssinica</i> var. <i>abyssinica</i>	52	8.4
<i>Phyllanthus limmuensis</i>	0	0.0
<i>Phyllanthus ovalifolius</i>	3	0.5
<i>Phytolacca dodecandra</i>	31	5.0
<i>Pittosporum viridiflorum</i>	21	3.4
<i>Polyscias fulva</i>	0	0.0
<i>Protea gaguedi</i>	14	2.3
<i>Prunus africana</i>	356	57.8
<i>Pterolobium stellatum</i>	25	4.1
<i>Arundinaria alpina</i>	13	2.1
<i>Rhus glutinosa</i> subsp. <i>glutinosa</i>	2	0.3

Species	Abundance	Density (ha ⁻¹)
<i>Ricinus communis</i>	0	0.0
<i>Ritchiea albersii</i>	37	6.0
<i>Rosa abyssinica</i>	2	0.3
<i>Rothmannia urcelliformis</i>	449	72.9
<i>Rubus apetalus</i>	43	7.0
<i>Rytigynia neglecta</i>	528	85.7
<i>Salix subterrata</i>	5	0.8
<i>Schefflera abyssinica</i>	10	1.6
<i>Senna septemtrionalis</i>	0	0.0
<i>Solanecio gigas</i>	40	6.5
<i>Solanum giganteum</i>	15	2.4
<i>Steganotaenia araliacea</i>	0	0.0
<i>Stereospermum kunthianum</i>	0	0.0
<i>Syzygium guinense</i>	0	0.0
<i>Teclea nobilis</i>	12	1.9
<i>Tiliacora troupinii</i>	189	30.7
<i>Cayratia ibuensis</i>	10	1.6
<i>Urera hypselodendron</i>	8	1.3
<i>Uvaria angolensis</i>	0	0.0
<i>Vepris dainellii</i>	84	13.6
<i>Vernonia amygdalina</i>	2	0.3
<i>Vernonia auriculifera</i>	300	48.7
<i>Vernonia myriantha</i>	18	2.9
Total	9900	1607.1

Appendix 6. Indicator values of species in plant community types (C₁ - C₅) and their significance values in the study area

Species	Indicator values (%)					P value
	C ₁	C ₂	C ₃	C ₄	C ₅	
<i>Millettia ferruginea</i>	67	0	0	0	0	0.001
<i>Vepris dainellii</i>	62	0	0	0	0	0.001
<i>Ehretia cymosa</i>	62	0	0	0	0	0.001
<i>Hippocratea pallens</i>	58	0	0	0	0	0.001
<i>Ritchiea albersii</i>	57	0	0	0	0	0.001
<i>Combretum paniculatum</i>	53	0	0	0	0	0.002
<i>Justicia diclipteroides</i>	53	0	0	0	0	0.001
<i>Lepidotrichilia volkensii</i>	51	0	0	0	0	0.002
<i>Dracaena steudneri</i>	51	0	0	0	0	0.001
<i>Phytolacca dodecandra</i>	44	0	0	0	0	0.007

Species	Indicator values (%)					P value
	C ₁	C ₂	C ₃	C ₄	C ₅	
<i>Tiliacora troupinii</i>	39	0	0	0	0	0.007
<i>Vernonia auriculifera</i>	0	58	0	0	0	0.001
<i>Croton macrostachyus</i>	0	57	0	0	0	0.001
<i>Solanum anguivi</i>	0	43	0	0	0	0.002
<i>Acacia abyssinica</i>	0	39	0	0	0	0.004
<i>Celtis africana</i>	0	0	78	0	0	0.001
<i>Rothmannia urcelliformis</i>	0	0	70	0	0	0.001
<i>Mimusops kummel</i>	0	0	55	0	0	0.001
<i>Paveta abyssinica</i>	0	0	49	0	0	0.003
<i>Prunus africana</i>	0	0	49	0	0	0.006
<i>Eugenia bukobensis</i>	0	0	36	0	0	0.006
<i>Deinbollia kilimandscharica</i>	0	0	0	85	0	0.001
<i>Hippocratea goetzei</i>	0	0	0	75	0	0.001
<i>Erythrococca trichogyne</i>	0	0	0	51	0	0.006
<i>Albizia gummifera</i>	0	0	0	50	0	0.004
<i>Justicia schimperiana</i>	0	0	0	49	0	0.002
<i>Canthium oligocarpum</i>	0	0	0	0	81	0.001
<i>Buddleja polystachya</i>	0	0	0	0	67	0.001
<i>Embelia schimperi</i>	0	0	0	0	67	0.001
<i>Pteris catoptera</i>	0	0	0	0	64	0.001
<i>Pycnostachys meyeri</i>	0	0	0	0	63	0.001
<i>Peperomia tetraphylla</i>	0	0	0	0	61	0.001
<i>Apodytes dimidiata</i>	0	0	0	0	61	0.002
<i>Bersama abyssinica</i>	0	0	0	0	59	0.001
<i>Teclea nobilis</i>	0	0	0	0	59	0.001
<i>Girardinia bullosa</i>	0	0	0	0	58	0.001
<i>Nuxia congesta</i>	0	0	0	0	56	0.001
<i>Thalictrum rhynchocarpum</i>	0	0	0	0	54	0.002
<i>Vernonia myriantha</i>	0	0	0	0	50	0.001
<i>Brucea antidysenterica</i>	0	0	0	0	47	0.003
<i>Maesa lanceolata</i>	0	0	0	0	46	0.001
<i>Clematis longicauda</i>	0	0	0	0	45	0.001
<i>Rumex nepalensis</i>	0	0	0	0	43	0.002
<i>Maytenus obscura</i>	0	0	0	0	39	0.003
<i>Jasminum abyssinicum</i>	0	0	0	0	37	0.006
<i>Juniperus procera</i>	0	0	0	0	35	0.006

Appendix 7. Pearson correlation coefficients between environmental variables (below diagonal) and their significance (above diagonal) in Awi, northwestern Ethiopia. Correlation is significant at $P < 0.05$. Alt – altitude, Asp – Aspect, Slo – Slope, Cut – Cutting, Graz – Grazing, EC – Electrical Conductivity, Ca – Calcium, Mg – Magnesium, Na – Sodium, K – Potassium, P – Phosphorous, OM – Organic Matter, N – Nitrogen

-	Alt	Asp	Slo	Cut	Graz	pH	EC	CEC	Ca	Mg	Na	K	P	OM	N	Sand	Clay	Silt
Alt	-	0.15	0.04	0.61	0.18	0.86	0.00	0.02	0.95	0.08	0.47	0.35	0.22	0.00	0.00	0.91	0.43	0.27
Asp	0.12	-	0.00	0.97	0.26	0.43	0.27	0.40	0.20	0.14	0.84	0.34	0.19	0.51	0.41	0.11	0.46	0.15
Slo	0.17	-0.23	-	0.05	0.02	0.49	0.37	0.00	0.02	0.06	0.18	0.01	0.01	0.01	0.72	0.90	0.94	0.79
Cut	0.04	0.00	-0.16	-	0.00	0.10	0.15	0.04	0.68	0.83	0.28	0.96	0.73	0.19	0.88	0.16	0.89	0.06
Graz	0.11	0.09	-0.19	0.43	-	0.51	0.06	0.00	0.00	0.99	0.65	0.31	0.00	0.07	0.87	0.07	0.02	0.93
pH	0.01	0.06	-0.06	0.13	-0.05	-	0.00	0.01	0.00	0.23	0.00	0.00	0.00	0.22	0.91	0.69	0.62	0.24
EC	-0.34	-0.09	-0.07	-0.12	-0.15	-0.25	-	0.04	0.27	0.36	0.65	0.17	0.45	0.06	1.00	0.00	0.04	0.00
CEC	0.19	0.07	0.36	-0.17	-0.31	0.21	0.17	-	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.33
Ca	0.01	0.10	0.19	-0.03	-0.24	0.41	0.09	0.56	-	0.07	0.00	0.00	0.00	0.00	0.56	0.07	0.00	0.44
Mg	0.14	0.12	0.15	0.02	0.00	0.10	0.07	0.31	0.15	-	0.62	0.00	0.07	0.02	0.59	0.11	0.62	0.08
Na	-0.06	0.02	0.11	-0.09	-0.04	0.30	-0.04	0.27	0.24	0.04	-	0.00	0.04	0.03	0.41	0.02	0.00	0.69
K	-0.08	-0.08	0.20	0.00	-0.08	0.40	-0.11	0.35	0.37	0.25	0.32	-	0.00	0.69	0.21	0.99	0.29	0.21
P	-0.10	-0.11	0.21	-0.03	-0.26	0.28	-0.06	0.40	0.48	0.15	0.17	0.64	-	0.33	0.83	0.11	0.00	0.28
OM	0.26	0.05	0.22	-0.11	-0.15	-0.10	0.15	0.43	0.25	0.19	0.17	-0.03	0.08	-	0.08	0.01	0.20	0.04
N	0.29	0.07	0.03	-0.01	0.01	-0.01	0.00	0.18	0.05	0.04	-0.07	-0.10	-0.02	0.14	-	0.70	0.58	0.22
Sand	0.01	-0.13	-0.01	-0.11	-0.15	-0.03	0.29	0.25	0.15	0.13	0.19	0.00	0.13	0.20	-0.03	-	0.00	0.00
Clay	0.06	0.06	-0.01	0.01	0.19	-0.04	-0.16	-0.23	-0.23	-0.04	-0.26	-0.09	-0.23	-0.10	-0.04	-0.73	-	0.09
Silt	-0.09	0.12	0.02	0.15	-0.01	0.09	-0.23	-0.08	0.06	-0.14	0.03	0.10	0.09	-0.17	0.10	-0.57	-0.14	-

Appendix 8. List of woody species recorded in the Intermediate evergreen Afromontane forest (IAF) and other vegetation types in Ethiopia.

Woody species	Family	Habit	Vegetation Type
<i>Acacia abyssinica</i>	Fabaceae	Tree	IAF, DAF, MAF
<i>Acacia lahai</i>	Fabaceae	Tree	IAF, ACB, DAF
<i>Acanthus eminens</i>	Acanthaceae	Shrub	IAF, DAF, MAF, RV
<i>Acanthus polystachius</i>	Acanthaceae	Shrub	IAF, DAF, MAF, RV
<i>Acanthus pubescens</i>	Acanthaceae	Shrub	IAF, CTW, DF
<i>Acanthus sennii</i> *	Acanthaceae	Shrub	IAF, DAF
<i>Acokanthera schimperi</i>	Apocynaceae	Shrub	IAF, DAF
<i>Albizia coriaria</i>	Fabaceae	Tree	IAF, TRF
<i>Albizia grandibracteata</i>	Fabaceae	Tree	IAF, TRF, RV
<i>Albizia gummifera</i>	Fabaceae	Tree	IAF, DAF, MF
<i>Albizia malacophylla</i>	Fabaceae	Tree	IAF, CTW, RV
<i>Albizia schimperiana</i>	Fabaceae	Tree	IAF, DAF, MAF, TRF
<i>Allophyllus abyssinicus</i>	Sapindaceae	Tree	IAF, DAF, MAF, BW, RV
<i>Apodytes dimidiata</i>	Icacinaceae	Tree	IAF, DAF, MAF, RV
<i>Arundinaria alpina</i>	Poaceae	Tree	IAF, DAF, MF, EB, AA
<i>Asparagus africanus</i>	Asparagaceae	Shrub	IAF, ACB, DAF, EB, AA
<i>Bersama abyssinica</i>	Meliantaceae	Shrub	IAF, DAF, MAF, RV
<i>Bothriocline schimperi</i> *	Asteraceae	Shrub	IAF, DAF, CTW, RV
<i>Bridelia micrantha</i>	Euphorbiaceae	Shrub	IAF, DAF, MAF
<i>Brucea antidysenterica</i>	Simaroubaceae	Tree	IAF, DAF, MAF
<i>Buddleia polystachya</i>	Loganiaceae	Tree	IAF, DAF, EB
<i>Calpurnia aurea</i>	Fabaceae	Shrub	IAF, DAF, MAF
<i>Canthium oligocarpum</i> subsp. <i>oligocarpum</i>	Rubiaceae	Shrub	IAF, ACB, DAF, MAF
<i>Capparis tomentosa</i>	Capparidaceae	Liana	IAF, ACB, DAF, RV
<i>Carissa spinarum</i>	Apocynaceae	Shrub	IAF, ACB, DAF, MAF, RV
<i>Cassipourea malosana</i>	Rhizophoraceae	Tree	IAF, DAF, MAF
<i>Celtis africana</i>	Ulmaceae	Tree	IAF, DAF, MAF, RV
<i>Chionanthus mildbraedii</i>	Oleaceae	Tree	IAF, RV
<i>Cissus petiolata</i>	Vitaceae	Liana	IAF, ACB, CTW, DAF, RV
<i>Clausena anisata</i>	Rutaceae	Shrub	IAF, DAF, MAF
<i>Clematis longicauda</i> *	Ranunculaceae	Liana	IAF, DAF, MAF
<i>Clematis simensis</i>	Ranunculaceae	Liana	IAF, DAF, MAF
<i>Clusia abyssinica</i>	Euphorbiaceae	Shrub	IAF, DAF
<i>Combretum aculeatum</i>	Combretaceae	Liana	IAF, DSS, ACB
<i>Combretum collinum</i>	Combretaceae	Liana	IAF, CTW
<i>Combretum molle</i>	Combretaceae	Tree	IAF, CTW, DAF, TRF
<i>Combretum paniculatum</i>	Combretaceae	Liana	IAF, MAF, TRF

Woody species	Family	Habit	Vegetation Type
<i>Cordia africana</i>	Boraginaceae	Tree	IAF, CTW, DAF, MAF, TRF
<i>Crotalaria rosenii</i> *	Fabaceae	Shrub	IAF, DAF
<i>Croton macrostachyus</i>	Euphorbiaceae	Tree	IAF, CTW, DAF, MAF
<i>Cussonia ostinii</i>	Araliaceae	Tree	IAF, DAF
<i>Dalbergia lactea</i>	Fabaceae	Liana	IAF, DAF, MAF, RV
<i>Deinbollia kilimandscharica</i>	Sapindaceae	Tree	IAF, DAF, MAF, TRF
<i>Diospyros abyssinica</i>	Ebenaceae	Tree	IAF, MAF
<i>Discopodium penninervium</i>	Solanaceae	Shrub	IAF, DAF, EB, AA
<i>Dombeya quinqueseta</i>	Sterculiaceae	Shrub	IAF, CTW
<i>Dombeya rotundifolia</i>	Sterculiaceae	Shrub	IAF, DAF
<i>Dombeya torrida</i>	Sterculiaceae	Tree	IAF, MAF, DAF
<i>Dovyalis abyssinica</i>	Flacourtiaceae	Tree	IAF, DAF, RV
<i>Dovyalis verrucosa</i>	Flacourtiaceae	Shrub	IAF, DAF, EB
<i>Dracaena steudneri</i>	Dracaenaceae	Tree	IAF, DAF, MAF, TRF
<i>Echinops giganteus</i>	Asteraceae	Shrub	IAF, DAF
<i>Ehretia cymosa</i>	Boraginaceae	Tree	IAF, DAF, MAF, RV
<i>Ekebergia capensis</i>	Meliaceae	Tree	IAF, DAF, MAF, BW
<i>Embelia schimperi</i>	Myrsinaceae	Liana	IAF, DAF, RV
<i>Englerina woodfordioides</i>	Loranthaceae	Shrub	IAF, DAF, MAF
<i>Entada abyssinica</i>	Fabaceae	Tree	IAF, DAF
<i>Erianthemum dregei</i>	Loranthaceae	Shrub	IAF, DAF, MAF
<i>Erythrina brucei</i> *	Fabaceae	Tree	IAF, DAF, MAF
<i>Erythrococca trichogyne</i>	Euphorbiaceae	Shrub	IAF, MAF
<i>Euclea racemosa</i>	Ebenaceae	Shrub	IAF, DAF, ACB, RV
<i>Euclea racemosa</i> subsp. <i>schimperi</i>	Ebenaceae	Shrub	IAF, DAF, ACB, RV
<i>Eugenia bukobensis</i>	Myrtaceae	Tree	IAF, MAF, TRF, RV
<i>Euphorbia abyssinica</i>	Euphorbiaceae	Tree	IAF, DAF
<i>Euphorbia ampliphylla</i>	Euphorbiaceae	Tree	IAF, DAF, MAF, TRF, RV
<i>Euphorbia candelabrum</i>	Euphorbiaceae	Tree	IAF, CTW, ACB
<i>Ficus lutea</i>	Moraceae	Tree	IAF, RV, MAF, DAF
<i>Ficus ovata</i>	Moraceae	Tree	IAF, RV, DAF
<i>Ficus sur</i>	Moraceae	Tree	IAF, DAF, MAF, TRF, RV
<i>Ficus sycomorus</i>	Moraceae	Tree	IAF, RV, MAF, DAF
<i>Ficus thonningii</i>	Moraceae	Tree	IAF, DAF, MAF, RV
<i>Ficus vasta</i>	Moraceae	Tree	IAF, RV, DAF
<i>Flacourtia indica</i>	Flacourtiaceae	Shrub	IAF, ACB, DAF, RV
<i>Galiniera saxifraga</i>	Rubiaceae	Shrub	IAF, DAF, MAF
<i>Gardenia ternifolia</i>	Rubiaceae	Tree	IAF, DAF
<i>Gongrolema angolense</i>	Asclepiadaceae	Liana	IAF, DAF, RV
<i>Gouania longispicata</i>	Rhamnaceae	Liana	IAF, DAF, MAF, TRF, RV

Woody species	Family	Habit	Vegetation Type
<i>Grewia bicolor</i>	Tiliaceae	Shrub	IAF, ACB
<i>Grewia ferruginea</i>	Tiliaceae	Shrub	IAF, DAF
<i>Helinus mystacinus</i>	Rhamnaceae	Liana	IAF, DAF, MAF
<i>Hibiscus macranthus</i>	Malvaceae	Shrub	IAF, DAF, MAF
<i>Hippocratea africana</i>	Celastraceae	Liana	IAF, DAF, MAF
<i>Hippocratea goetzei</i>	Celastraceae	Liana	IAF, MAF, TRF
<i>Hippocratea pallens</i>	Celastraceae	Liana	IAF, MAF, TRF
<i>Hypericum quartinianum</i>	Hypericaceae	Shrub	IAF, DAF
<i>Hypericum revolutum</i>	Guttiferae	Shrub	IAF, DAF
<i>Jasminum abyssinicum</i>	Oleaceae	Liana	IAF, DAF
<i>Justicia schimperiana</i>	Acanthaceae	Shrub	IAF, DAF, MAF, RV
<i>Kanahia laniflora</i>	Asclepiadaceae	Shrub	IAF, RV
<i>Landolphia buechananii</i>	Apocynaceae	Liana	IAF, DAF, MAF, RV
<i>Lepidotrichilia volkensii</i>	Meliaceae	Tree	IAF, DAF, MAF, RV
<i>Lippia adoensis</i> var. <i>adoensis</i> *	Verbenaceae	Shrub	IAF, DAF
<i>Lobelia gibroa</i>	Lobeliaceae	Shrub	IAF, DAF, MAF
<i>Maesa lanceolata</i>	Myrsinaceae	Shrub	IAF, DAF, MAF, RV
<i>Maytenus addat</i> *	Celastraceae	Shrub	IAF, DAF, MAF
<i>Maytenus arbutifolia</i>	Celastraceae	Shrub	IAF, DAF
<i>Maytenus gracilipes</i> subsp. <i>arguta</i>	Celastraceae	Shrub	IAF, DAF
<i>Maytenus obscura</i>	Celastraceae	Tree	IAF, DAF, EB
<i>Maytenus undata</i>	Celastraceae	Shrub	IAF, DAF, MAF, EB
<i>Microglossa pyrifolia</i>	Asteraceae	Shrub	IAF, DAF, MAF, RV
<i>Millettia ferruginea</i> *	Fabaceae	Tree	IAF, DAF, MAF, RV
<i>Mimusops kummel</i>	Sapotaceae	Tree	IAF, DAF, MAF, RV
<i>Nuxia congesta</i>	Loganiaceae	Tree	IAF, DAF, MAF, EB, AA
<i>Ocimum lamifolium</i>	Lamiaceae	Shrub	IAF, ACB, DAF
<i>Olea capensis</i> subsp. <i>macrocarpa</i>	Oleaceae	Tree	IAF, DAF, MAF, EB
<i>Olinia rochetiana</i>	Oliniaceae	Shrub	IAF, DAF
<i>Otostegia integrifolia</i>	Lamiaceae	Shrub	IAF, DAF
<i>Otostegia tomentosa</i> subsp. <i>ambigiens</i>	Lamiaceae	Shrub	IAF, DAF, MAF
<i>Otostegia tomentosa</i> subsp. <i>tomentosa</i> *	Lamiaceae	Shrub	IAF, DAF
<i>Oxyanthus speciosus</i> subsp. <i>stenocarpus</i>	Rubiaceae	Shrub	IAF, DAF, MAF, RV
<i>Paveta abyssinica</i> var. <i>abyssinica</i>	Rubiaceae	Shrub	IAF, DAF, RV
<i>Pavetta oliveriana</i>	Rubiaceae	Shrub	IAF, RV, DAF
<i>Pergularia daemia</i>	Asclepiadaceae	Liana	IAF, DAF
<i>Phragmanthera regularis</i>	Loranthaceae	Shrub	IAF, DAF, MAF
<i>Phyllanthus limuensis</i> *	Euphorbiaceae	Shrub	IAF, MAF

Woody species	Family	Habit	Vegetation Type
<i>Phyllanthus ovalifolius</i>	Euphorbiaceae	Liana	IAF, DAF, RV
<i>Phytolacca dodecandra</i>	Phytolaccaceae	Liana	IAF, DAF
<i>Piliostigma thonningii</i>	Fabaceae	Tree	IAF, CTW
<i>Pittosporum viridiflorum</i>	Pittosporaceae	Tree	IAF, DAF, MAF
<i>Podocarpus falcatus</i>	Podocarpaceae	Tree	IAF, DAF, MAF
<i>Polyscias fulva</i>	Araliaceae	Tree	IAF, MAF, TRF
<i>Premna schimperi</i>	Lamiaceae	Shrub	IAF, DAF
<i>Protea gaguedi</i>	Proteaceae	Tree	IAF, DAF
<i>Prunus africana</i>	Rosaceae	Tree	IAF, DAF, MAF
<i>Psydrax schimperiana</i>	Rubiaceae	Shrub	IAF, CTW, DAF
<i>Pterocarpus lucens</i>	Fabaceae	Tree	IAF, CTW
<i>Pterollobium stellatum</i>	Fabaceae	Liana	IAF, ACB, DAF
<i>Rhamnus prinoides</i>	Rhamnaceae	Shrub	IAF, DAF, MAF
<i>Rhus glutinosa</i> subsp. <i>glutinosa</i> *	Anacardiaceae	Shrub	IAF, ACB, CTW, DAF
<i>Rhus natalensis</i>	Anacardiaceae	Shrub	IAF, DAF
<i>Rhus retinorrhoea</i>	Anacardiaceae	Shrub	IAF, DAF
<i>Rhus vulgaris</i>	Anacardiaceae	Tree	IAF, DAF, MAF
<i>Ritchiea albersi</i>	Capparidaceae	Shrub	IAF, DAF, MAF
<i>Rosa abyssinica</i>	Rosaceae	Shrub	IAF, DAF, EB
<i>Rothmannia urcelliformis</i>	Rubiaceae	Shrub	IAF, DAF, MAF, TRF, RV
<i>Rubus apetalus</i>	Rosaceae	Shrub	IAF, DAF
<i>Rumex nervosus</i>	Polygonaceae	Shrub	IAF, DAF
<i>Ruttya speciosa</i>	Acanthaceae	Shrub	IAF, DAF, RV
<i>Rytigynia neglecta</i>	Rubiaceae	Shrub	IAF, DAF, MAF
<i>Salix subserrata</i>	Salicaceae	Tree	IAF, RV, DAF, RV
<i>Sapium ellipticum</i>	Euphorbiaceae	Tree	IAF, MAF, TRF, RV
<i>Satureja abyssinica</i> subsp. <i>abyssinica</i>	Lamiaceae	Shrub	IAF, CTW, DAF
<i>Schefflera abyssinica</i>	Araliaceae	Tree	IAF, DAF, MAF
<i>Schrebera alata</i>	Oleaceae	Shrub	IAF, DAF, MAF
<i>Senna petersiana</i>	Fabaceae	Shrub	IAF, DAF, CTW, RV
<i>Sericostachys scandens</i>	Amaranthaceae	Liana	IAF, DAF, MAF
<i>Solanecio gigas</i> *	Asteraceae	Shrub	IAF, DAF, MAF, EB
<i>Solanum anguivi</i>	Solanaceae	Shrub	IAF, CTW, DAF, TRF
<i>Solanum giganteum</i>	Solanaceae	Shrub	IAF, DAF, MAF, TRF, RV
<i>Steganotaenia araliacea</i>	Apiaceae	Tree	IAF, ACB, CTW, DAF
<i>Stereospermum kunthianum</i>	Bignoniaceae	Tree	IAF, CTW, DAF
<i>Syzygium guineense</i>	Myrtaceae	Tree	IAF, DAF, MAF
<i>Tacazzea conferta</i>	Asclepiadaceae	Liana	IAF, DAF, MAF, RV
<i>Tapinanthus globiferus</i>	Loranthaceae	Shrub	IAF, DAF, MAF
<i>Teclea nobilis</i>	Rutaceae	Shrub	IAF, DAF, MAF, RV

Woody species	Family	Habit	Vegetation Type
<i>Tiliacora troupinii</i> *	Menispermaceae	Liana	IAF, DAF, MAF
<i>Trema orientalis</i>	Ulmaceae	Tree	IAF, RV, DAF
<i>Turraea holstii</i>	Meliaceae	Shrub	IAF, DAF, MAF
<i>Urera hypselodendron</i>	Urticaceae	Liana	IAF, DAF
<i>Uvaria angolensis</i>	Annonaceae	Liana	IAF, RV, DAF
<i>Vangueria apiculata</i>	Rubiaceae	Shrub	IAF, RV, DAF
<i>Vangueria volkensii</i>	Rubiaceae	Shrub	IAF, DAF, CTW, ACB
<i>Vepris dainellii</i> *	Rutaceae	Tree	IAF, DAF, MAF, TRF
<i>Vernonia amygdalina</i>	Asteraceae	Shrub	IAF, DAF, MAF, RV
<i>Vernonia auriculifera</i>	Asteraceae	Shrub	IAF, DAF, MAF
<i>Vernonia hochstetteri</i>	Asteraceae	Shrub	IAF, DAF
<i>Vernonia leopoldi</i> *	Asteraceae	Shrub	IAF, DAF
<i>Vernonia myriantha</i>	Asteraceae	Shrub	IAF, DAF, MAF, RV
<i>Ximenia americana</i>	Olcaceae	Shrub	IAF, ACB, CTW

* Endemic to the Flora area (Ethiopia and Eritrea)