Impact of climate and land use on plant diversity, carbon storage and leaf area index in the Jimma Highlands, Southwest Ethiopia

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Impact of climate and land use on plant diversity, carbon storage and leaf area index in the Jimma Highlands, southwest Ethiopia

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This is to certify that the Dissertation prepared by Dereje Denu Rebu, entitled: *Impact of Climate and Land use on Plant Diversity, Carbon Storage and Leaf Area Index in the Jimma Highlands, Southwest Ethiopia* and submitted in fulfillment of the Requirements for the Degree of Doctor of Philosophy (Biology: Botanical Sciences) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Impact of Climate and Land use on Plant Diversity, Carbon Storage and Leaf Area Index in the Jimma Highlands, Southwest Ethiopia
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The study aimed at the impact of climate and land use on plant diversity, live carbon storage (AGC) and leaf area index (LAI) in the Jimma Highlands of Ethiopia. Data on woody species were collected from 155; 20 m × 20 m sample plots which were subdivided into 2 m×2 m subplots for herbaceous species inventory. Thirty-one plots of one ha each were randomly distributed along a study transect for -measuring diameter at breast height for all woody species with DBH ≥ 10 cm. Upward hemispherical images of the forest/tree canopy were taken at 12 points in the 20 m × 20 m plots established within each one hectare plot. Two SPOT5 satellite images (path 134 / row 133) captured simultaneously on 17th December and aerial photographs taken in October 2012 were used for LULC mapping. The transect was classified into five major land use types from SPOT5 images and aerial photography. Natural forest was further separated into the natural forest with coffee shrub/tree beneath and those with no coffee under the canopy based on field observation. Two hundred and eight-seven plant species belonging to 220 genera and 82 families were collected and identified. The highest plant species richness per hectare was recorded from woodland and the least was from the cropland. The highest mean abundance of tree species was recorded from the planation forest and the least was from the pasture. Mean annual temperature and soil pH have significantly explained the variation in herbaceous species richness; sand and clay particles significantly explained the variation in tree species richness. Species richness, abundance and diversity also vary along vertical stratification in semi-forest coffee (SFC) and degraded natural forest (DNF). The highest AGC storage was recorded from the plantation forests (152.25±24.98) followed by DNFs (82.03±32.08) and SFCs (61.52±24.98). Land use types showed significant mean difference in AGC and LAI. Tree species abundance and richness combined, have explained about 82% of the variation in AGC across the land use types. There was significant linear relationship between AGC storage and some climate variables such as mean annual temperature, mean annual rainfall and potential evapotranspiration; between AGC and some edaphic factors such as soil cation exchange, sand and pH. Basal area, richness of shrub, tree and entire plant species combined have significantly explained about 82% and 81% of the variations in LAI_true_v6 and LAI_true_v5 respectively. LAI_true_v6 explained about 75% of the variation in AGC. Mean annual temperature and annual temperature range significantly explained about 21% of the variation in LAI_V5. Climate change under the current and projected scenarios affected the distribution of five plant species across Ethiopia. In conclusion, plant richness, abundance, distribution, carbon storage and leaf area index are affected by land use and climate variables.

Key words: Carbon storage, climate change, Jimma highlands, LAI, land use change, plant richness

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Acronyms and abrevations

abund_4th_root	fourth root transformed abundance
AGB	above ground biomass
AGC	above ground live carbon
ANOVA	analysis of variance
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
AUC	area under curve
BA	basal area
BA_log	Log transformed basal area
bio1	mean annual temperature
bio10	mean temperature warmest quarter
bio12	mean annual rainfall
bio13	rainfall wettest month
bio14	rainfall driest month
bio15	rainfall seasonality
bio16	rainfall wettest quarter
bio17	rainfall driest quarter
bio2	mean diurnal range in temperature
bio3	isothermality
bio4	temperature seasonality
bio5	maximum temperature warmest month
bio6	minimum temperature coolest month
bio7	annual temperature range
BD	bulk density
CEC	cation exchange capacity
CEM	climate envelop models
CI	confidence interval
CSA	Central Statistical Authority

DBH	diameter at breast height
DEM	digitalelevation model
DNF	degraded natural forest
EFAP	Ethiopian Forestry Action Program
EMA	Ethiopian Mapping Agency
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nations
GBIF	Global Biodiversity Information Facility
GCP	Ground control points
GDEM	Global Digital Elevation Model
GIS	Geographic information system
GLMs	Generalized linear models
GPS	Global Positioning system
Gt	Gigatonne
ha	hectare
IPCC	International Panel on Climate Change
IUFRO	International Union of Forestry Research Organization
IVI	Importance value index
LAI	Leaf area index
LAI_eff_v5	Effective leaf area index from CAN EYE version five
LAI_eff_v6	Effective leaf area index from CAN EYE version six
LULC	Land use/land cover
Maxent	Maximum Entropy
mi	annual moisture index
mimq	Moisture index moist quarter
MSS	Multi Spectral Scanner
pet	Potential evapotranspiration
RCP	Representative concentration pathway
RF	relative frequency
ROC	Receiver operating characteristics

SDM	Species distribution model
SFC	Semi-forest coffee
SOC	Soil organic carbon
SPSS	statistical package for Social Science
Stand_Coef	Standardized coefficient
t C ha^{-1}	tonne of carbon per hectare
TM	landsat Thematic Mapper
un	under coffee canopy
UNESCO	United Nations Education, Science and Culture Organization
UNFPA	United Nations population Fund
Unstand_Coef	unstandardized coefficient
VIF	Variance inflation factor
°C	Degree Centigrade

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CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

The impact of land use/land cover (LULC) change and climate variables on biodiversity is widely understood across the world. The term biodiversity has wider definition and includes all forms of life on earth at any level of organization as clearly indicated at the Rio de Jeneiro Convention on Biodiversity in 1992 (UN, 1992). According to this convention, biodiversity is defined as the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes associated with them. This includes diversity within species, between species and of ecosystems. Diversity within and between species can also be considered genetic diversity and species diversity respectively. According to Heywood and Watson (1995) estimation, about 300,000 species of vascular plants have been documented out of the estimated global total volume of 400,000 species of vascular plants . Habitat loss due to anthropogenic LULC change and global warming are threats to biodiversity across the world (Kappelle *et al*., 1999) and are causes for the current extinction of species (IPCC, 2007; Pimm *et al*., 2014). Land use/land cover change also affects plant species richness, diversity, abundance (Martınez *et al*., 2009) and biomass (Fearnside *et al*., 2009; Kauffman *et al*., 2009).

The distribution of biodiversity across the world is not even. Some areas are characterized by high species concentration mainly composed of high levels of

endemism and rapid rate of depletion (Myers, 1998). Human induced LULC change resulted in the formation of many ecological islands within highly converted habitat (Jenkins, 1992). This could interrupt the interactions among all biological entities on the planet and as a result the loss of one particular species could impact the persistence of another species. Human induced anthropogenic pressures affect the healthy functioning of an ecosystem. Ehrlich (1981), Myers (1998), Marina (2010), Cardinale *et al.* (2012) showed the impact of biodiversity loss on ecosystem integrity, which could threaten the existence of mankind.

The increasing human population and accompanying needs has increased pressure on the natural resources including plant cover, animal life, mineral resources and land. According to FAO (2010), forests cover 31% of the land on the planet, of which around 13 million is deforested each year. The annual loss of natural forest in the tropics was estimated to be 15.2 million hectares (FAO, 2001). In Ethiopia, the land cover change is dramatic and resulted in the decline of Ethiopian high forest cover from about 35–40% in the 19 century (Breitenbach, 1961) to 2.3% in 1990 (EFAP, 1994). The annual loss of closed forest and the entire natural vegetation in Ethiopia is about 10,000 ha (Landon, 1996) and 160,000–200,000 ha (Konemund *et al.*, 2002) respectively. Ethiopia lost 269,795.88 ha of forest cover within 13 years time (2000-2013) which is equivalent to about 20,754 ha per year (Hansen, *et al.*, 2013). FAO (2010) put the Ethiopian forest cover at about 11% (12.2 million ha) of the Ethiopian land area. This could probably be due to the change in FAO's forest definition.

The forest loss due to human induced land use change causes the loss of biodiversity and compromises the provision of ecosystem goods and services such as pollination services, erosion control, cycling of materials involving biotic and abiotic components, carbon storage and climate regulation. Deforestation disrupts the healthy functioning of an ecosystem through habitat fragmentation and formation of landscape mosaics. The fragments (formed as a result of deforestation) are surrounded by other land use types usually referred to as matrix. The matrix around the fragment may have positive, negative or neutral effect on the patch (Franklin *et al.*, 2002), usually depending on the type of land use.

Climate change is another threat to the global biodiversity. According to IPCC (2014), the earth's temperature has increased by approximately 0.65°C–1.06°C over the past 132 years. According to the report, the period from 1983–2012 was the warmest 30 year period of the last 1400 years in the Northern Hemisphere. The two main periods of warming were recorded between 1910 and 1945 and from 1976 onwards. The rate of warming from 1976 onwards has approximately been doubled that of the first period and, thus, greater than at any other time during the last 1,000 years (IPCC, 2001). Of the past 10 centuries, the 20th century was the warmest of all, and the 10 years in 1990s were the warmest of the entire period (IPCC, 2001). The change in the climate and the occurrence of this warming pattern is an evidence for the human induced climate change that resulted from the increased emission of greenhouse gases (IPCC, 2001). According to IPCC (2014), the global mean surface temperature increases by 2.6°C–4.8°C by the end of 21st century under the extreme representative concentration pathway (RCP8.5), the scenario with the highest

greenhouse gas emission. The rise for Africa was predicted up to 4.5°C provided that the current addition of greenhouse gases from fossil fuels continued (Platts *et al*., 2014). Africa is also more vulnerable to the climate change impacts than the developed nations due to its dependence on subsistence agriculture and natural resources as the main source of livelihood.

Climate change has severe impact on the terrestrial as well as aquatic ecosystems. Climate change also has a negative impact on the entire biodiversity and ecosystem functioning such as seasonality/cycling of natural events, water cycles, erosion control, pollination services, provison of fresh water and nutrient cycling. The degree of vulnerability to climate change among the people in the world is different with developing countries being more affected by climate change impacts. Africans are mostly dependent on natural resources for their livelihoods including food, shelter, medicine and the impact of climate variability on the biodiversity directly affects natural resources and the associated livelihoods of many African nations. Most Africans are dependent on rain-fed, hand to mouth subsistence agriculture which is directly affected by climate variability.

Climate change has put the distribution of biodiversity including plants under pressure (IPCC, 2014). It affects the spatial distribution of plants (latitude, elevation). According to Grabherr *et al*. (1994) and Parmesan and Yohe (2003), plants are changing their distributional ranges both in altitude and latitude in response to changing regional climates. Pounds *et al.* (1999), Still *et al.* (1999),

Thomas *et al.* (2004), Platts *et al*. (2013) also showed the range shift in species distribution in response to climate change.

Ethiopia is endowed with different land features and topographies ranging from 125 m below sea level at Kobar sink to 4620 m above sea level (the peak of Ras Dashen). This diversified habitat types results in the formation of different agro-climatic zones in Ethiopia which contribute to the formation of diversified flora occurrence and distribution in the country. There are about 6,000 species of higher plant taxa, of which 10% are endemic, occurring in Ethiopia due to this diversified ecological and geographical setting that results in different natural resources (Ensermu Kebessa and Sebsebe Demissew, 2014).

Carbon storage is one of the most important ecosystem services that human beings obtain from the natural resources. Carbon sequestration and storage in plant biomass has been widely accepted as the most important regulators of climate change. Green plants convert CO_2 (one of the most important greenhouse gases) into organic food during the process of photosynthesis and store in their biomass. In this regard, forests are important sinks of carbon because they trap carbon in their biomass throughout their life. According to Chave *et al*. (2014), about 50% of the above ground live plant biomass is carbon. Globally, forests store about 289 Gt of carbon in their biomass (FAO, 2010). Deforestation caused about 20% of greenhouse gas emissions worldwide and about 70% of emissions in Africa (Gibbs *et al.*, 2007).

Leaf is an interface between the plant canopy and the surrounding atmosphere. Leaf area index (LAI) is very important biophysical variable which takes part in the conversion of CO_2 to organic food and insures continuity of natural interactions of organisms in the food web (Pfefier *et al.,* 2012).

The removal of tree cover in conversion from its natural setting to human modified landscapes also affects the live carbon storage in the living plant biomass (Kauffman *et al*., 2009). The current rate of LULC change is contributing to more carbon emission into the atmosphere and reducing the carbon sink and enhancing the climate change (IPCC, 2000) and loss of biodiversity (Bellard *et al*., 2012). The removal of natural vegetation also affects the plant leaf area index.

The impact of land use and climate variables on plant species richness, abundance, LAI, AGC storage in woody species biomass has not been assessed so far in the Jimma Highlands. The impact of climate change on distribution of some plant species such as *Cordia africana* (multipurpose tree), *Acacia abyssinica* (important coffee shade tree), *Millettia ferruginea* (important coffee shade tree), *Schefflera abyssinica* (important honey source) and *Phytolacca dodecandra* (important medicinal plant) has not been assessed in Ethiopia so far. Therefore, there is a need to assess the impact of land use and climate variables on plant diversity, richness, above ground live carbon storing capacity and leaf area indices of different land use types in the study transect. There is also a need to assess the impact of climate change on the distribution of the selected plant species across Ethiopia.

1.2. Research Questions and Objectives

1.2.1. Research questions

- Is there any difference in plant species richness, tree species abundance and diversity across the land use types in the study transect of the Jimma Highlands?
- Do the same canopy trees dominate the semi-forest coffee forests across the transect?
- Is there any variation in above ground live carbon storage and LAI among the land use types across the transect in the Jimma Highlands?
- Is there any relationship between environmental variables (climate and edaphic) and plant species richness, AGC and LAI in the Jimma Highlands?
- Is there any change in habitat suitability for the distribution of the target plant species under the present and future projected climates in Ethiopia?

1.2.2. General objective

The general objective of this study was to determine the difference in plant species richness, diversity and abundance and determine the relationships of this to carbon storage and leaf area index across different land use types along an altitudinal transect in the Jimma Highlands; using these insights, the study then focused on modelling the distribution of some key plant species under current and future projected climates across Ethiopia.

1.2.3. Specific objectives

The specific objectives of this study include:

1. Determining the variation in plant species richness, diversity, abundance and dominance across different land use types in the study transect of the Jimma Highlands;
2. Determine the dominant canopy trees in semi-forest coffee across the transect in the Jimma Highlands;
3. Find out the difference in carbon storage among different land use types in the study transect of the Jimma Highlands;
4. Find out the difference in LAI among different land use types in the study transect of the Jimma Highlands;
5. Determine the relationships between environmental variables and plant species richness, abundance, AGC and LAI
6. Model habitat suitability for the distribution of five plant species under the current and future climate change scenarios across Ethiopia.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Land Use/Land Cover Change

Anthropogenic activities are the main cause of land cover change. About 13 million hectare of forest cover is lost annually due to deforestation (FAO, 2006). In the tropics alone, 15.2 million hectare of forest cover is lost each year (FAO, 2001). Anthropogenic land use change is the primary cause for the reduction of total vegetation area in Africa (Niang *et al.*, 2014). The annual loss of closed forest and natural vegetation in Ethiopia is about 10,000 ha (Landon, 1996) and 160,000–200,000 ha (Konemund *et al*., 2002) respectively. According to Sala *et al.* (2000), land use change has probably the largest effect followed by climate change and elevated carbon dioxide on the terrestrial biodiversity.

Ethiopia is one of the countries in Africa where the anthropogenic LULC change has excarbated the forest loss (EFAP, 1994; Kumelachew Yeshitela, 2001; Tadesse Woldemariam and Masresha Fetene, 2007). There has been a considerable reduction in the Ethiopian high natural forest cover since 19 century. It was 35–40% in the 19 century (Breitenbach, 1961), 16% in the early 1950's, 3.1% in 1982, 2.7 in 1989 and 2.3% in 1990 (EFAP, 1994). The study conducted on Shaka Forest (part of the Afromontane rainforest in southwest Ethiopia), pointed out that the dense closed forest declined from about 55,304 ha to 43,424 ha by 2001 and open forest decreased from 46,594 ha to 35,077 ha during the same period (Tadesse Woldemariam and

Masresha Fetene, 2007). As a result the size of disturbed forests increased by 16,355 ha and the agricultural land increased from 8,620 ha to 14,672 ha.

LULC change is the most important problem that has caused the forest loss in Ethiopia. Among the causes of LULC change contributing to the loss of the entire forest resources and associated biodiversity are rapid human population growth, poverty, forest clearing for cultivation, over-grazing, and exploitation of forests for fuel wood, construction and lack of proper policy framework. The human population growth in Ethiopia could be the most important driving force behind the loss of forest biodiversity. According to the UNFPA (2009) report, the Ethiopian population increased by 361% during the period of 1950–2010. UNFPA's (2009) human population projection also showed that the Ethiopian population will increase by 105% (reach 173.8 million) by 2050.

In a country like Ethiopia, with mostly agrarian community, the population growth has direct relationship with the LULC change. In Ethiopia, 95% of the cultivated land is occupied by smallholder subsistence agriculture (Shibru Tedla and Kifle Lamma, 1998). The rising human population has increased the need for new cultivatable land and additional energy supply. The cumulative effects of the small holder agricultural production and increasing human population lead to loss of natural forest and land degradation in Ethiopia. The human population of Jimma Zone, for example, increased from 1,960,033 to 2,495,795 (CSA, 1996; CSA, 2008).

The rapid population growth led to expansion of agricultural land, increased exploitation of fuel wood and construction material. These in turn led to loss of vegetation (deforestation). According to EFAP (1994), one of the reasons for the decline of Ethiopian forest cover is attributed to energy requirements. About 94% of the energy requirement in Ethiopia relies on biomass alone, of which trees and shrubs contribute the largest proportion (Haileleul Tebicke, 2002).

The new investment opportunities in southwestern Ethiopia are converting the few remaining Afromontane rainforests into other land use systems such as coffee and tea plantations (Taye Bekele *et al*., 2001). The study on Chewaka-Utto in southwest Ethiopia (where most remnant forests of the country are present) showed the conversion of natural forest from 85% in 1996 to 76.3% in the year 1999 (Kumelachew Yeshitela, 2001) due to clearing of the forest for tea and *Eucalyptus* plantations. Another study on Shaka Forest (also in southwest Ethiopia) showed the decline of dense forest cover from about 60% in 1973 to 20% in 2005 (Tadesse Woldemariam and Masresha Fetene, 2007). New settlements in forests are increasing and have resulted in the conversion of forestland into agriculture and other land use systems. The annual deforestation rate in Kafa zone (southwest Ethiopia) where the country has a UNESCO recognized biosphere, is approximated to be 22,500 ha.
(http://www.nabu.de/en/aktionenundprojekte/kafa/projectarea/climateprote.)

LULC change is one of the threats to biodiversity. Of the estimated 13 million species worldwide, only 1.6 million has been described (Heywood and Watson, 1995). Biodiversity is not equally and evenly distributed throughout the world. Mountains, for example, support about one-quarter of terrestrial biodiversity

worldwide and nearly half of the world's biodiversity Hotspots (Spehn *et al*., 2010). As Myers (1998) indicated there are areas with high species concentration mainly composed of high levels of endemism and rapid rates of depletion. Kappelle *et al.* (1999) in his review indicated that habitat alteration and loss, over-harvesting, chemical pollution, invasive species and increasing human population pressure are the major threats to the global biodiversity.

2.2. Carbon Storage

Antropogenic LULC change affects the health and wealth of an ecosystem. Carbon dioxide is the most important green house gas. Forests could be used as both carbon sink and carbon source. When it is managed and well conserved, it is important sink of carbon by converting CO_2 to organic food and storing in their biomass. When deforested, they are sources of CO_2 by emiting the carbon from their biomass through burning and decomposition. Acording to FAO (2010), global forest stores about 289 Gt of carbon in their biomass. LULC change and deforestation affected the carbon storing capacity of ecosystems. Carbon storage is one of the ecosystem services through which the climate could be regulated. Studies showed that LULC change affects above ground woody carbon stock (Asner *et al.*, 2003), carbon emission into the atmosphere (Achard, *et al.*, 2004, Kaplan, *et al.*, 2010). According to IPCC (2000) report, about 136 Gt C is emitted as a result of land-use change, mainly from forest ecosystems, leading to an increase of CO_2 by 176 Gt in the atmosphere.

In the tropics, deforestation induced changes in the atmospheric circulation (Avissar *et al.,* 2004). About 20% of global greenhouse gas emission resulted from deforestation. The amount of greenhouse gas emitted due to forest loss varies from region to region. In Africa, deforestation caused about 70% of greenhouse gas emision (Gibbs *et al.*, 2007). The destruction of tropical forests due to human activities contributed up to 17% of global CO_2 emission (IPCC, 2007). Anthropogenic LULC change played an important role in carbon emision world wide. Houghton (1999) reported that LULC change contributed about 33% to total anthropogenic carbon emison for the last 150 years. Acording to Friedlingstein *et al.* (2010), the percent contribution of LULC change to anthropogenic carbon emission was reduced to 12.5% mainly due to rise in emission from fossil fuels (during the period 2000-2009). From 2005–2010 carbon stocks in forest biomass declined by an estimated 0.5% Gt annually due to reduction in global forest cover (Yitebitu Moges *et al.*, 2010).

Agro-forestry is composed of mixed plant species. Each species of plants in the agro-forestry has the capacity to sequester carbon and convert into its biomass. As Montagnini and Nair (2004) indicated, if proper management is designed for agro-forestry practices they could serve as effective carbon sinks. The average estimation of stored carbon in agro-forestry practices indicated that 9, 21, 50, and 63 Mg C ha^{-1} in semi-arid, sub-humid, humid and temperate regions respectively (Montagnini and Nair, 2004). Most countries in sub-Saharan Africa practice smallholder agriculture. Ethiopia is one of these countries with about 85% of its population practicing

smallholder agriculture. In countries having agricultural communities with smallholder agro-forestry practices in the tropics the rate of carbon sequestration ranges from 1.3 to 3.5 Mg ha^{-1} yr^{-1} (Montagnini and Nair, 2004). In addition to its importance in directly sequestering carbon from the atmosphere and serving as mitigation to reduce the CO_2 concentration in the atmosphere, it also serves indirectly by reducing the human pressure on the natural forests. The soil management practices for the improvement of agro-forestry enhances carbon storage in trees and soils (Montagnini and Nair, 2004).

Global forest ecosystems store about 2.1 Gt of carbon (on average) annually (FAO, 2015). Studies showed that a significant portion of the absorbed carbon is returned to the atmosphere through deforestation and forest fire. According to FAO (2003) estimation, about 25% of the carbon emission from all human activities in the tropics was attributed by tropical deforestation. IPCC (2000) also indicated that tropical deforestation contributed about 25% net annual carbon emissions. The three approaches by which forest managements help to reduce carbon in the atmosphere are carbon sequestration, carbon conservation and carbon substitution.

The basic premise of carbon sequestration potential of land use systems including agro-forestry revolves around the fundamental biological/ecological processes of photosynthesis, respiration and decomposition (Nair and Nair, 2003). Essentially, carbon sequestered is the difference between carbon gained by photosynthesis and

carbon lost or released by respiration of all components of the ecosystem. The overall gain or loss of carbon is usually represented by net ecosystem productivity.

Reduction of natural forests due to human land use change reduced the amount of carbon that would be stored in the forest. The decline in carbon storage is critical when the forest is changed into agricultural lands for annual crops. Mixed agro-forestry practices in which a variety of perennial tree species are available contribute greatly in the amount of carbon they absorb from the atmosphere and store in their biomass. Agro-forestry systems including shade coffee farm help in carbon storage (Polzot, 2004; Schmitt-Harsh *et al.,* 2012; Getachew Tadesse *et al.*, 2014).

Traditional coffee plantation is one of the most important agro-forestry practices both in environment conservation and in carbon sequestration. As it was indicated by Tadesse Woldemariam and Feyera Senbeta (2008), in Ethiopia for example, there are four different coffee producing systems: forest coffee, semi-forest coffee, shade coffee and non-shade coffee systems. Of all these coffee agro-forestry systems, this study addressed only the semi-forest coffee system which is commonly found in the study transect. Multi-strata shade coffee system provides a partial compensation for carbon loss (Van Noordwijk *et al.*, 2002). This demonstrates the importance of coffee shade trees in converting carbon dioxide of the atmosphere and storing in their biomass. This can be used as one of the mitigation measures for climate change by maintaining the normal level of carbon concentration in the atmosphere.

Trees are terrestrial carbon sinks. Worldwide, forest plantations were estimated to cover 124 million hectares in 1995; 187 million hectares in 2000 (FAO, 2000) and 264 million hectares between 2000 and 2010 (FAO, 2010). According to FAO (2000), the annual rate of planting trees was 4.5 million hectares. The annual rate of planting trees increased to 5 million hectares from 2000–2010 (FAO, 2010). Forest plantation showed an increasing trend in all continents from 1990 to 2010. Compared to primary forests, plantation forests store relatively small amount of carbon (Thornley and Cannell, 2000)

In an ecosystem, interactions between biodiversity and carbon storage have been observed. Linear relationships with varying strengths were observed between biodiversity and carbon stock (Midgley *et al*., 2010; Talbot, 2010). There are also evidences showing the relationship between carbon storage and species richness and abundance in an ecosystem. Strassburg *et al*. (2010) showed positive relationship between terrestrial carbon stocks and biodiversity. Talemos Seta and Sebsebe Demissew (2014) showed positive relationship between above ground carbon storage and species richness (strong corellation) and with stem density (weak correlation).

The climate variables (temperature and moisture) have direct and indirect impacts on the physiological activities of plants which in turn could affect the plant growth and carbon storage. Tian *et al*. (1998) showed that dry weather and warmer temperatures decrease net primary productivity. Increased precipitation leads to an increase in the soil moisture content and this in turn affect the ecosystem productivity (Tian *et al.*,

1998). Any change in precipitation pattern could also affect the plant growth (Myneni *et al.,* 1997). Gentry (1982) showed a strong relationship between precipitation and productivity of an ecosystem.

2.3. Leaf area index (LAI)

Leaves are the most important parts of a plant for photosynthesis, gas exchange, water regulation and energy fluxes. They help as an interface between the plant canopy and the atmosphere. The orientations of foliage in three dimensional spaces govern the interaction between plant canopy structure and atmosphere (Fieber *et al*., 2014). This derives the energy flux between the canopy and atmosphere (Koetz *et al*., 2006). Leaf area index (LAI) is a very important biophysical parameter that characterizes the interaction between the canopy and the atmosphere. Watson (1947) defined LAI (which is applicable for broad leaves) as the total one-sided area of leaf surface per unit ground area. Natural events and human activities could affect the canopy leaf area index, which in turn could affect the ecosystem productivity. Quantification of this dimensionless plant canopy trait is complex due to temporal and spatial variability of an ecosystem. There are direct methods (Hutchison *et al*., 1986; Neumann *et al*., 1989) and indirect ways (Norman and Campbell, 1989) to quantify LAI.

The direct methods of acquiring LAI are difficult for large spatial extents due to its time consuming and work intensive nature (Jonckheere, 2004; Zheng and Moskal, 2009). As an alternative to some practical limitations of the direct method of LAI

estimation, several indirect optical devices have been developed since 1960's (Facchi *et al*., 2010). LICOR LAI-2000 Plant Canopy Analyzer and Decagon AccuPAR-80 ceptometer are the two mostly used optical devices for LAI estimation. These optical devics determine LAI from the radiation transmitted through the canopy. According to Jonckheere (2004), incoming radiation, plant canopy structure and its optical properties determine the energy intercepted by a canopy. LAI estimation from hemispherical photos has been introduced and developed since 1980's (Facchi *et al*., 2010). RGB cameras with fine resultions solved the problem of distinguishing leaves from the the sky (in case of upward hemi-images) or the ground (for the downward hemi-images) (Jonckheere, 2004). CAN-EYE is one of the image processing software packages used for estimating LAI from hemispherical images (Facchi *et al*., 2010).

2.4. Climate Change and Plant Distribution

Plants respond to climate change through range shift in their spatial distribution both in latitude and altitude (Grabherr *et al*., 1994; Parmesan and Yohe, 2003). Many terrestrial and aquatic species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to climate change (IPCC, 2014). The species in the alpine region are prone to the impact of climate change compared to those in the lowland or midlands (Thomas *et al*., 2004). The current rate of plant migration in response to the changing climate is faster than the past migrations. When the species at the lower altitude shift their geographic ranges upward, what will happen to those at the higher elevations? In

response to this, Thomas *et al*. (2004) indicated the possible maximum of extinction risk of the species in the alpine zone. Grabherr *et al.* (1994) in his study on Swiss Alps indicated the pronounced range shift of plant species to the higher elevations. The rate of expected upward shift is 8–10m per decade based on the mean temperature change for the last 90 years (Grabherr *et al.*, 1994). Pounds *et al.* (1999) and Still *et al.* (1999) showed the loss of many cloud forest species and invasion by the species from the lower elevations due to climate change.

There are documented range shifts in plant distribution by 6.1 km per decade towards the pole (Parmesan and Yohe, 2003). Tree species changed their elevation or latitude range in response to changes in Quaternary climate (Davis and Shaw, 2001). The climate change together with change in the human land use system may disrupt the relationship of migration and adaptation (Davis and Shaw, 2001). This clearly affects the productivity and persistence of several species. On the basis of the current scenarios of carbon dioxide, climate, vegetation and land use changes the scenarios of changes in biodiversity for the year 2100 has been developed. The future climate projections are based on the anthropogenic greenhouse gas emissions which are summarized under four different representative concentration pathways-RCP2.6, RCP4.5, RCP6.0 and RCP8.5) (IPCC, 2014). Of the four representative oncentration pathways, RCP2.6 keeps global warming below 2°C preindustrial temperature and RCP8.5 considers the extreme emissions of greenhouse gases, while the remaining two are considered intermediate.

Climatic change is not only affecting the distribution of plants, but also impacts the phenology or the seasonal activities of plants (IPCC, 2014). Plants have a fixed period of time for flowering, for shedding their leaves and to be in foliage, to produce fruits and seeds. These events happen at a regular cycle within the year. The climate change may interrupt and affect this natural cycling of events in plants and has a meaningful impact on the survival of plants.

Climate and climate factors affect the distribution of vegetation. In Ethiopia, for example, there are different vegetation types based on climate and topographic variations. There are two main topographic factors that govern the Ethiopian climate. One is the location of Ethiopia in relation to the equator and the second is the relief condition of Ethiopia. Ethiopia is located closer to the equator (the southern boundary is at approximately 3°30' north latitude) and its relief ranges from 125 meters below sea level to 4533m above sea level.

Species distribution models (SDM) are used to show the impact of climate change in the distribution of the species under consideration. SDM relates the spatial distribution of organisms with environmental covariates. Species distribution models are applied in various areas of study such as conservation work, alien species management and in the study of evolutionary changes (Corsi *et al*., 1999; Peterson *et al*., 1999; Guisan and Zimmermann, 2000; Kriticos and Randall, 2001; Welk *et al*., 2002; Guisan and Thuiller, 2005).

Based on the type of biological data (occurrence data), the method of modelling and the software applied are different. The biological data could fall in one of the following two data sets.

1. **Presence/absence data**
2. **Presence only data**

In presence/absence data, there is a need to have both occurrence and absence records for the species desired to model, while we need to have occurrence records (longitude and latitude) of the species for presence only data to run the model. According to Ponder *et al.* (2001), there is shortage of absence data in the tropics where the sampling was poor and at the same time, where conservation is very important. There are ample presence records in the tropics, while the absence data are poorly available. General purpose statistical models such as generalized linear models and generalized additive models address the presence/absence data types.

There are different types of climate envelop models such as Bioclim, Domain, General additive models and Maxent (Maximum Entropy). Among the existing Climate Envelop Models, Maximum Entropy Species distribution modelling approach was originally designed for statistical mechanics (Jaynes, 1957) and was applied for species habitat distribution modelling by Philips *et al.* (2006). It is one of the climate envelop models applied for making extrapolations from presence only data. When it is applied to presence only species distribution modelling, the study area makes up the space on which the Maxent probability distribution is defined, the points with known species occurrence records constitute the sample points, and the features are environmental variables which could be climatic, elevational, edaphic, vegetation or other environmental variables depending on the data at hand.

According to Philip *et al*. (2006), Maxent is advantageous in handling presence only data with environmental variables, avoiding model over-fitting through regularization and converge to the optimum probability distributions, among others.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area

3.1.1. Location of study area

This study was carried out in the Jimma Highlands, southwest Ethiopia (Figure 1) from November 2012–April 2014. The study area was designated "Jimma Highlands" by the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) Project. Jimma Highland is the wettest part of Ethiopia and belongs to the Eastern Afromontane Biodiversity Hotspot (Mittermeier *et al*., 2004). The landscape is a mosaic of different land uses such as semi-forest coffee (henceforth, SFC), croplands, pastures, natural forests, woodlands and plantation forests. The plantation forests are composed of exotic species such as *Cupressus lusitanica*, *Eucalyptus camaldulensis*, *Grevillea robusta* and *Pinus patula.* The study transects ranges from 1500–2200 m above sea level.

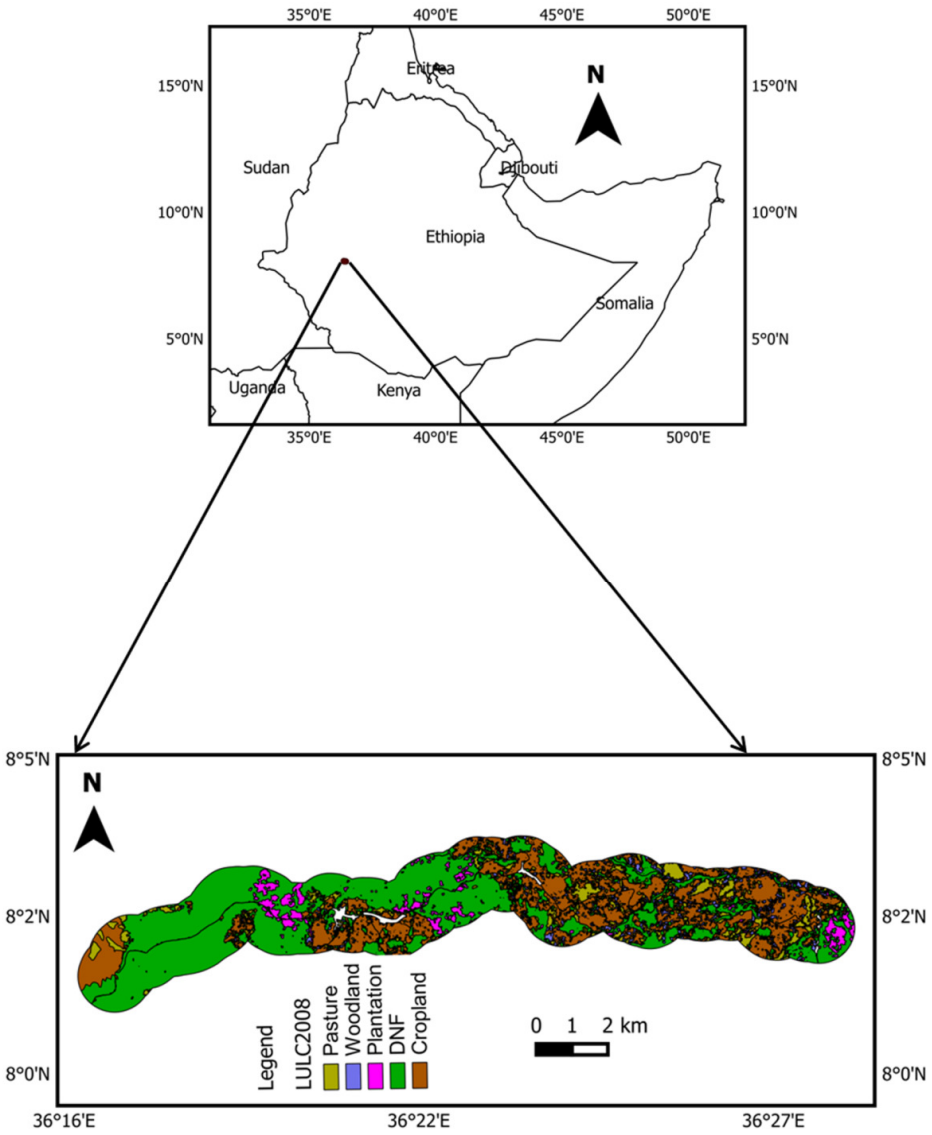


Figure 1: Map of East Africa including Ethiopia showing location of the study area in Jimma Highlands (designated by CHIESA Project) and landuse types

3.1.2. Climate

Southwest Ethiopia is the wettest region of the country with eight months of heavy rains (March-October). The precipitation and temperature data for 17 years (1990–2007) were obtained from Ethiopian Meteorology Agency (Jimma station) for

constructing the climate diagram following Walter (1985) (Figure 2). As it is indicated in Figure , Jimma (including the entire southwest Ethiopia) is characterised by uni-modal rainfall pattern. The average monthly precipitation (1990–2007) was 1563 mm. The average monthly maximum and minimum temperatures for the period of time indicated above are 30°C and 7.7°C respectively (Figure 2). The mean annual maximum temperature ranges from 26.53-28.63°C, while the mean annual minimum temperature ranges from 3.1-12.2°C. The arid period prevails in February and the rest relatively represents the humid period. The area in black represents the per-humid period of the year getting above 100 mm of rainfall on average. This area extends from March to October.

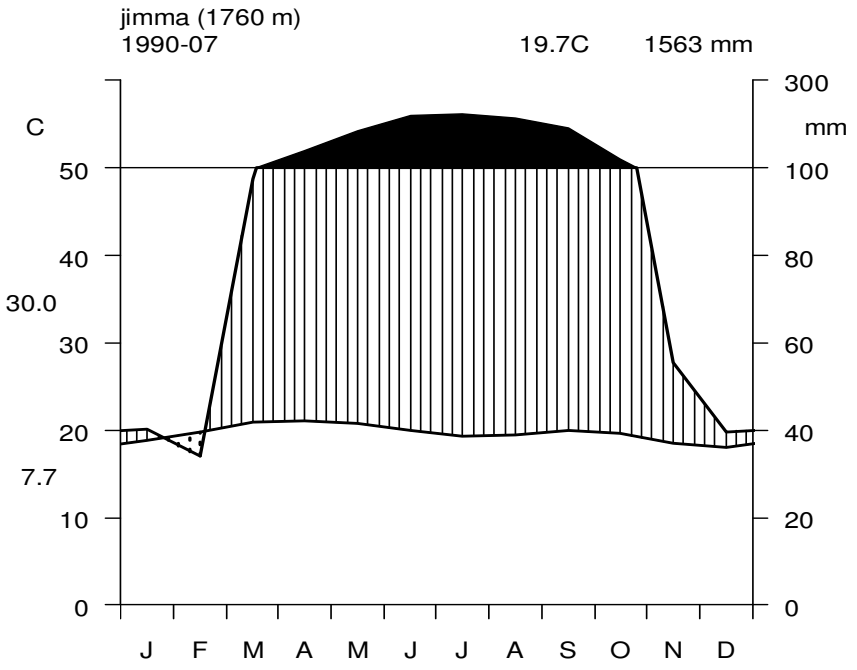


Figure 2: Climate diagram of Jimma Highlands, southwest Ethiopia

3.1.3. Human population and economy

According to 2007 Ethiopian census report (CSA, 2008), the human population of Setema and Gumay districts were 103,748 (males = 50999, females = 52749) and 61,333 (males = 30707, females = 30626) respectively. About 97% of the population of Setema and 95% of Guma districts were Muslems and the remaining belong to Christianity. Oromo is the major ethnic group in both districts. There are some Amhara and Tigre settlers from northern Ethiopia. The majorities of the population in both districts are rural and depend on smallholder subsistence agriculture. Coffee (*Coffea arabica*) and "Chat" (*Catha edulis*) farming is the main agriculture activity in both districts for generating income. Traditional honey farming is another source of income in the districts. The conservation of forests patches for coffee farming made both districts ideal places for honey production. Particularly the conservation of *Schefflera abyssinica* (local name = Gatama) in Jimma Zone contributed to the production of white honey which has priority in the local market compared to honey from other sources. The common crops in both districts include cereals such as maize, sorghum, teff, barley and wheat and pulses such as *Vicia faba* and *Pisum sativum*. Animal farming is another important sector in supporting the rural community in both districts. The community has been using horse back as a means of transportation in both Setema and Gumay districts. In the past, horse was used for transportation purposes within and out of the districts, but nowadays, vehicles have replaced the horse back for longer journeys like from one district to another.

3.1.4. Land uses

According to the agricultural offices of Setema and Gumay districts the land use types are classified into arable land, pasture, and moist montane forest and degraded land. About 27% of the total land area of Setema District was arable, while pasture and forests represent about 13% and 55% respectively. The remaining land (about 5%) is degraded and has no use. In Gumay District, the cultivable land is about 61%, while pasture, forest and unusable land (swamps and mountains) represent about 8%, 5% and 20% respectively. Setema District has more forest cover compared to the neighbouring Gumay District.

3.2. Materials

3.2.1. Data acquisition

There are two sources of data in this study.

1. **Primary data**

   The primary data were directly collected during the field work from November 2012 - April 2014 in the Jimma Highlands.

2. **Secondary data**

Specific wood densities for woody species were acquired from Global Wood Density Database (Chave *et al*. 2009; Zanne *et al.,* 2009). Climate variables were taken from down scaled AFRICLIM 1km resolution for East Africa (Platts *et al.*, 2014) from KITE website (http://www.york.ac.uk/environment/research/kite/). Enhanced vegetation index (EVI) and normalised difference vegetation index (NDVI) for the

year 2012 were downloaded from MODDIS sattelite imagery (https://lpdaac.usgs.gov/products/modis_products_table/mod13q1) using the Google search engine. The *hd* file formats were converted to *tif* format in R free statistical software version 3.0.1 (R Core Team, 2014). Extraction of EVI and NDVI values from grid cells for the transect was caried out in QGIS version 2.2.0-Valmiera. Soil data for 1km resolution were downloaded from World Soil Information Database (ISRIC, 2013) as additional input. Appendix 1 shows the soil and evapotranspiration data for the study plots along the transect in the Jimma Highland.

Plant species occurrence data were obtained from herbarium specimens and from databases. The occurrence data were collated from the herbarium specimens housed at the National Herbarium (ETH), Addis Ababa University. The data bases of Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/) and TROPICOS (Missouri Botanical Garden) (http://www.tropicos.org/) were also used for collecting the occurrence data across Ethiopia.

3.2.2. Field equipment and software

Global positioning system (GPS) for recording the location of species (longitude, latitude and altitude); hemispherical camera (Nikon D7000) with fish eye lenses for taking upward hemispherical images which later processed to produce LAI, clinometer for measuring slope angle and determine tree height; compass for determination of direction and aspect of the study plots; diameter tape for taking the diameter of tree trunk at breast height; digital range finder which measures the

distance from the observer and the tree trunk, and Photo camera, water balance, plant press and tripod (camera stand) were used in the field data collection. Laptop and desktop computers were used for collecting secondary data from different sources via the Google search engine.

Without the application of software data organization and processing, it was unthinkable to accomplish the objectives of the study. Therefore, the following softwares have been utilized.

1. Quantum GIS free software version 2.2 Valmiera for image manipulation
2. R free software version 3.0.1
3. Past free software
4. CAN-EYE free software
5. PC-ORD version 5.31

3.3. Methods

3.3.1. Study design

The study design varied based on the aspects to be studied. This study addressed:

1. Plant species richness, diversity, abundance and distribution;
2. Plant canopy structure and stratification;
3. Carbon storage in different land use types across the transect and its association with climate variables; and

4. Leaf area index and its association with climate variables.

The study transect with a total area of 46 km^2 (23 km × 2 km) was laid from Ageyo (a village between Toba and Dembi towns) northwest of Jimma in the upper Didessa River Basin. The transect was placed along an altitudinal gradient (1500–2300 m a.s.l.) by the CHIESA Project. The project incorporated a range of different aspects such as impact of climate change on plant diversity and distribution, carbon storage and land use/land cover changes.

Thirty-one plots of 100 m × 100 m (major plot) were established in different land use types such as croplands, forests (SFC, degraded natural forest (henceforth, DNF), plantation forest), woodland and pasture along the transect. Stratified random sampling technique was used for putting the sample plots across the transect. The main land use types for the transect were identified from 2008 SPOT5 satellite image and was confirmed during the reconnaisence survey which was conducted before the start of actual data collection. The major plots were placed randomly in each land use type and their four corners were geo-referenced and the vertices have been marked to easily trace the plot boundary for the next visit. Five subplots of 20 m × 20 m were laid at the corners and the center of each major plot (100 m × 100 m) (Figure 3). The 20 m × 20 m plot was marked at 10 m from the corners and at 5 m into the plot from the 10 m mark from the corners (Figure 4). Small plots of 2 m by 2 m were established at the center and four corners of the 20 m × 20 m plot.

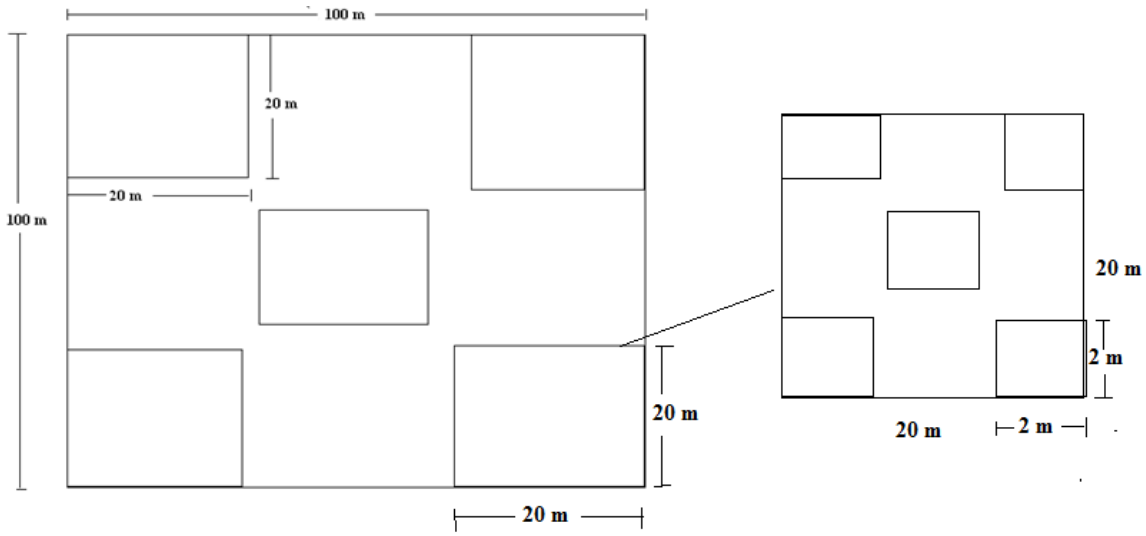


Figure 3: Sampling design for AGC and vegetation data collection

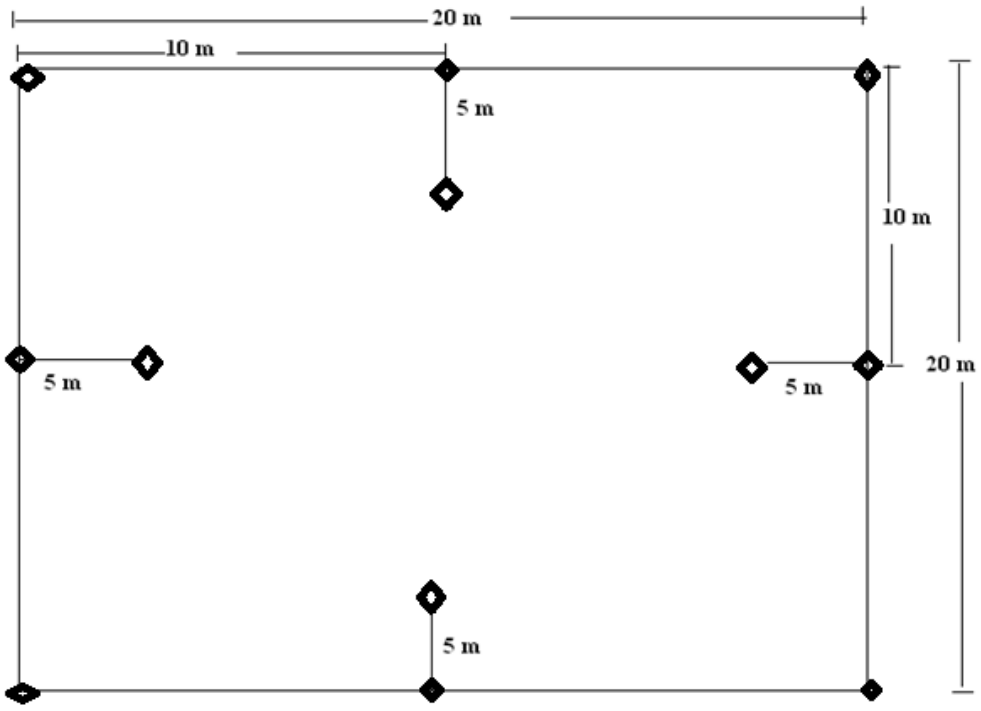


Figure 4: Sampling design for LAI data collection

Diameter at breast height (DBH) and height of all woody species with DBH ≥ 10cm were taken from the one hectare plot for the study of carbon storage. The 20 m × 20 m plots nested within the one hectare plots were used for collecting data on

occurrence of woody species, upward hemispherical images for determination of leaf area index (LAI). Thirty-five plots of 20 m × 20 m were also used for collecting cover abundance values from SFC system. This was used for grouping SFC plots based on the similarities in the cover abundance values of the canopy trees. The 2 m × 2 m plots were used for collecting occurrence data on herbaceous species. Another 29 plots of size 20 m × 20 m (400 m^2) were placed in SFC of size less than one hectare, along the transect. This was designed for collecting data on LAI (both above and below the coffee canopy).

3.3.2. Data analysis

3.3.2.1. Land use/Land cover mapping

The LULC map was produced for the year 2008 using SPOT5 satellite image. The SPOT5 images from 2008 used for land cover mapping were two satellite images taken on path 134 and row 133, December 17, 2008. These were utilized (i) in panchromatic mode at 2.5 m spatial resolution with 0.48–0.71 μm wavelengths, and (ii) in multispectral mode at 10 m spatial resolution with four bands: green (0.50–0.59 μm), red (0.61–0.68 μm), near infrared (0.78–0.89 μm), and short-wave infrared (1.58–1.75 μm).

In addition to the satellite images for the year 2008 LULC map, true-color aerial photographs were used and acquired in a flight campaign arranged in October 2012 using University of Helsinki's NIKON D3X camera and EnsoMOSAIC aerial

imaging system. The spatial resolution of the final aerial image was 0.5 meter. Global Digital Elevation Model with 30 m resolution was used in SPOT5 satellite image pre-processing from ASTER. We collected ground control points and training areas from field work in order to get the LULC map.

The classification was based on information obtained from a set of similar pixles which is referred to as Object Based Image Analysis (OBIA) and applied in two levels: (i) Classification of the transect into different major land use types (ii) separation of indigenous and exotic forests from the forest cover. The Nearest Neighbor supervised classification method was used for classifying segmented image objects and it was based on Land Cover Classification System. The final classified image was at 2.5 m spatial resolution.

3.3.2.2. Species area curve

Before applying different analyses such as species diversity, similarity indices, modelling species distribution and carbon storage, species area curve analysis was applied using PC-ORD Version 5.31 for windows (McCune and Mefford, 2006). This helped to evaluate the sampling effort in the species data collection.

3.3.2.3. Species diversity

Species richness, abundance, diversity, dominance and diversity profile were determined using PAST computer software for windows (Hammer *et al.*, 2001). Percent and relative frequency of occurrence of each species in the entire study area

as well as in each land use types were determined using excel spread sheet. Species richness in each plant growth form was also determined for each land use type.

The assessment of plant diversity in the study area was also one of the targets of this study. Shannon-Wiener diversity index (Sannon and Wiener, 1949) was used to determine species diversity from the quantitative data on abundance of each species obtained from the sample plots and presence/absence data. Species diversity, richness and evenness were evaluated using Shannon-Wiener Diversity index and Simpson evenness index.

$$H = -\Sigma Pi ln Pi$$

Where,

H = Shannon and Wiener diversity index,

Pi = the ratio of a species average to the total species average

Ln = the natural logarism to base e (loge)

The species evenness is calculated using the following formula

$$J = H_{max}/lnS$$

Where,

J = the species evenness

Hmax = *lnS*, in which S stands for the number of species

3.3.2.4. Basal area

The DBH of all woody species in SFC and the DNF was measured at 1.3 m above the ground. Importance value index for each tree species was calculated from the basal area, frequency and abundance. The basal area for the woody species was determined from the DBH measurement. The basal area was calculated by multiplying diameter by pie. Basal area is calculated from the following formula.

Basal area (BA) = π * (diameter/2)2

3.3.2.5. Analysis of variance

One way analysis of variance was used to determine the difference between each land use type in plant species richness, tree species abundance and basal area across the transect. Pearson correlation was used to evaluate the linear relationships between species richness in herb, shrub and tree growth forms and assess the realtionships with environmental variables such as climate, edaphic and topography. The linear relationships between tree species abundance and environmental variables were also determined using Pearson correlation coefficient. Multiple regression analysis was also conducted to determine the amount of variation in species abundance and richness explained by edaphic, topographic and climatic variables.

3.3.2.6. Classification and grouping study plots

The study plots were classified based on species presence/absence data using PC-ORD Version 5.31 for windows (McCune and Mefford, 2006). The plots in SFC

system were classified and grouped using two-way cluster analysis. Group linkage method and Sorensen (Bray Curtis) distance measurer were used to classify canopy trees into groups based on their similarities in cover abundance values. Modified Braun-Blanquet approach was used for estimation of cover abundance values. Naming of the groups of canopy trees was based on the dominant species (highest cover abundance value).

3.3.2.7. Vertical stratification

Vertical stratification in SFC and DNF was determined following the IUFRO classification scheme (Lamprecht, 1989). According to this scheme, trees with >2/3 height of the tallest tree represent upper storey, trees with height between 1/3 and 2/3 of the tallest tree represent the middle storey and trees with height < 1/3 of the tallest tree represent the lower storey. The richness, abundance, diversity, dominance of plant species in each storey was analysed. The analysis was not done for plantation forests, woodland, cropland and pasture due to absence of strata in the repective land use types.

3.3.2.8. Carbon storage

Carbon storage in all land use types was organized in Microsoft excel spread sheet and the data were taken into SPSS 16.0 for windows for analysis. The above ground live biomass was calculated using the updated, non-destructive allometric equation (Chave *et al.*, 2014). The above ground live biomass was, therefore, calculated from

the following equation, where wood specific gravity, DBH and height of the woody spcies are used as input data.

$$AGB = 0.0673*(\rho D^2H)^{0.976}$$

Where "AGB" stands for above ground live biomass, "ρ" for wood specific gravity, "D" for diameter at breast height and "H" for height of the woody species.

Wood specific gravity was obtained at species-level from the Global Wood Density database (Chave *et al.,* 2009; Zanne *et al.,* 2009).The above ground live carbon (AGC) was estimated at 50% of the AGB (Chave *et al.* 2014). Shapiro-Wilk normality test confirmed that the data distributed normally and hence parametric test was used.

Data exploration, descriptive statistics and analysis of variance (ANOVA) were used to evaluate the distribution of data, carbon storage in each land use types and comparing different land use types in terms of carbon storage. Pearson correlation was used to determine the linear relationship between species richness (herb, tree and shrub) and AGC; between tree species abundance and AGC. Multiple regressions were conducted to determine the amount of variation in AGC explained by tree species richness and abundance combined (explanatory variables). Pearson correlation was also used to determine the relationships between AGC and climate variables, AGC and edaphic variables, AGC and topographic variables. Multiple

regression analysis was also conducted to determine the amount of variation in AGC explained by potential evapotranspiration, soil pH, CEC and sand (edaphic factors).

3.3.2.9. Leaf area index (LAI)

The upward hemispherical images taken from the plots were organized in excel spreadsheet in the appropriate format for thresholding in MATLAB computer software. MATLAB was used for thresholding the images and CAN-EYE computer software was used for converting the images into digital numbers. The CAN-EYE produces true leaf area index and effective leaf area index based on the presence and /or absence of vegetation clumping. Both data sets were tested for normality. Effective leaf area index was excluded from the analysis due to failure to satisfy the assumption of normal distribution even after transformations.

LAI were produced from two versions of Can_Eye (V5.1 and V6.1) based on the differences in the regularization term that imposes constraints for the improvement of LAI. In Can_Eye V5.1, the regularization term uses average leaf angle which asumes the average leaf angle close to 60^0, while Can_Eye V6.1 uses the retrieved plant area index which is close to the one retrieved from the zenital angle of 57^0.

The linear relationships between above ground live carbon storage (AGC) and LAI, species richness and LAI, tree species abundance and LAI were analyzed using R-free software version 3.0.1. Analysis of variance was also used to determine the

difference among different land use types in LAI. Multiple regression analysis was conducted with the explanatory variables having significant linear relationship with the LAI. This was used to know the variation in LAI explained by the independent variables. The difference between the LAI taken above the coffee canopy and below the coffee canopy was tested using paired sample t-test.

3.3.2.10. Species Distribution Model

Maxent entropy (Phillips *et al.*, 2006) was used for modelling the distributions of five plant species encountered in the study transect. The presence records (longitude and latitude) of species were used as input for the model. Five plant species were selected for modelling their distribution across Ethiopia. The selection was based mainly on: (1) occurrence in the study transect (Jimma Highlands), (2) the species should be indigenous, (3) have economic /medicinal values among the community, (4) their ecological role in the ecosystem. There are documented economic and medicinal values of *Cordia africana* (Dawit Abebe and Ahadu Ayehu, 1993; Fichtl and Admasu Adi, 1994; Legesse Negash, 1995; Riedl and Edwards, 2006; World agroforestry, 2009; Sarah Tewoldeberhan *et al*., 2013), (*Millettia ferruginea* (Thulin, 1989; Fichtl and Admassu Adi, 1994; Berhanu Alemu *et al*., 2013), *Schefflera abyssinica* (Fichtl and Admassu Adi, 1994), *Phytolacca dodecandra* (Aklilu Lemma *et al*., 1972; Polhill, 2000; Hailu Tadeg, 2005). *Acacia abyssinica*, *Millettia ferruginea* and *Cordia africana* are selected for shade provision by coffee growers (Diriba Muleta *et al*., 2011). Based on the above three points, *Acacia abyssinica*, *Cordia africana*, *Millettia ferruginea*, *Phytolacca dodecandra* and *Schefflera*

abyssinica were selected for modelling, which are decribed below. Climate data were obtained from AFRICLIM (Platts *et al.*, 2014).

Acacia abyssinica Hochst.ex Benth. (Fabaceae)

Cordia africana Lam. (Boraginaceae)

Millettia ferruginea (Hochst.) Bak. (Fabaceae)

Phytollaca dodecandra L'Herit. (Phytolaccaeae)

Schefflera abyssinica (Hochst. ex A. Rich.) Harms (Araliaceae)

3.3.2.10.1. Model building

The occurrence data for each of the five species were divided into training and test data. Seventy five percent of the occurrence data were used for training; while 25% were used for testing (referred to as random test percentage) the performance of the model. This setting allows us to set aside 25% of the presence data to be used to evaluate the model's performance. In the absence of test data (25% in this case), the model uses the training data to evaluate itself and as a result the model will be inflated. The use of test data, therefore; avoids such inflated model outputs. Of the three replicate run types that Maxent allows for using, the subsample option was chosen. Ten replicates were made for each species and the average over the ten model outputs was taken for interpretation and discussion.

The species have different number of occurrence localities- *Acacia abyssinica* (n = 92), *Cordia africana* (n = 108), *Millettia ferruginea* (n = 75), *Phytolacca dodecandra* (n = 113) and *Schefflera abyssinica* (n = 104). Overlapping data were avoided and only those data points which were not overlapping were used in the modelling. For *Acacia abyssinica,* 40 for training and 13 for testing were used, for *Cordia africana* 47 for training and 15 for testing, for *Millettia ferruginea*, 49 for training and 16 for testing, for *Phytolacca dodecandra*, 36 for training and 12 for testing, and for *Schefflera abyssinica*, 33 for training and 11 for testing.

In MaxEnt, it is possible to run a model several times and then take the average of the results from all models (Philips *et al*., 2006). In this study, the model was executed to replicate 10 times and then the average was taken. This result was combined with the result from the 25% test data for evaluating the model performance. Executing multiple runs also provide a way to measure the amount of variability in the model.

In the default setting, the number of iterations (convergence) was set to 500. In this study, the number of iterations was increased to 5000 to allow adequate time for the model to converge. This helps to avoid either over prediction or under prediction. The application of regularization avoids or reduces model over-fit. The default value of 1 was accepted for regularisation for this study.

CHAPTER FOUR

4. Results

4.1. Land Use/Land Cover

The 2008 land cover map (Figure 5) showed five main land cover categories in the transect: these are pasture, woodland, cropland, natural and plantation forests. From the field observation, the natural forests without coffee are found towards the end of the transect, while the natural forests upto around 2000 m elevation were occupied by SFC. Therefore, the natural forests were further classified into those with coffee and those without coffee. Hence, the main LULC types of this study area were:

1. Cropland
2. Pasture
3. SFCs
4. Woodland
5. DNFs
6. Plantation forests

Plant species richness, diversity, abundance, vegetation structure, carbon storage and leaf area indices were all affected by LULC types and hence have been addressed separately.

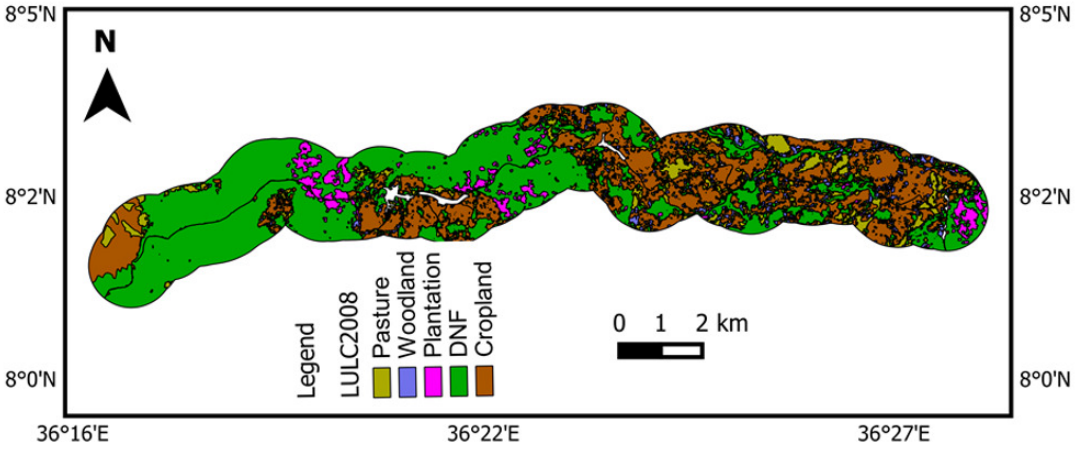


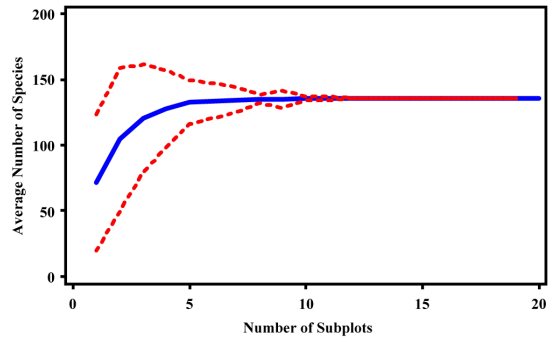
Figure 5: Land use/cover across the study transect in the Jimma Highlands for the year 2008

4.2. Plant Species Richness and Diversity

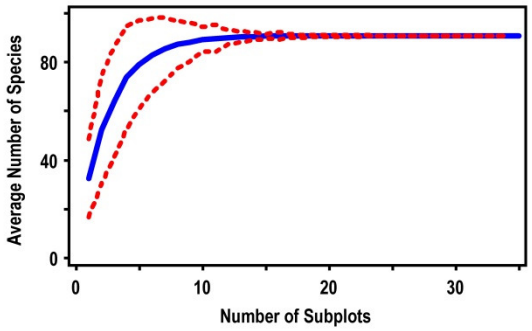
4.2.1. Species richness in each land use type

4.2.1.1. Species area curve

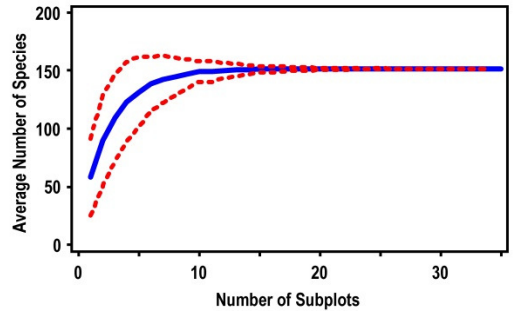
The species area curve in all land use types levelled off after some sample plots were surveyed. This showed that the sampling effort was exhaustive (Figure 6). The number of sample plots for plant species data collection (400 m^2) was 35 for SFC, 35 for cropland, 25 for pasture, 20 for woodland, 20 for DNF and 20 for plantation forests. Species richness and growth form distributions in each land use types are presented below.



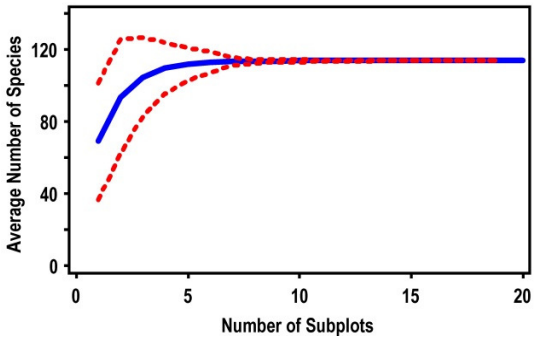
Woodland



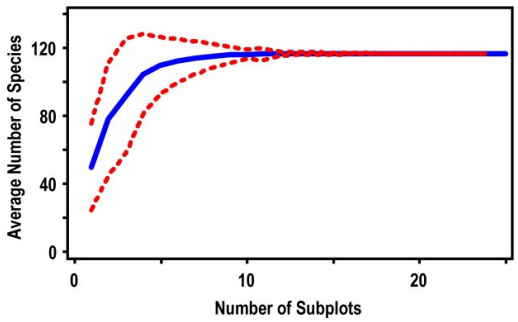
Cropland



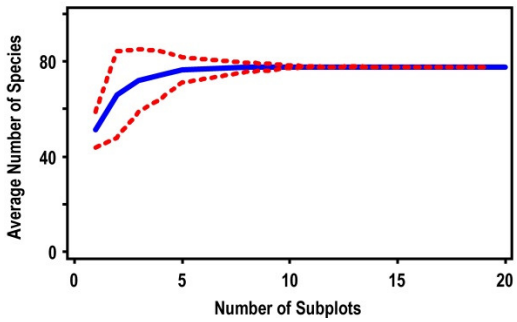
SFC



DNF



Pasture



Plantation

Figure 6: Species area curve for all land use types across the transect in the Jimma Highlands

4.2.1.2. Species richness in DNF

The natural forest in the study transect is surrounded by villages and is used as common pool for firewood, materials for building houses, timber and other non-timber forest products. As a result, it is highly degraded. This natural forest is composed of 114 (28.25 ha^{-1}) species of plants that are distributed among 103 genera and 50 families (Appendix 2). The top 13 families were composed of about 56% of

the species in the natural forest and the remaining 37 families together contributed about 44% of the total species composition. Asteraceae is the most species rich family (11 species) in the DNF followed by Rubiaceae and Fabaceae each of them with eight and seven species respectively. Twenty-five families were represented by one species each. The number of herbaceous and tree species in the DNF is almost the same. There are slightly more herbs than trees, while the lianas have the lowest species diversity compared to the remaining three growth forms (Table 1).

Table 1: Growth form distribution of plant species in DNF

Growth form	**Species richness**	**Species richness ha^{-1}**	**% Composition**
Herb	36	9.0	31.58
Liana	11	2.75	9.65
Shrub	32	8.0	28.07
Tree	35	8.75	30.70

4.2.1.3. Species richness in woodlands

Woodland is a stand of trees with the height of 8-20 m and a canopy cover of at least 40% of the surface (White, 1983). In this study transect, woodlands are composed of 136 (34 ha^{-1}) plant species (Appendix 3) distributed among 105 genera and 44 families. Asteraceae and Fabaceae were equally species-rich families; each of them containing 18 species together contributing to 26.48% of the total species composition in the woodland. Lamiaceae and Euphorbiaceae follow with 11(8.09%)

and 9 (6.62%) species respectively. The families with one representative species in the woodland are 22, together contributing about 16% of the species composition in the woodland. Most of the plants in the woodland are herbaceous followed by shrub species. Liana growth form is the least species rich compared to all the rest (Table 2).

Table 2: Growth form distribution of plant species in woodland

Growth form	**Species richness**	**Species richness ha^{-1}**	**%Composition**
Herb	56	14	41.18
Liana	9	2.25	6.62
Shrub	39	9.75	28.68
Tree	32	8	23.53

4.2.1.4. Species richness in cropland

Cropland is composed of 91(13 ha^{-1}) plant species occurring in 81 genera and 37 families (Appendix 4). Species richness is the highest in the family Asteraceae compared to other plant families in the cropland along the study transect. Fabaceae is the second species rich family followed by Euphorbiaceae, Malvaceae and Poacaeae. Most families are composed of one species. Out of the four plant growth forms, herbs are the most species rich group, while liana is the least growth form in species richness (Table 3). When woodland, degraded natural or coffee forests are converted to plots of annual crops, the trees, shrubs and lianas are removed. The tree species

are scattered in farm land and their number per hectare is about three species on average. Liana growth form is the most affected in agricultural field.

Table 3: Growth form distribution of plant species in cropland

Growth form	**Species richness**	**Species richness ha^{-1}**	**% Composition**
Herb	50	7.14	54.95
Liana	2	0.29	2.20
Shrub	17	2.43	18.68
Tree	22	3.14	24.18

4.2.1.5. Species richness in SFC

SFC ranked third in plant species richness per hectare and relatively the richest land use type in plant family composition in the study transect. SFC is composed of 152 (52.96%) of plant species (Appendix 5) spread among 130 genera and 55 families. Asteraceae and Fabaceae are the most species rich families. Euphorbiaceae ranked third in species richness followed by Acanthaceae, Malvaceae and Rubiaceae each of them with equal number of species. Twenty-four families in the SFC were represented only by one species each.

Variation was also observed in plant growth forms. Most of the species in the SFC are herbs, while liana is the least growth form in species richness (Table 4). Liana is the growth form which is affected most in SFC. The most frequently occurring plant

species in SFC are *Coffea arabica*, *Celts africana* and *Ehretia cymosa*. All of these plants were recorded from all study plots of SFC. Plant species like *Achyranthes aspera*, *Albizia gummifera, Cordia africana*, *Croton macrostachyus*, *Desmodium repandum, Vepris dainellii*, *Vernonia amygdalina* and *Vernonia auriculifera* were the second most frequent species in the SFC. The most frequently occurring species belong to the tree growth form. Of the most frequent species, *Desmodium repandum* and *Achyranthes aspera* were herbaceous species and *V. auriculifera* is a shrub, while all the remaining are trees.

Table 4: Growth form distribution of plant species in SFC

Growth form	Species richness	Species richness ha^{-1}	% Composition
Herb	67	9.57	44.08
Liana	3	0.34	1.97
Shrub	34	4.86	22.37
Tree	48	6.86	31.58

4.2.1.6. Species richness in pasture

There are 90 genera and 39 plant families with 113 plant species occurring in pastures along the study transect (Appendix 6). Asteraceae is the most species rich family in the pasture; Fabaceae and Poaceae follow. Euphorbiaceae, Lamiaceae and Rubiaceae rank fourth species rich families with equal number of species. About half of the families have ≥ 2 species, while the rest are represented by one species each.

Lianas have fewer occurrences when compared with the remaining plant growth forms. Herb growth form is the most species rich group (Table 5).

Table 5: Growth form distribution of plant species in pasture

Growth form	Species richness	Species richness ha^{-1}	% Composition
Herb	51	10.2	45.13
Liana	7	1.4	6.19
Shrub	32	6.4	28.32
Tree	23	4.6	20.35

4.2.1.7. Species richness in plantation forests

There are 79 plant species occurring in the plantation forests (Appendix 7). The highest growth form in species richness in the plantation forests was tree and the least was liana (Table 6). The plots of monoculture plantations include *Cupressus lusitanica*, *Eucalyptus camaldulensis*, *Grevillea robusta* and *Pinus patula*. The number of trees in the monoculture plantations showed the regenerating capacity of indigenous tree species under the canopy of plantations of exotic species.

Table 6: Growth form distribution of plant species in plantation forest

Growth form	Species richness	Species richness ha^{-1}	% composition
Herb	27	6.75	34.18
Liana	3	0.75	3.80
Shrub	21	5.25	26.58
Tree	28	7	35.44

4.2.2. Plant species across the transect

4.2.2.1. Plant species richness

From the study conducted in all land use types along the established study transect, in the Jimma Highland, 287 species of plants were collected and identified. These 287 plant species have been distributed among 220 genera and 82 families (Appendix 8). The first 12 families contributed more to the species composition in the study transect than the remaining 70 families (Table 7). Three families (Cupressaceae, Proteaceae and Pinaceae) are represented by single exotic species each.

Table 7: Species rich families across the study transect and their percent composition

Family	**Richness**	**% Composition**
Asteraceae	33	11.58
Fabaceae	25	8.77
Euphorbiaceae	14	4.91
Lamiaceae	14	4.91
Rubiaceae	14	4.91
Poaceae	13	4.59
Acanthaceae	10	3.51
Malvaceae	9	3.16
Solanaceae	8	2.81
Moraceae	7	2.46
Amaranthaceae	6	2.11
Ranunculaceae	6	2.11
Remaining 70 families	128	44.6

Species richness in different land use types vary. The species composition in all land use types were compared using X^2 statistics. The test showed that the species composition is affected by land use type ($Xi^2_{(5)}$ = 32.258, the critical value at p = 0.05 significant level for 5° of freedom is 11.07) (Table 8). The calculated X^2 is greater than the critical value confirming that the land use types affected plant species richness.

Table 8: X^2-test for species composition in different land use types

	SFC	DNF	woodland	Cropland	pasture	plantation	Total
Present	152	114	136	91	113	79	685
Absent	135	173	151	196	173	208	1036
Total	287	287	287	287	287	287	1722
Frequency	0.53	0.40	0.47	0.32	0.39	0.28	0.40
Expected Presence	114.17	114.17	114.17	114.17	114.17	114.17	
Expected Absence	172.83	172.83	172.83	172.83	172.83	172.83	
Ob-exp	37.83	-0.17	21.83	-23.17	-1.17	-35.17	
(Ob-exp)2	1431.361	0.027778	476.6944	536.6944	1.361111	1236.694	
(Ob-exp)2/exp	12.5375	0.0002	4.1754	4.7010	0.0119	10.8324	$Xi^2_{(5)}$=32.258

The number of plant species per hectare increased from highly modified land use types to less modified ones (Figure 7). The land use types in decreasing order of plant species richness per hectare are woodland, DNF, SFC, pastureland, monoculture plantation of exotic species and cropland of annual crops (Figure 7).

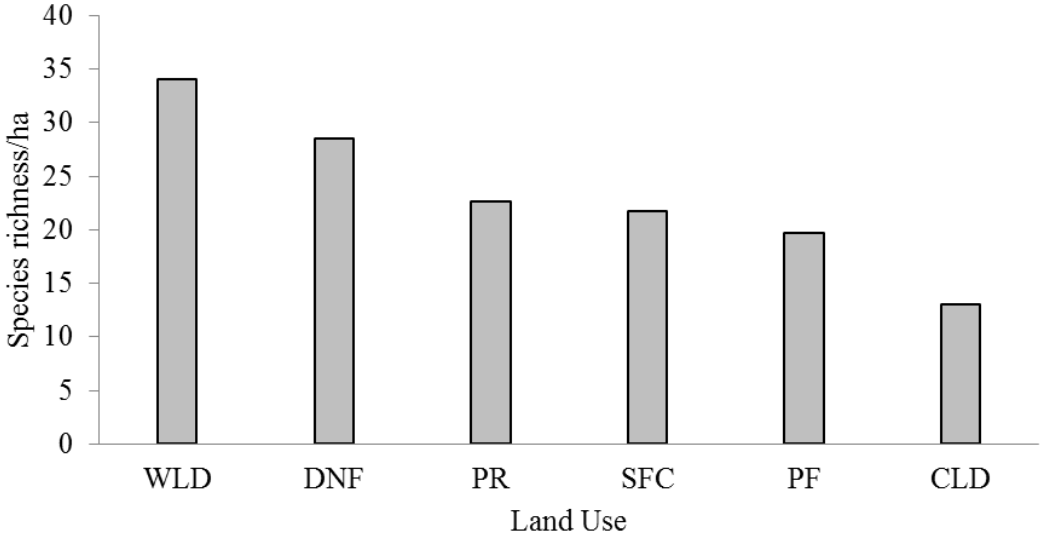


Figure 7: Plant species richness per hectare in different land use types across the transect (WLD = woodland, DNF, SFC = semi-forest coffee, PR = pasture, PF = plantation forest, CLD = cropland)

4.2.2.2. Woody species richness and diversity

Woody species richness, abundance and diversity vary from land use to land use. The highest woody species richness was recorded from SFC followed by DNF and woodland.The least woody species with dbh ≥10 cm was obtained from cropland (Table 9). The land use types also vary in woody species abundance. Plantation forest is characterized by the highest density of trees. The number of stems per hectare is 236 in DNF, while it is 129.7 ha^{-1} in SFC, whereas the least abundance was recorded from cropland with 6.7 ha^{-1}.

Table 9: Species richness, abundance, dominance, diversity and evenness in different land use types

	SFC	Cropland	Woodland	Pasture	DNF	Plantation
Richness	44	9	27	14	32	13
Abundance	908	47	464	31	944	3193
Dominance	0.10	0.18	0.17	0.11	0.08	0.27
Shannon	2.75	1.90	2.18	2.43	2.82	1.47
Evenness	0.35	0.74	0.33	0.81	0.53	0.33

4.2.2.3. Plant growth form distribution

Plant species collected from the sample plots along the study transect were distributed among four major plant growth forms (herb, liana, shrub and tree). The most species rich plant growth form was herb, while the growth form with least number of species was liana.

4.2.2.4. Frequency of occurrence of species

The 287 plant species distributed in the entire study area vary in frequency of occurrence along the transect (Appendix 8). Nine plant species occurred in about 50% of the study plots. These are *Acacia abyssinica*, *Achyranthes aspera*, *Agerantum conyzoides*, *Albizia gummifera*, *Bidens pilosa*, *Cordia africana*, *Croton macrostachyus*, *Maesa lanceolata* and *Vernonia auriculifera* (Appendix 8). Five of these plants were trees and three of them were herbs and there was one shrub.

Eight plant species occurred only once and these are *Cupressus lusitanica*, *Eucalyptus camaldulensis*, *Grevillea robusta*, *Kosteletzkya begoniifolia*, *Nuxia congesta*, *Pinus patula*, *Schrebera alata* and *Sesbania sesban*. *Cupressus lusitanica*, *Eucalyptus camaldulensis*, *Grevillea robusta*, *Pinus patula* and *Sesbania sesban* were exotic species and the first four are in plantations. *Sesbania sesban* has been used as shade tree in home gardens and was seen in the wild escaping from the home gardens. *Kosteletzkya begoniifolia*, *Nuxia congesta* and *Schrebera alata* are indigenous species and have rare occurrence in the study area.

4.2.3. Climate variables and edaphic factors against species richness

The richness of herbaceous species showed significant linear relationships with mean annual rainfall, mean annual temperature, maximum temperature warmest month, mean annual temperature, annual moisture index, potential evapotranspiration and soil pH (Appendix 9). The linear relationships of the herbaceous species richness with rainfall wettest month, silt, soil bulk density, cation exchange capacity, sand and clay was not significant. The linear relationship of the shrub species was only significant with the soil clay, but its relation was not significant with other variables (Appendix 9). Tree species richness was only significant with sand and clay (Appendix 9). The relation with elevation and other variables was not significant.

4.2.3.1. Multiple regression analysis

The regression analysis made with the variables showed significant relationship with herbaceous species richness. Most of the variables were excluded due to collinearity

and only two variables (mean annual temperature and soil pH) were taken for the analysis. The two variables combined together have significantly explained 20.5% (R^2 = 0.205, R^2_{adj} = 0.148, SE = 7.85) of the variation in herbaceous species richness. The contribution of each separate variable to the model was not significant (Table 10).

The two soil properties having significant relationships with the tree species richness were tested for collinearity prior to conducting the multiple regression analysis. The variance inflation factor for both variables was <5 (Table 11). The two variables combined together have explained about 20% (R^2 = 0.196, R^2_{adj} = 0.138, SE = 7.12) of the variation in tree species richness. The soil clay explained about 17% of the variation in shrub richness.

Table 10: Contribution of mean annual temperature and pH to the regression analysis of herb richness

		Unstand_Coef		**Stand_Coef**			
Model		**B**	**SE**	**Beta**	**t**	**p**	**VIF**
	Constant	-71.572	36.082		-1.984	0.057	
	bio1	0.391	0.353	0.375	1.106	0.278	4.04
	pH	0.346	1.336	0.088	0.259	0.798	4.04

Dependent variable: Herb

Table 11: Contribution of each explanatory variable to the regression analysis of tree species richness

	Unstand_Coef		Stand_Coef			
Model	**B**	**SE**	**Beta**	**T**	**p**	**VIF**
Constant	20. 647	72.931		0.283	0.779	
Sand	0.958	1.164	0.219	0.823	0.417	2.457
Clay	-0.907	0.959	-0.251	-0.945	0.353	2.457

Dependent variable: Tree

4.2.4. Classification of study plots on the bases of species presence/absence

The sample plots were clustered into three (with about 12.5% similarity) using the species occurrence data (presence/absence) across all land use types in the study transect (Figure 8). Jaccard similarity index was the measure of similarity used to group the sample plots. The plots from different land use types were classified based on their similarities in species composition.

Group I: Includes all forest types (DNF, SFC, plantation forest) and some plots of woodland in the transect. The DNFs are represented by 20 sample plots, SFC by 35 plots, plantation forests by 20 plots and the woodlands by 10 plots. All plots in the DNF were composed of indigenous plant species such as *Apodytes dimidiata*, *Croton macrostachyus*, *Galiniera saxifraga*, *Polyscias fulva*, *Prunus africana*, *Schefflera*

abyssinica and *Syzygium guineense*, while the plantation forests are mainly composed of *Cupressus lusitanica, Eucalyptus camaldulensis*, *Grevillea robusta* and *Pinus patula*, which are all exotic species. The SFC were composed of the trees retained on the plot by the coffee growers for the purpose of shade provision for the coffee shrubs beneath. All the shade trees in the SFC were indigenous species. The most important trees in the SFC were *Albizia gummifera*, *Acacia abyssinica*, *Celtis africana, Cordia africana*, *Croton macrostachyus* and *Millettia ferruginea*. The woodland plots in this group are also compsed of indigenous species such as *Acacia abyssinica*, *Combretum molle*, *Entada abyssinica* and *Terminalia schimperiana*.

Group II: Group II includes all plots of pastureland and 10 plots from the woodlands. All the plant species in pasture and woodlands in this group were indigenous. The trees found doted in the pastureland include *Ficus vasta*, *Sapium ellipticum*, *Syzygium guineense*, *Prunus africana* and *Croton macrostachyus*.

Group III: All plots of croplands were grouped together due to their similarity in species composition.The tree species dotted in the croplands include *Acacia abyssinica*, *Cordia africana* and *Croton macrostachyus* and all of them are indigenous species.

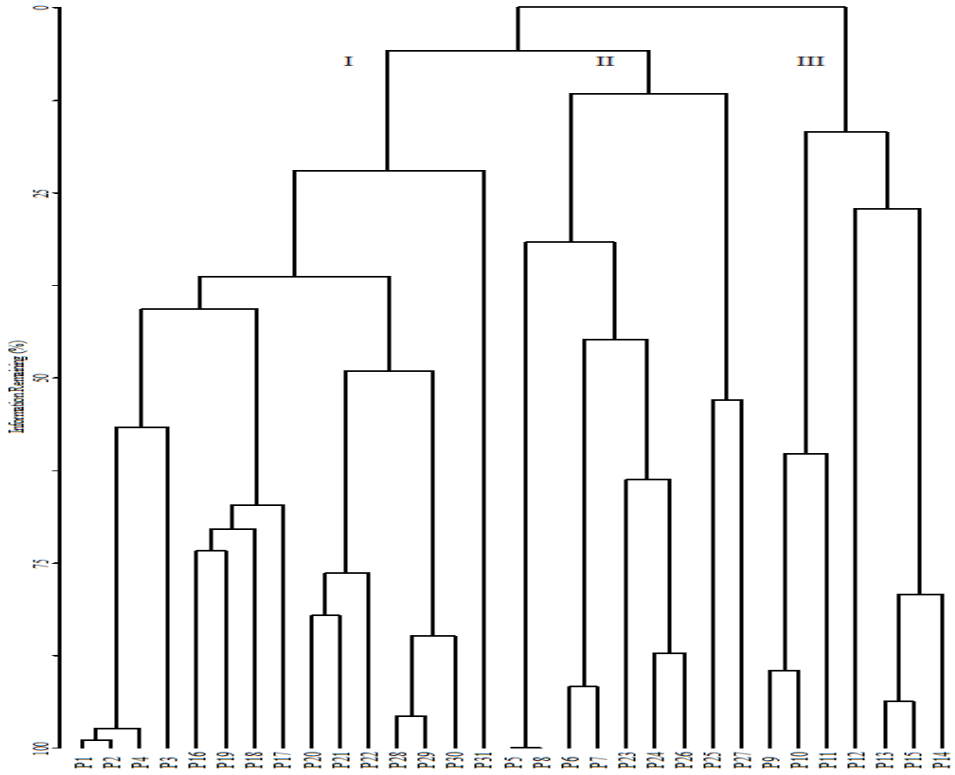


Figure 8: Cluster analysis based on species presence/absence (P1–4 = DNF, P5–8 = woodland, P9–15 = Cropland, P16–22 = SFC, P23–27 = Pastureland, P28–31 = Plantation forest)

4.2.5. Groups of canopy trees in SFC

The canopy trees in the SFC were classified into four groups based on the cover abundance values taken from 35 sample plots along the transect (Figure 9 and Appendix 10). The group linkage method and Sorensen (Bray Curtis) distance measurer in two ways cluster analysis was used for grouping the canopy trees into groups. The two-way cluster analysis shows the grouping of sample plots and the species cluster showing the plots in which the species has occurred. Based on the calculated average value of cover abundance the coffee plots were classified into

four distinctive groups. Naming of the groups was based on the dominant species (highest cover abundance value).

Croton macrostachyus and *Albizia gummifera* (Group I)

This group of coffee shade trees was made up of five sample plots and was named after two dominant tree species in the group (*Croton macrostachyus*, relative cover abundance = 8 and *Albizia gummifera,* relative cover abundance = 7.4). *Cordia africana*, *Ehreta cymosa*, *Allophylus abyssinicus*, *Schefflera abyssinica*, *Prunus africana*, *Diospyros abyssinica*, *Ficus sur*, *Bersama abyssinica*, *Apodytes dimidiata*, *Celtis africana*, *Galiniera saxifraga*, *Vernonia amygdalina and Pittosporum viridiflorum* are other species in decreasing order of average cover abundance values.

Cordia africana and *Acacia abyssinica (Group* II)

This group of shade trees in the SFC was composed of 15 sample plots and it was named after two dominant canopy trees (*Cordia africana,* cover abundance = 6.7 and *Acacia abyssinica*, cover abundance = 5.3). Other plant species in this group include *Albizia gummifera*, *Croton macrostachyus*, *Celtis africana*, *Ficus thonningi*, *Vepris dainellii*, *Clausena anisata*, *Vernonia amygdalina*, *Vernonia auriculifera*, *Sapium ellipticum*, *Ehreta cymosa*, *Vangueria apiculata*, *Maesa lanceolata*, *Prunus africana*, *Allophylus abyssinicus*, *Bridelia micrantha*, *Ficus sur*, *Ficus vasta*, *Polyscias fulva*, *Syzygium guineense*, *Diospyros abyssinica*, *Podocarpus falcatus*, *Schrebera alata*, *Trichilia dregeana*, *Dracaena steudneri* and *Grewia ferruginea*.

Millettia ferruginea and *Acacia abyssinica* (Group III)

This group was named by two coffee shade trees (*Millettia ferruginea* and *Acacia abyssinica*) with 6.6 and 4.4 cover abundance values respectively. This group is composed of five sample plots. Included in this group are *Croton macrostachyus*, *Cordia africana*, *Albizia gummifera*, *Bersama abyssinica*, *Prunus africana*, *Sapium ellipticum*, *Schefflera abyssinica*, *Ekebergia capensis*, *Polyscias fulva*, *Maesa lanceolata* and *Maytenus arbutifolia*

Croton macrostahyus and *Diospyros abyssinica* (Group IV)

Group IV is compsed of 10 sample plots and was named by two tree species (*Croton macrostachyus* and *Diospyros abyssinica*) with relatively high average abundance values (6 and 5.7 respectively) than any plant species in the group. The other plant species in this group in decreasing order of average abundance values are *Millettia ferruginea*, *Cordia africana*, *Ficus mucuso*, *Dracaena steudneri*, *Celtis africana*, *Albizia gummifera*, *Ficus sur*, *Trilepisium madagascariense*, *Ficus vasta*, *Vepris dainellii*, *Chionanthus mildbraedii*, *Ficus thonningi*, *Sapium ellipticum*, *Trichilia dregeana*, *Ehreta cymosa*, *Rothmania urcelliformis*, *Bersama abyssinica*, *Flacourtia indica*, *Prunus africana*, *Syzygium guineense*, *Vangueria apiculata*, *Terminalia schimperiana*, *Phoenix reclinata* and *Maesa lanceolata.*

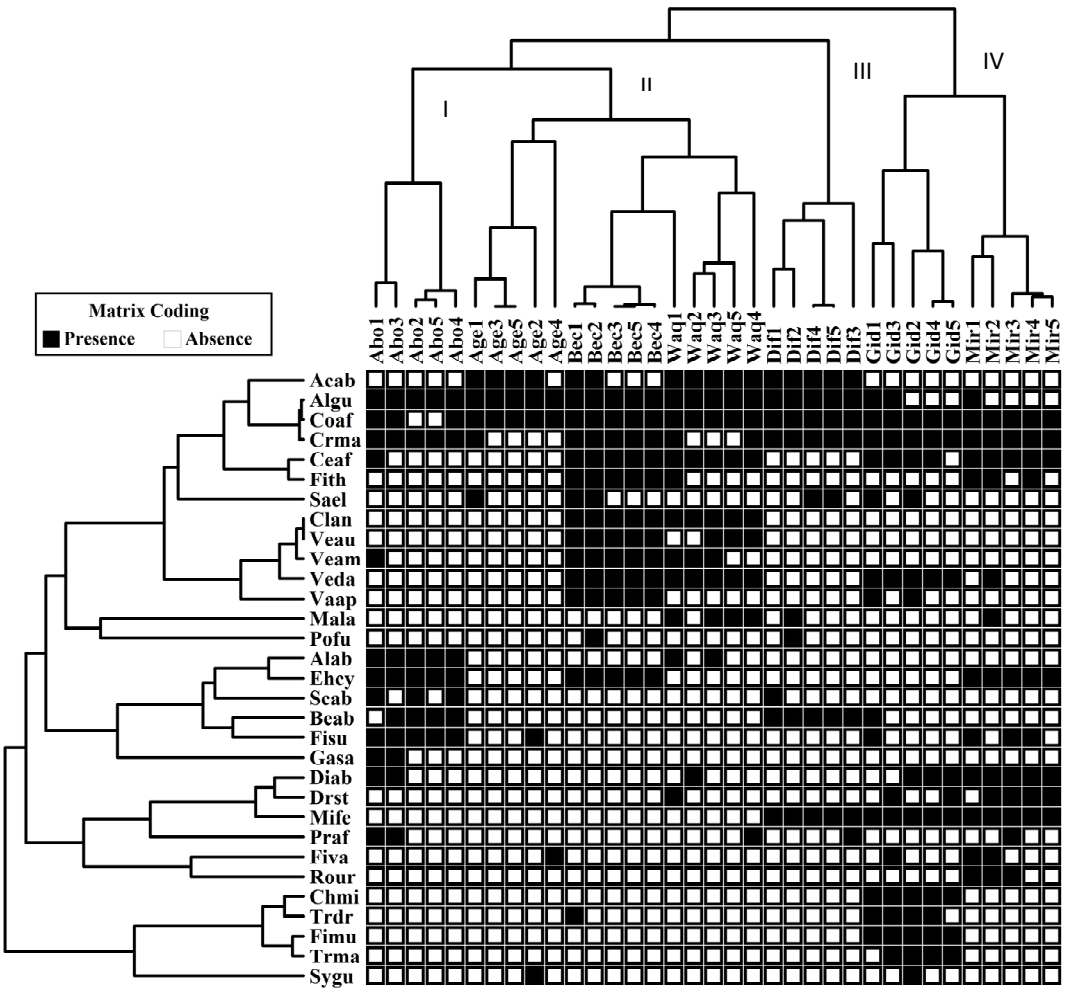


Figure 9: Group of canopy trees in the SFC in the study transect in the Jimma Highlands (I, II, III and IV represent group 1-4 respectively)

High species richness was observed in group II and IV compared to the species richness in gropu I and III (Table 12). Group IV was with the highest species diversity, while group III was the least in species diversity (Table 12). Group I was the most dominant group compared to groups.II, III and IV.

Table 12: Species richness, abundance, dominance, diversity and evenness in different groups of SFC

	Group_I	Group_II	Group_III	Group_IV
Richness	15	27	13	26
Abundance	48.40	41.33	27.20	52.30
Dominance	0.10	0.08	0.13	0.07
Shannon_H	2.47	2.79	2.27	2.92
Evenness	0.79	0.60	0.74	0.71

4.2.6. Vegetation structure

4.2.6.1. Land use type and plant species abundance

The plant species abundance varies from land use to land use type (Figure 10). It shows a decline in mean abundance of plant species from plantation forest to pastureland. The mean abundance for plantation forest was the highest, while pasture was the least in tree species abundance (Table 16).

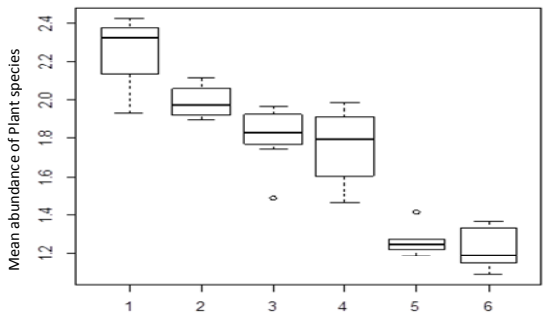


Figure 10: Box plot of species abundance in different land use types (1 = plantation forest, 2 = DNF, 3 = SFC, 4 = woodland, 5 = cropland, 6 = pasture)

Analysis of variance test showed significant difference within land use types in plant species abundance (Table 13). A post hoc test showed significant differences between SFC and cropland, pasture, plantation forests, but it did not show any significant variation from DNF and woodland (Table 14). Cropland showed a strong significant relationship with DNF, plantation forests, woodland, but did not show significant difference from pasture (Table 14). As with the cropland, the variation between DNF and pasture was also significant and pasture was also different from plantation forests and with woodland. A significant statistical difference was also shown between plantation forest and woodland wheras three homogenous groups were also produced (Table 15).

Table 13: Difference in species abundance (4th root_abundance) across different land use types

	SS	**df**	**MS**	**F**	**P**
Between Groups	3.483	5	0.697	28.824	0.00
Within Groups	0.556	23	0.024		
Total	4.038	28			

Table 14: Pairwise comparison in species abundance between different land use types (LB = lower bound, UB = upper bound)

					95% CI	
Land use 1	**Land use 2**	**MD1 & 2**	**SE**	**P**	**LB**	**UB**
	Cropland	0.54	0.09	0.00	0.28	0.81
	DNF	-0.18	0.10	0.47	-0.48	0.12
	Pasture	0.59	0.09	0.00	0.30	0.87
	Plantation	-0.42	0.11	0.01	-0.75	-0.09
SFC	Woodland	0.05	0.10	1.00	-0.25	0.35
	DNF	-0.72	0.10	0.00	-1.03	-0.41
	Pasture	0.04	0.09	1.00	-0.25	0.33
	Plantation	-0.96	0.11	0.00	-1.30	-0.62
Cropland	Woodland	-0.49	0.10	0.00	-0.81	-0.18
	Pasture	0.77	0.10	0.00	0.44	1.09
	Plantation	-0.24	0.12	0.36	-0.61	0.13
DNF	Woodland	0.23	0.11	0.33	-0.11	0.57
	Plantation	-1.00	0.11	0.00	-1.36	-0.65
Pasture	Woodland	-0.54	0.10	0.00	-0.86	-0.21
Plantation	Woodland	0.47	0.12	0.01	0.10	0.84

Table 15: Homogeneous subsets among land use types in tree species abundance

Tukey HSD

land use type	N	Subset for alpha = 0.05		
		1	2	3
Pasture	5	1.2249		
Cropland	6	1.2673		
Woodland	4		1.762	
SFC	7		1.8116	
DNF	4		1.99	1.99
Plantation	3			2.2294
P		0.998	0.279	0.233

Table 16: Mean abundance of tree species in different land use types

land use type	Mean	N	Std.
SFC	135.86	7	71.17
Cropland	7.33	6	4.37
DNF	257.5	4	99.79
Pasture	6.2	5	4.49
Plantation forest	751	3	508.69
Woodland	122.25	4	94.89
Total	165.45	29	264.43

4.2.6.2. Climate variables and edaphic factors against species abundance

Acorrelation was conducted to evaluate the relationship between plant species abundance, some climate and edaphic variables and elevation (Appendix 11). Of all the climate, edaphic and topographic variables, elevation, mean annual rainfall,, maximum temperature warmest month, mean annual temperature, annual moisture index, potential evapotranspiration, pH, cation exchange capacity and sand showed significant linear relationship with the species abundance. Most of these variables were excluded from multiple regression analysis due to collinearity effect among themselves. Only four variables (PET, pH, CEC and sand) with variance inflation factor (VIF) < 10 were taken into the model (Table 17). Combined together, the four variables significantly explained about 47% of the variation in species abundance (R^2 = 0.47, R^2_{adj} = 0.38, SE = 0.30, F = 5.29, P = 0.003). The separate contribution of sand to the model was statistically significant (P = 0.01), while the remaing three variables have no significant contribution separately (Table 17).

Table 17: Contribution of each predictor variable to the model and VIF value for each explanatory variable, (PET = Potential evapotanspiration, CEC = cation exchange capacity, BLD = bulk density), dependent variable: abundance

Model	Unstand_Coef		Stand_Coef			
	B	SE	Beta	t	P	VIF
Constant	4.73	1.97		2.40	0.02	
PET	0.00	0.00	-0.46	-1.17	0.25	6.91
PH	-0.05	0.06	-0.32	-0.95	0.35	5.03
CEC	0.06	0.05	0.34	1.30	0.20	3.15
Sand	0.107	0.04	0.51	2.78	0.01	1.52

4.2.6.3. Basal area across land use types

Relatively, larger basal area was calculated for plantation forests followed by DNF and SFC. The minimum basal area was recorded for pasture and cropland (Figure 11). Among the species occurring across the transect, *Albizia gummifera* was the top tree species in basal area contribution in the SFC (Table 18). *Croton macrostachyus*, *Ficus mucuso* and *Cordia africana* were second, third and fourth with the basal area contribution in the SFC (Table 18). *Ficus sur*, *Apodytes dimidiata*, *Schefflera abyssinica*, *Syzygium guineense*, *Albizia gummifera* and *Celtis africana* have contributed >1 basal area ha^{-1} in the DNFs (Table 19).

One way ANOVA test showed significant mean difference in basal area among the land use types (Table 20). Multiple comparison tests showed significant differences between DNF and pasture, woodland, croplandand plantation forest; between SFC and pasture, woodland, cropland and plantation forest; between pasture and plantation forest; between woodland and plantation forest; between cropland and plantation forest. Significant statistical difference was not observed between DNF and SFC, between pasture and woodland, pasture and cropland and between woodland and cropland.

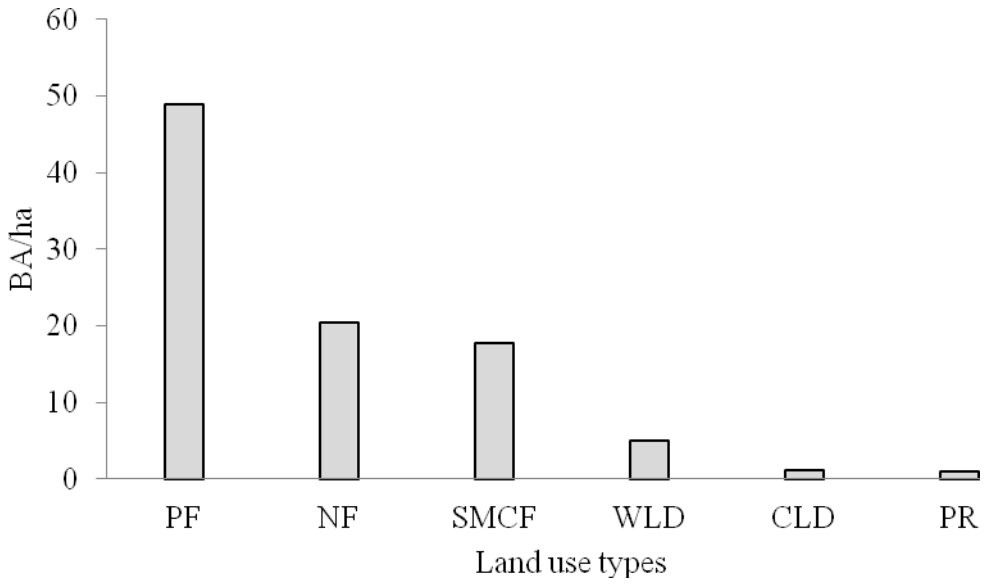


Figure 11: Tree species basal area in each land use type across the transect in the Jimma Highlands (PF = Plantation Forest, DNF = Degraded natural forest, SFC = Semi-forest coffee, WLD = Woodland, CLD = Cropland, PR = Pasture)

Table 18: Basal area contribution of tree species in SFC

Species	**BA (Total)**	**BA ha^{-1}**	**%BA**
Albizia gummifera	25.19	3.60	20.27
Croton macrostachyus	19.45	2.78	15.65
Ficus mucuso	15.98	2.28	12.85
Cordia africana	11.59	1.66	9.32
Dracaena steudneri	8.17	1.17	6.57
Acacia abyssinica	7.47	1.07	6.01
Millettia ferruginea	5.19	0.74	4.18
Ficus sur	4.35	0.62	3.50
Ficus vasta	4.28	0.61	3.44
Ehretia cymosa	3.02	0.43	2.43
Sapium ellipticum	2.72	0.39	2.19
Ficus thonningii	2.64	0.38	2.13
Celtis africana	2.61	0.37	2.10
Diospyros abyssinica	2.05	0.29	1.65

Table 19: Basal area contribution of tree species in DNF

DNF	BA (Total)	BA ha^{-1}	% BA
Ficus sur	19.19	4.80	23.42
Apodytes dimidiata	12.02	3.01	14.67
Schefflera abyssinica	8.89	2.22	10.85
Syzygium guineense	7.72	1.93	9.42
Albizia gummifera	5.87	1.47	7.16
Celtis africana	4.55	1.14	5.56
Macaranga capensis	3.57	0.89	4.36
Olea welwitschii	2.33	0.58	2.84
Chionanthus mildbraedi	2.26	0.57	2.76
Millettia ferruginea	2.24	0.56	2.74

Table 20: The difference of land use types in basal area

	SS	df	MS	F	P
Between Groups	6067.48	5	1213.50	29.81	0.00
Within Groups	936.30	23	40.71		
Total	7003.77	28			

4.2.7. Vertical stratification in SFC and DNF

Following the IUFRO classification scheme, vertical structure of trees was classified in the SFC and DNF into three layers. Height of the tallest tree was used to decide on the cut points for each layer. In the SFC, *Albizia gummifera was* the tallest tree

(height = 40 m), while the tallest tree in the DNF was *Apodytes dimidiata* (height = 35 m). The vertical stratification for the SFC and DNF was addressed one after the other. Based on the height of *Albizia gummifera*, the SFC was classified into lower, middle and upper storeys. The abundance per hectare of tree species increased from the lower to the middle and decreased from the middle to the upper storey (Figure 12) as listed in Table 21. The six most abundant tree species are indicated in Figure 13. Some tree species such as *Albizia gummifera*, *Croton macrostachyus* and *Celtis africana* have representative trees in all the three storeys.

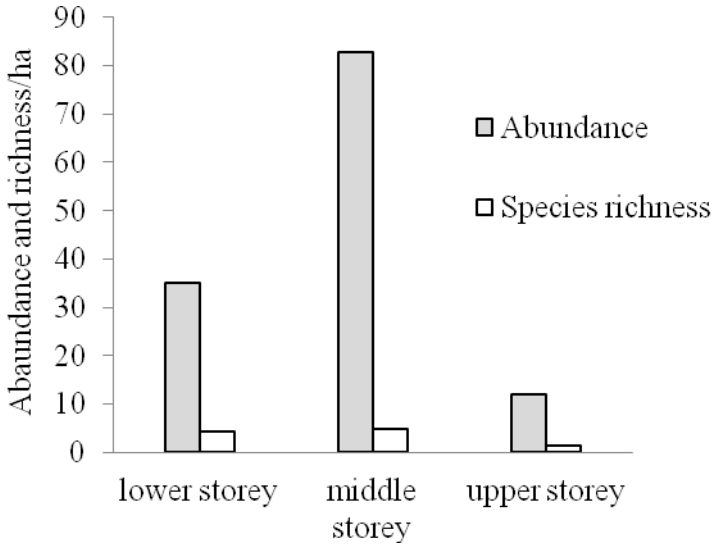


Figure 12: Tree species richness and abundance in the vertical stratification of canopy trees in SFC (lower < 13.33m, middle = 13.33–26.67m, upper > 26.67m)

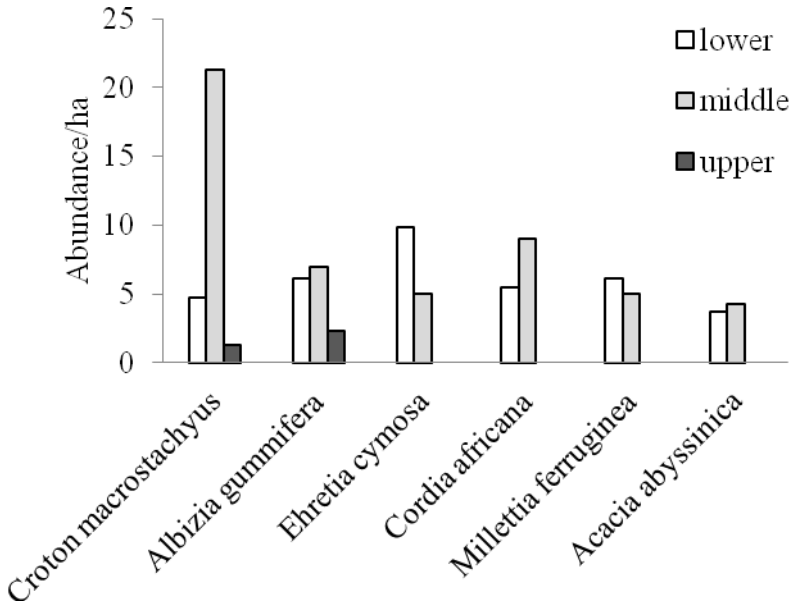


Figure 13: Abundance of six major canopy trees in the vertical stratification of canopy trees in SFC (lower = <13.33m, middle = 13.33–26.67m, upper = >26.67m)

The emergent tree species in the DNF was *Apodytes dimidiata*. The middle storey was relatively with more number of species compared to the lower and upper storeys (Figure 14). Tree species are most abundant in the middle storey compared to the lower and upper storeys (Figure 14) and are listed in Table 23. The six most abundant tree species in the DNF are indicated in (Figure 15). Some tree species such as *Albizia gummifera*, *Apodytes dimidiata, Croton macrostachyus*, *Millettia ferruginea*, *Prunus africana*, *Schefflera abyssinica* and *Syzygium guineense* were represented in all the three storeys.

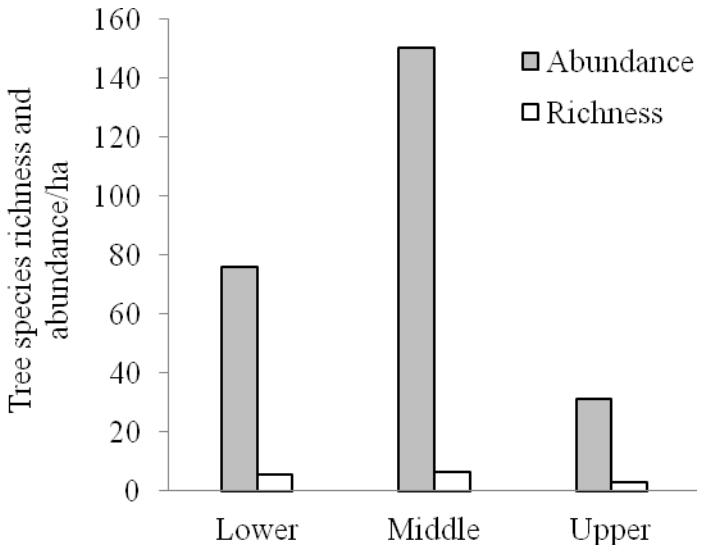


Figure 14: Tree species abundance and richness in the lower, middle and upper storeys of the canopy trees in DNFs (lower <11.67m, middle = 11.67–23.33m, upper = >23.33m)

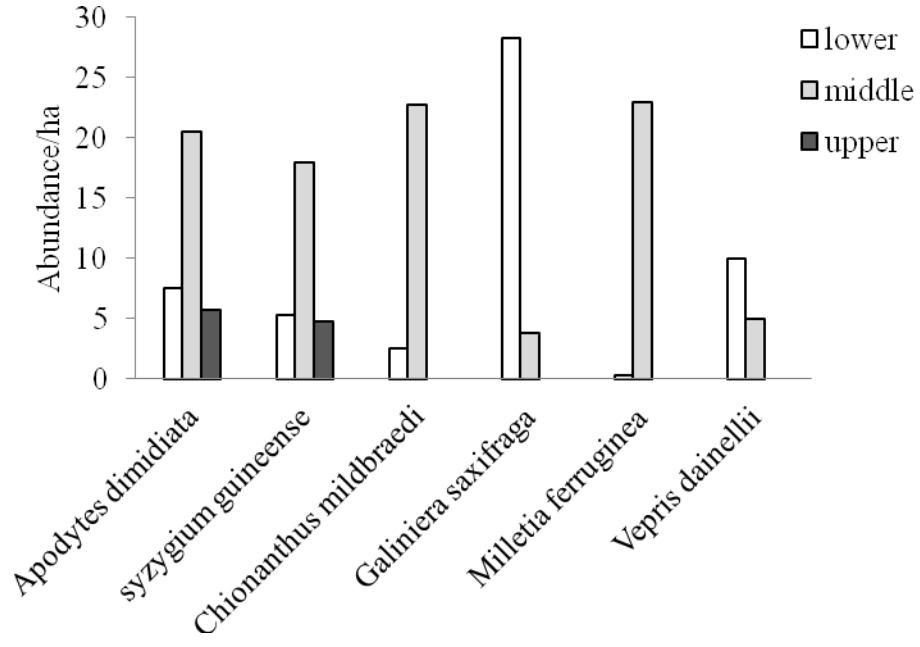


Figure 15: Abundance of six most important canopy trees in the vertical stratification of DNF (lower <11.67m, middle = 11.67–23.33m, upper = >23.33m)

Table 21: Tree species abundance per hectare in SFC

Species name (in SFC)	**Lower**	**Middle**	**Upper**	**Sum**	**Abundance ha^{-1}**
Croton macrostachyus	33	149	9	191	27.29
Albizia gummifera	43	49	16	108	15.43
Ehretia cymosa	69	35	0	104	14.86
Cordia africana	38	63	0	101	14.43
Millettia ferruginea	43	35	0	78	11.14
Acacia abyssinica	26	30	0	56	8
Celtis africana	6	23	1	30	4.29
Vepris dainellii	25	5	0	30	4.29
Dracaena steudneri	7	19	0	26	3.71
Ficus mucuso	0	22	0	22	3.14
Clausena anisata	14	0	0	14	2
Diospyros abyssinica	4	10	0	14	2
Vernonia amygdalina	11	1	0	12	1.71
Bersama abyssinica	10	1	0	11	1.57
Ficus sur	1	10	0	11	1.57
Allophylus abyssinicus	1	9	0	10	1.43
Ficus thonningii	2	7	0	9	1.29
Vernonia auriculifera	8	0	0	8	1.14
Chionanthus mildbraedii	7	0	0	7	1
Maesa lanceolata	7	0	0	7	1
Sapium ellipticum	1	6	0	7	1
Vangueria apiculata	7	0	0	7	1
Prunus africana	0	5	0	5	0.71
Trichilia dregeana	1	4	0	5	0.71
Ficus vasta	0	4	0	4	0.57
Schefflera abyssinica	1	3	0	4	0.57
Trilepisium madagascariense	0	4	0	4	0.57

Species name (in SFC)	Lower	Middle	Upper	Sum	Abundance ha^{-1}
Ekebergia capensis	3	0	0	3	0.43
Grewia ferruginea	3	0	0	3	0.43
Rothmania urcelliformis	1	2	0	3	0.43
Bridelia micrantha	1	1	0	2	0.29
Galiniera saxifraga	2	0	0	2	0.29
Polyscias fulva	1	1	0	2	0.29
Syzygium guineense	0	2	0	2	0.29
Apodytes dimidiata	0	1	0	1	0.14
Flacourtia indica	1	0	0	1	0.14
Maytenus arbutifolia	1	0	0	1	0.14
Phoenix reclinata	1	0	0	1	0.14
Pittosporum viridiflorum	1	0	0	1	0.14
Podocarpus falcatus	1	0	0	1	0.14
Schrebera alata	1	0	0	1	0.14
Terminalia schimperiana	1	0	0	1	0.14

Table 22: Tree species abundance per hectare in DNF

Species	**Lower**	**Middle**	**Upper**	**Sum**	**Abundanceha^{-1}**
Albizia gummifera	2	11	11	24	6
Allophylus abyssinicus	11	26	0	37	9.25
Apodytes dimidiata	30	82	23	135	33.75
Bersama abyssinica	21	16	0	37	9.25
Brucea antidysenterica	1	0	0	1	0.25
Canthium oligocarpum	5	5	0	10	2.5
Celtis africana	0	11	18	29	7.25
Chionanthus mildbraedi	10	91	0	101	25.25
Cordia africana	0	20	0	20	5
Croton macrostachyus	3	23	5	31	7.75
Ekebergia capensis	0	0	1	1	0.25
Ficus sur	0	26	27	53	13.25
Ficus sycamoras	0	2	0	2	0.5
Galiniera saxifraga	113	15	0	128	32
Macaranga capensis	2	28	0	30	7.5
Maytenus arbutifolia	6	0	0	6	1.5
Millettia ferruginea	1	92	9	102	25.5
Nuxia congesta	3	1	0	4	1
Olea welwitschii	0	0	2	2	0.5
Oxyanthus speciosus	2	0	0	2	0.5
Phoenix reclinata	5	5	0	10	2.5
Podocarpus falcatus	0	7	0	7	1.75
Polyscias fulva	1	1	0	2	0.5
Prunus africana	2	3	3	8	2
Psychotria orophila	4	0	0	4	1
Rothmania urcelliformis	0	5	0	5	1.25
Schefflera abyssinica	3	16	5	24	6
Syzygium guineense	21	72	19	112	28
Teclea nobilis	18	16	0	34	8.5

Species	Lower	Middle	Upper	Sum	Abundanceha^{-1}
Trichilia dregeana	0	2	2	4	1
Vangueria apiculata	0	5	0	5	1.25
Vepris dainellii	40	20	0	60	15

4.2.7.1. Vertical stratification and species diversity in SFC

Diversity, abundance, dominance and evenness of species varied along the vertical stratification of SFC. The individual trees that remain in the lower, those reaching and remaining in the middle and those reaching the upper storey are composed of different number of species (Table 23). The dominance increased from lower to upper storey (Table 23). The Shannon diversity index also shows variation in species diversity in the three storeys showing declines from the lower, via the middle to the upper storey (Table 23).

The species diversities in the three storeys were compared using bootstrapping (one of the two randomization procedures). The diversity profile test confirmed that the three storeys showed significant difference in species diversity (Figure 16). The bootstrapping test showed significant difference in species diversity index between lower and middle, lower and upper and middle and upper storeys (Table 23).

Table 23: Species abundance, richness and diversity in SFC

	Lower storey	**Middle storey**	**Upper storey**
Species	36	27	3
Abundance	383	501	26
Dominance	0.09	0.13	0.5
Shannon_H	2.77	2.48	0.79
Evenness_$e^{H/S}$	0.44	0.44	0.74

Table 24: Species richness, abundance, dominance, diversity and evenness comparison between middle and upper storey; lower and middle storey; lower and upper storey

Layer	**middle**	**upper**	**Boot p**
Species	27	3	0
Abundance	501	26	0
Dominance	0.13	0.5	0
Shannon (H)	2.48	0.79	0
Evenness $e^{H/S}$	0.44	0.74	0.5
Layer	**lower**	**middle**	**Boot p**
Species	36	27	0
Abundance	383	501	0
Dominance	0.09	0.13	0
Shannon (H)	2.77	2.48	0
Evenness $e^{H/S}$	0.44	0.44	0.97
Layer	**lower**	**upper**	**Boot p**
Species	36	3	0
Abundance	383	26	0
Dominance	0.09	0.5	0
Shannon (H)	2.77	0.79	0
Evenness $e^{H/S}$	0.44	0.74	0.7

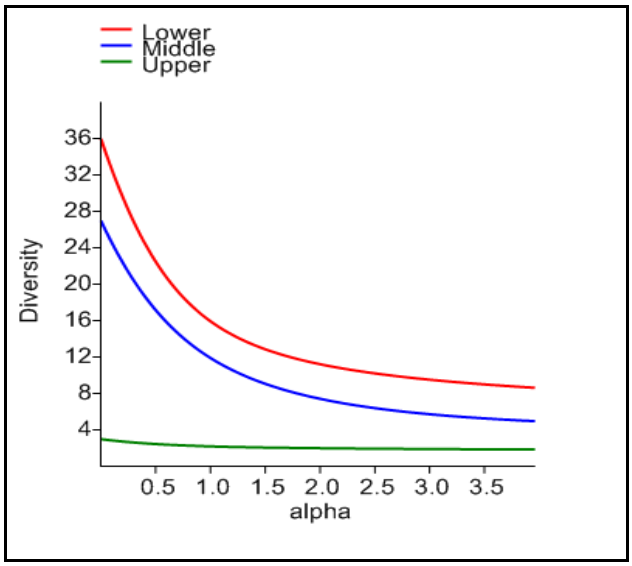


Figure 16: Diversity profile test in the lower, middle and upper storeys of the canopy trees in the SFC

4.2.7.2. Vertical stratification and species diversity in DNFs

Like in the SFC, diversity, abundance, dominance and evenness of species varied from the lower to the upper storey in the DNF. The three storeys are different in the number of canopy trees in the lower, middle and upper storeys (Table 25). The middle storey is the most diverse storey compared to the lower and upper storeys (Table 25), while the dominance was lower in the middle than in the upper and lower storeys (Table 26). Species evenness increased from the lower to the upper storeys.

The species diversities in the three storeys of the DNF were compared using bootstrapping. The diversity profile confirmed that there was significant difference in species diversity between the lower and the middle; the middle and the upper storeys and hence were comparable, while the lower and the upper storeys did not show any significant difference in diversity and hence were not comparable (Figure 17). The bootstrapping test showed significant difference in species diversity index between

lower and middle; the middle and upperstoreys, but there was no significant difference between the lower and the upper storeys (Table 26). Species richness showed significant difference between the lower and the upper; the middle and the upper, but not between the lower and the middlestoreys (Table 26). The abundance showed significant variation throughout the three storeys, while the dominance showed significant difference between the lower and the middle; the middle and the upperstoreys (Table 26).

Table 25: Species richness, abundance, dominance, diversity and evenness in DNF (lower = <13.67 m, middle = 13.67–26.67 m, upper = >26.67 m)

	Lower	**Middle**	**Upper**
Species	22	26	12
Abundance	304	601	125
Dominance	0.18	0.09	0.14
Shannon (H)	2.23	2.69	2.13
Evenness_$e^{H/S}$	0.42	0.57	0.7

Table 26: Comparison of species diversity, richness, abundance, dominance and evenness between lower and middle; lower and upper; lower and middle storeys

Layer	**Lower**	**Middle**	**Boot p**
Species	22	26	0.28
Abundance	304	601	0
Dominance	0.18	0.09	0
Shannon (H)	2.23	2.69	0
Evenness $e^{H/S}$	0.42	0.57	0.01
Layer	**Lower**	**Upper**	**Boot p**
Species	22	12	0
Abundance	304	125	0
Dominance	0.18	0.14	0.07
Shannon (H)	2.23	2.13	0.49
Evenness $e^{H/S}$	0.42	0.7	0
Layer	**Middle**	**Upper**	**Boot p**
Species	26	12	0
Abundance	601	125	0
Dominance	0.09	0.14	0
Shannon (H)	2.69	2.13	0
Evenness $e^{H/S}$	0.57	0.7	0.18

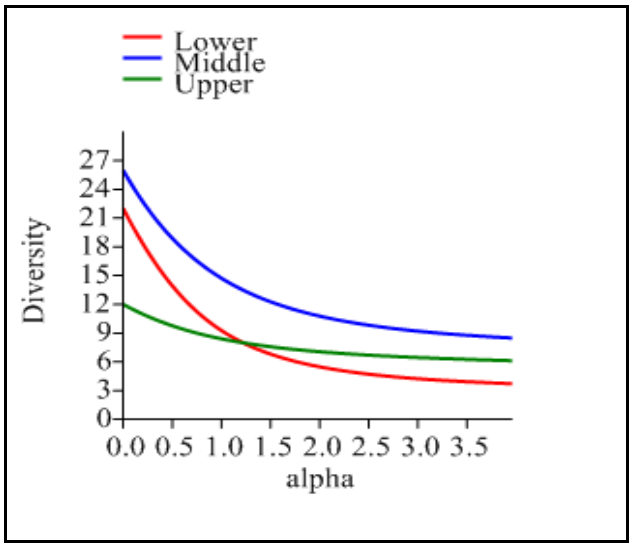


Figure 17: Diversity profile of canopy trees in the lower, middle and upper storeys in the DNF

4.3. Carbon storage

Carbon storage in DNF, SFC, plantation forest, pasture, woodland and cropland (Figure 18) of Jimma Highlands has been computed from DBH and height data of the woody species with DBH ≥ 10 cm. The above ground live carbon storage in these land use types is presented below.

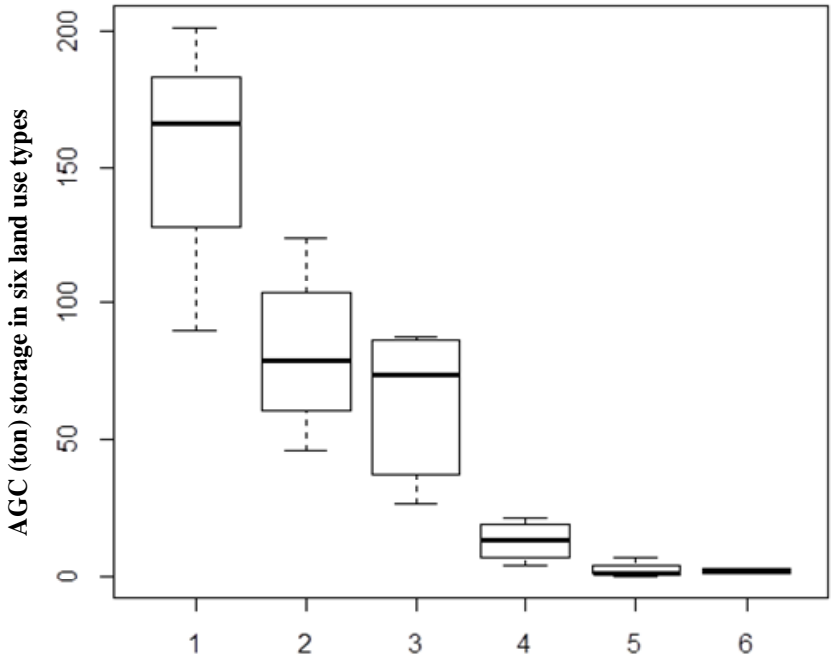


Figure 18: Boxplot for AGC storage in different land use types in Jimma transect (1 = plantation forest, 2 = DNF, 3 = semi-managed coffee forests, 4 = woodland, 5 = pasture, 6 = cropland)

4.3.1. Carbon storage in SFC

The traditional coffee management system in Ethiopia played an important role in carbon storage. Most of the SFC are characterized by very tall trees with a large

diameter trunk. These trees were primarily maintained for shade provision for coffee shrubs beneath, but now they are also important source of ecosystem services such as climate regulation, soil and water conservation, pollination services and carbon storage. The tree species in the SFC (Appendix 12) are important sink of carbon. The tree species belonging to 38 genera and 26 families in the SFC stored about 62 t C ha^{-1}. The most importnt tree species in carbon stoarge in SFC of the transect are *Albizia gummifera* (ca. 15 t C ha^{-1}), *Croton macrostachyus* (ca. 10 t C ha^{-1}), *Ficus mucuso* (ca. 7 t C ha^{-1}), *Acacia abyssinica* (4 t C ha^{-1}), *Dracaena steudneri* (ca. 4 t C ha^{-1}), *Cordia africana* (4 t C ha^{-1}) and *Millettia ferruginea* (ca.3 t C ha^{-1})(Appendix 12).

The five most important plant families in carbon storage in SFC of the study area were Fabaceae (ca. 22 t C ha^{-1}), Moraceae (ca. 12 t C ha^{-1}), Euphorbiaceae (ca. 11 t C ha^{-1}), Boraginaceae (ca.5 t C ha^{-1}) and Dracaenaceae (ca. 4 t C ha^{-1}). The five families with least contribution to the carbon storage were Tiliaceae (0.002 t C ha^{-1}), Pittosporaceae (0.002 t C ha^{-1}), Arecaceae (0.015 t C ha^{-1}), Combretaceae (0.0l6 t C ha^{-1}) and Podocarpaceae (0.019 t C ha^{-1}) (Appendix 12).

4.3.2. Carbon storage in DNFs

The DNF in the study transect was found to be a sink for about 82 t C ha^{-1} which is distributed among 32 species of trees belonging to 31 genera and 20 families (Appendix 13). The 10 top tree species in carbon storage are *Ficus sur*, *Apodytes dimidiata*, *Syzygium guineense*, *Celtis africana*, *Albizia gummifera*, *Schefflera*

abyssinica, *Olea welwitschii*, *Millettia ferruginea*, *Prunus africana* and *Macaranga capensis*. Five tree species that contributed least to carbon storage are *Brucea antidysenterica*, *Oxyanthus speciosus*, *Psychotria orophila*, *Vangueria apiculata* and *Maytenus arbutifolia* (Appendix 13). Ten most important plant families in AGC storage are *Moraceae*, *Icacinaceae*, *Fabaceae*, *Myrtaceae*, *Ulmaceae*, *Araliaceae*, *Oleaceae*, *Euphorbiaceae*, *Rosaceae* and *Melianthaceae* (Appendix 13). Simaroubaceae, Celastraceae and Arecaceae are the families with least AGC storage in the DNF.

4.3.3. Carbon storage in woodland

The tree species with DBH ≥ 10 cm in the woodlands across the transect were found to be a sink for about 13 t C ha^{-1}. This amount of carbon was distributed among 26 plant species which belong to 22 genera and 13 families (Appendix 14). The top five plant species in woodland with high carbon storage are *Acacia abyssinica*, *Maesa lanceolata*, *Ficus sycomoras*, *Cordia africana* and *Entada abyssinica*. Five families with higher carbon storage in the woodland are Fabaceae, Moraceae, Myrsinaceae, Combretaceae and Boraginaceae. Myrtaceae and Rubiaceae are the two families in the woodland with the least AGC storage in the woodland.

4.3.4. Carbon storage in pasture

The scattered trees in pasture across the transect were found to be a sink for about 3 t C ha^{-1}. This was distributed among 13 woody species with DBH ≥ 10 cm belonging to 13 genera and 10 families. *Ficus vasta* was the most important tree species in

AGC storage (Appendix 15). Moraceae is the most important plant family in carbon stoarge (Appendix 15).

4.3.5. Carbon storage in cropland

Cropland is the least of all land use types in carbon storage (Appendix 16). The two most important tree species in cropland are *Cordia africana* and *Prunus africana*. Boraginaceae is the most important family in carbon storage (Appendix 16).

4.3.6. Carbon storage in plantation forests

Plantation forest in our study transect was found to be a sink for about 82 t C ha^{-1}. More carbon was stored in this land use type due to management inputs and more density of trees in it than in any land use type in the transect. According to the information obtained from the local community the plantation forests are in the range of 30-40 yeas and no commercial harvesting have been reported so far.

4.3.7. Above ground live carbon storage across the transect

The highest AGC storage was recorded from plantation forests and the minimum was recorded from cropland (Table 27). The boxplot analysis showed the highest accumulation of carbon in the biomass of forests (plantation, DNF, SFC) the least carbon storage in the biomass of trees in the cropland and pasture (Figure 18).

The land use types showed significant mean differences in carbon storage at 95% confidence level (Table 28). Multiple comparisons (Table 29) showed significant

mean difference in carbon storage between SFC and cropland, pasture and woodland. Significant difference was also observed between cropland and DNF, cropland and plantation forest. The variation between DNF and pasture, DNF and woodland, pasture and plantation, pasture and woodland and plantation and woodland were statistically significant (Table 29). Significant statistical difference has not been observed between SFC and DNF, SFC and plantation forest, between cropland and pasture, cropland and woodland, between DNF and plantation forest. The homogeneity test also showed three groups of land use types in carbon storage (Table 29). Based on the similarity in AGC storage, the land use types were categorised under three sub-groups (Table 30).

Table 27: Average AGC in six land use types across the transect

Land use	**Mean**	**N**	**Std.**
SFC	61.52	7.00	24.98
Cropland	2.03	6.00	0.82
DNF	82.03	4.00	32.08
Pastureland	2.51	5.00	2.67
Plantation forest	152.25	3.00	56.81
Woodland	12.87	4.00	7.60
Total	44.54	29.00	53.33

Table 28: Analysis of variance of different land use types in AGC storage in the study transect

	SS	**df**	**MS**	**F**	**P**
Between Land uses	2.747	5	0.549	42.23	0.00
Within land uses	0.295	23	0.013		
Total	3.041	28			

Table 29: Multiple comparison test for the differences of land use types in AGC in the Jimma Highlands (MD = mean difference, LB = lower bound, UB =bound)

(I) landuse	(J) landuse	MD	SE	P	95% CI	
					LB	UB
SFC	Cropland	0.58	0.06	0.00	0.38	0.77
	DNF	-0.07	0.07	0.94	-0.29	0.15
	Pasture	0.61	0.07	0.00	0.40	0.81
	Plantation	-0.21	0.08	0.13	-0.45	0.04
	Woodland	0.31	0.07	0.00	0.09	0.53
Crop	DNF	-0.64	0.07	0.00	-0.87	-0.41
	Pasture	0.03	0.07	1.00	-0.18	0.25
	Plantation	-0.78	0.08	0.00	-1.03	-0.53
	Woodland	-0.27	0.07	0.02	-0.49	-0.04
DNF	Pasture	0.67	0.08	0.00	0.44	0.91
	Plantation	-0.14	0.09	0.60	-0.41	0.13
	Woodland	0.37	0.08	0.00	0.13	0.62
Pasture	Plantation	-0.81	0.08	0.00	-1.07	-0.56
	Woodland	-0.30	0.08	0.01	-0.54	-0.07
Plantation	Woodland	0.51	0.09	0.00	0.25	0.78

Table 30: Homogeneity test of land use types in AGC across the study transect in the Jimma Highlands

land use	N	Subset for alpha = 0.05		
		1	2	3
Pasture	5	1.049		
Cropland	6	1.0824		
Woodland	4		1.3497	
SFC	7			1.6581
DNF	4			1.7235
Plantation	3			1.8632
P		0.998	1	0.112

4.3.8. Carbon storage and species richness and abundance

The correletion coefficient between AGC storage and plant species richness in different growth forms was analysed (Table 31). Liana was excluded due to the assuption of normal distribution. AGC storage satisfied the assumption of normal distribution after 4^{th}-root transformation. The linear relationship between herbaceous species and carbon storage was not significant and shrub species and AGC storage was also not significant. The analysis showed significant linear relationship between carbon storage and tree species richness and abundance.

Multiple linear regresion model was conducted (Table 32–34) using the tree species richness and abunadnce which showed significant relationships with the carbon

storage in the linear coreletion analysis. Both variables combined have explained about 82% of the variation in AGC storage (Table 32). The contribution of tree species abundance to the model was significant, while that of tree species richness was not (Table 34).

Table 31: Linear relationships between AGC and tree, herb and shrub richness and tree species abundance

	Pearson Correlation	**Trees**	**Herb**	**Shrub**	**Abundance**
GC (4^{th} root)	R	0.601	-0.018	0.288	0.904
	P	0.001	0.928	0.129	0
	N	29	29	29	29

Table 32: Variation in AGC explained by tree species richness and abundance combined

Model	**R**	**R^2**	**R^2_{adj}**	**SE**
1	0.908	0.824	0.81	0.14366

Predictors: Constant, abundance, trees

Table 33: Multiple regression analysis for prediction of AGC using abundance and tree species richness

Model		SS	df	MS	F	P
1	Regression	2.505	2	1.252	60.679	0.00
	Residual	0.537	26	0.021		
	Total	3.041	28			

Predictors: Constant, abundance (4^{th}-root), trees; Dependent variable: AGC (4^{th}-root)

Table 34: Contribution of tree species richness and abundance to the model

Model	Unstand_Coef		Stand_Coef	t	P
	B	SE	Beta		
Constant	0.142	0.124		1.144	0.26
trees	0.004	0.004	0.094	0.912	0.37
Abundance_4^{th}-root	0.736	0.089	0.848	8.258	0.00

Dependent variable: AGC (4^{th}-root)

4.3.9. Climate variables and AGC storage

The linear relationships between AGC storage in woody species biomass and most climate variables were statistically significant, while the relationships with some variables were not significant. (Appendix 17). The variables showing significant relationships with AGC were used as predictive variables in multiple regression

analysis although most of them were excluded due to collinearity effect among themselves. They show very high variance inflation factor (VIF) when put together in the model showing strong linear relationships among themselves. All pairs of variables having significant correlation with the AGC showed higher VIF (>10) and finally a single variable with relatively higher Pearson correlation value was taken as a predictive variable in linear regression analysis of AGC. The climate variable with relatively higher linear relationship was evapotranspiration. This variable was taken into the model to predict the AGC. Potential evapotranspiration explained 21% (R^2 = 0.21, SE = 0.298, F = 7.159, P = 0.013) of the variation in AGC along the study transect. The ANOVA test for the linear regression showed significant variation (Table 35).

Table 35: Linear regression prediction of AGC by potential evapotranspiration (pet = potential evapotranspiration

Model		**SS**	**df**	**MS**	**F**	**P**
	Regression	0.637	1	0.637	7.159	0.013
	Residual	2.404	27	0.089		
	Total	3.041	28			

Predictors: Constant, pet; Dependent variable: AGC (4^{th}-root)

4.3.10. Edaphic factors and AGC storage

Pearson correlation depicted significant relationships between AGC and soil cation exchange capacity, AGC and sand, and AGC and soil pH (Table 36). Soil cation

exchange capacity and sand showed a positive relationship with AGC, while pH showed a negative relationship. AGC decreased with increasing pH and *vice versa*. Among the soil textures, silt and clay did not show significant linear relationships with AGC. The three edaphic factors (ECE, sand and pH), which showed significant linear relationships with AGC were selected for carbon prediction in multiple regression analysis (Tables 37 and 38). Before conducting the multiple regression analysis, the three variables were tested for collinearity and all of them showed VIF< 5 (Table 38) and were taken into the model. The three variables (CEC, sand and pH) combined, have significantly explained about 60% (R^2 = 0.604, R^2_{adj} = 0.556, SE = 0.220, F = 12.685, P = 0.00) of the variation in AGC.

The unstandardized regression coefficient tells us that for every unit increase of CEC, the AGC storage increases by 0.089 (controlling the effect of pH and sand). For every unit increase of pH (controlling the effect of sand and CEC), the AGC decreases by 0.145 and the same is true for sand in which the AGC increases by 0.075 for a unit increase of sand (controlling the effect of pH and CEC). The contribution of each of the three variables to the model was statistically significant (Table 38).

Table 36: Linear relationships between AGC and soil factors (CEC = cation exchange capacity, BD = bulk density)

		Silt	CEC	BD	Sand	Clay	pH
	Cor	-0.08	-0.39	-0.15	0.47	-0.35	-0.64
AGC(4^{th}_	P	0.66	0.04	0.43	0.01	0.06	0.00
Root	N	29	29	29	29	29	29

Table 37: Prediction of AGC by using soil pH, sand and soil cation exchange capacity

Model		SS	df	MS	F	P
	Regression	1.835	3	0.612	12.685	0.00
1	Residual	1.206	25	0.048		
	Total	3.041	28			

Predictors: Constant, pH, Sand, CEC; Dependent variable: AGC (4^{th}-root)

Table 38: Contribution of each variable (CEC, sand and pH) to the model

Model	Unstand_Coef		Stand_Coef			
	B	SE	Beta	t	P	VIF
Constant	4.67	1.47		3.18	0.004	
CEC	0.09	0.04	0.57	2.51	0.019	3.23
Sand	0.08	0.03	0.41	3.05	0.005	1.15
pH	-0.15	0.03	-0.995	-4.54	0.000	3.03

Dependent variable: AGC (4^{th}-root)

4.4. Leaf Area Index (LAI)

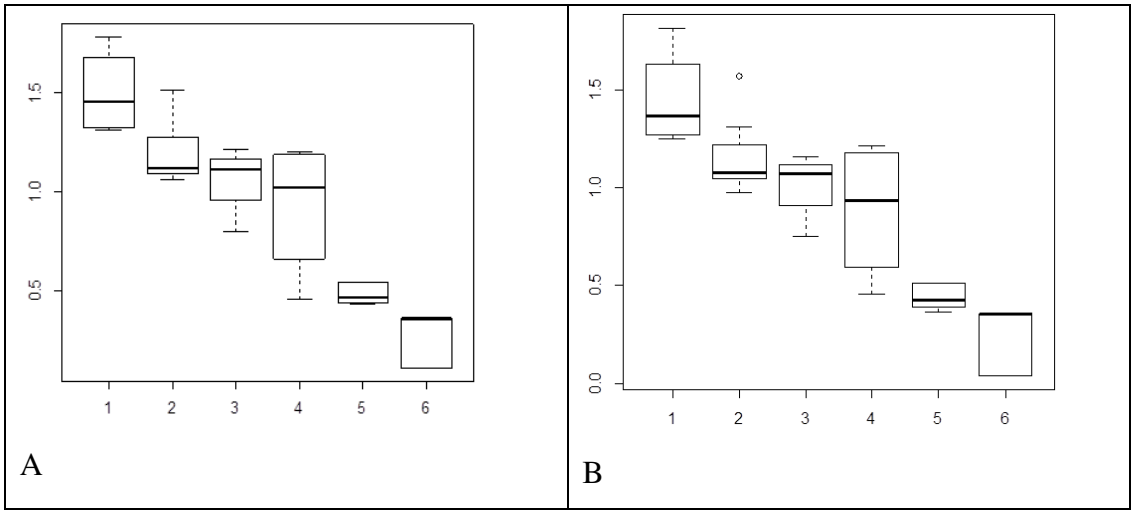


Figure 19: Boxplot analysis of LAI (A = True LAI_ V6, B = True LAI V5, 1 = DNF, 2 = SFC, 3 = plantation forest, 4 = woodland, 5= pasture, 6 = cropland)

Based on the inclusion and exclusion of vegetation clumping and different CAN-EYE versions, four LAI outputs were produced. LAI_true accounts for vegetation clumping, while LAI_effective does not. The result between LAI_true and LAI_effective are different due to the clumping effect of vegetation. The data were checked for normality prior to testing for significance variation between the outputs from the two different versions of Can-Eye. The normality test showed that LAI_effective did not satisfy the assumption of normal distribution (LAI_eff_v6 (n = 29, W = 0.88, P = 0.004) LAI_eff_v5 (n = 29, W = 0.87, P = 0.002), while the square root transformed LAI_true from both versions of CAN-EYE fulfill the assumption of normality (LAI_true_v6 (n = 29, W = 0.94, P = 0.07), LAI_true_v5 (n = 29, W = 0.94, P = 0.13)). Therefore, LAI_eff was excluded from this analysis and the parametric tests were conducted only for LAI_true from both versions of CAN-EYE.

In both LAI_true_v6 and v5, mean of LAI_true_v6 was higher than mean of LAI_true_v5 (Table 40). Boxplot test for both LAI_true_v6 (Figure 19A) and LAI_true_v5 (Figure 19B) showed that the LAI decreases in different land use types along the following orders: DNF, SFC, plantation forest, woodland, cropland and pasture. The paired sample t-test showed significant statistical difference between LAI_true_v6 and LAI_true_v5 under two versions of Cay-Eye (Tables 39 and 40).

Table 39: Mean True leaf area index (under CAN-EYE version 6 and 5) in six land use types along the study transect

	CAN-EYE_v6			**CAN-EYE_v5**		
Land use	**Mean**	**N**	**Std.**	**Mean**	**N**	**Std.**
SFC	1.47	7	0.43	1.39	7	0.53
Cropland	0.23	6	0.05	0.19	6	0.06
DNF	2.29	4	0.69	2.15	4	0.79
Pasture	0.08	5	0.06	0.08	5	0.07
Plantation	1.11	3	0.43	1.02	3	0.41
Woodland	0.95	4	0.59	0.88	4	0.61

Table 40: Mean±SE of true LAI under both v_6 and v_5 of CAN-EYE

		Mean±SE	**N**
Pair 1	LAI_true_v6	0.98±0.16	29
	LAI_true_v5	0.91±0.15	29

Table 41: Paired T-test showing significant statistical differences between True_LAI under version 6 and Version_5 of CAN-EYE

			95% CI				
	Mean	**SEM**	**Lower**	**Upper**	**t**	**df**	**P**
LAI_true_v6							
LAI_true_v5	0.07	0.02	0.025	0.108	3.32	28	0.003

4.4.1. LAI and Land Use Categories

Land use categories were found very important determinants of LAI_true from both versions of CAN-EYE. Analysis of variance showed significant mean difference in LAI_true_v6 and LAI_true_v5 within all land use types. There was significant mean difference among land use types in LAI_true_v5 and LAI_true_v6 (Table 42). Tukey's multiple comparison tests (Table 43) showed significant mean difference in LAI_true_v5 between SFC and cropland, SFC and pasture; Cropland and DNF, cropland and planation forest, cropland and woodland; between DNF and pasture, DNF and woodland; between pasture and plantation forests, and pasture and woodland. Significant statistical difference was not seen between SFC and DNF; SFC and planation forest, SFC and woodland; between cropland and pasture; between DNF and plantation forest and, and between planation forest and woodland.

There were also significant statistical differences (Table 44) in LAI_true_v6 between SFC and cropland, SFC and pasture; between cropland and DNF, cropland and plantation forest, cropland and woodland; between DNF and pasture, DNF and

woodland; between pasture and planation forest, and pasture and woodland. The difference between SFC and DNF, SFC and plantation, SFC and woodland, DNF and planation forest, and planation forest and woodland were not significant.

Table 42: Analysis of variance showing significant differences in LAI_true_v6 and v5 and among land use types in the transect

		SS	**df**	**MS**	**F**	**P**
LAI_true_v6_sqrt	Between Groups	5.255	5	1.051	27.919	0.00
	Within Groups	0.866	23	0.038		
	Total	6.121	28			
LAI_true_v5_sqrt	Between Groups	5.144	5	1.029	21.997	0.00
	Within Groups	1.076	23	0.047		
	Total	6.219	28			

Table 43: Multiple comparisons showing differences in LAI_true_v6 between each land use types (SFC, DNF, MD = mean difference, LB = lower bound, UB = upper bound)

Dependent Variable LAI_true_v5						
Land use		**MD**			**95% CI**	
I	**J**	**I&J**	**SE**	**P**	**LB**	**UB**
SFC	Crop	0.727	0.120	0.000	0.354	1.100
	DNF	-0.286	0.136	0.316	-0.707	0.134
	Pasture	0.935	0.127	0.000	0.542	1.328
	Plantation	0.170	0.149	0.859	-0.293	0.633
	Woodland	0.278	0.136	0.345	-0.142	0.699
Crop	DNF	-1.013	0.140	0.000	-1.446	-0.580
	Pasture	0.208	0.131	0.614	-0.198	0.614
	Plantation	-0.557	0.153	0.015	-1.031	-0.082
	Woodland	-0.449	0.140	0.039	-0.882	-0.015
DNF	Pasture	1.221	0.145	0.000	0.771	1.671
	Plantation	0.457	0.165	0.100	-0.056	0.969
	Woodland	0.565	0.153	0.013	0.090	1.039
Pasture	Plantation	-0.765	0.158	0.001	-1.255	-0.275
	Woodland	-0.657	0.145	0.002	-1.107	-0.206
Plantation	Woodland	0.108	0.165	0.985	-0.405	0.621

Table 44: Multiple comparisons showing differences in LAI_true_v6 between each land use types (SFC, DNF, LB = lower bound, UB = upper bound, MD = mean difference)

Dependent variable: LAI_true_v6						
Land use		**MD**			**95% CI**	
I	**J**	**I&J**	**SE**	**P**	**LB**	**UB**
SFC	Crop	0.724	0.108	0.000	0.389	1.059
	DNF	-0.296	0.122	0.185	-0.674	0.081
	Pasture	0.946	0.114	0.000	0.594	1.299
	Plantation	0.164	0.134	0.821	-0.252	0.579
	Woodland	0.280	0.122	0.232	-0.097	0.658
Crop	DNF	-1.020	0.125	0.000	-1.409	-0.632
	Pasture	0.222	0.117	0.431	-0.142	0.587
	Plantation	-0.560	0.137	0.005	-0.986	-0.134
	Woodland	-0.444	0.125	0.019	-0.832	-0.055
DNF	Pasture	1.243	0.130	0.000	0.839	1.647
	Plantation	0.460	0.148	0.050	0.001	0.920
	Woodland	0.577	0.137	0.004	0.151	1.002
Pasture	Plantation	-0.782	0.142	0.000	-1.222	-0.343
	Woodland	-0.666	0.130	0.000	-1.070	-0.262
Plantation	Woodland	0.116	0.148	0.967	-0.343	0.576

4.4.2. LAI and plant basal area, abundance and richness

A Pearson correlation test (Table 45) showed significant linear relationships between LAI_true_v6 and tree species basal area (BA_log), total plant species richness, richness in shrub, tree species and woody species abundance (abund_4^{th}_root). The test also showed significant linear relationships between LAI_true_v5 and tree BA_log, shrub, tree species, total plant richness and woody species abundance. Herbaceous species richness was not significantly related to both LAI_true_v6 and LAI_true_v5.

Multiple regressions with the explanatory variables having significant linear relationships with both LAI_true_v6 and v5 (BA_log, richness of shrubs, trees, total richness and abundance_4^{th}_root transformed) was conducted (Tables 45-49). The variables were tested for collinearity and all of them were with VIF < 10 (Table 47). The variables combined together have significantly explained about 82% (R^2 = 0.824, R^2_{adj} = 0.786, SE = 0.22) and 81% (R^2 = 0.811, R^2_{adj} = 0.77, SE = 0.23) of the variations in LAI_true_v6 and LAI_true_v5 respectively. Log transformed BA was the only variable with the highest contribution to the model of LAI_v6 and LAI_v5.

Table 45: Linear relationships between True leaf area indices, basal area, plant species richness and abundance (BA = basal area, abund_4th = 4th root transformed tree species abundance)

	Pearson	**BA_log**	**Herb**	**Shrubs**	**Trees**	**richness**	**abund_4th**
LAI_v6	Cor.	0.87	0.11	0.41	0.73	0.50	0.79
	P	0.00	0.56	0.03	0.00	0.01	0.00
	N	29	29	29	29	29	29
LAI_v5	Cor.	0.86	0.11	0.41	0.72	0.49	0.78
	P	0.00	0.59	0.03	0.00	0.01	0.00
	N	29	29	29	29	29	29

Table 46: Analysis of variance for the multiple regression of LAI_v6 with explanatory variables

Model		**SS**	**df**	**MS**	**F**	**P**
1	Regression	5.044	5	1.009	21.553	0
	Residual	1.077	23	0.047		
	Total	6.121	28			

Predictors: Constant, abundance (4th-root), richness, BA (log), tree species richness

Dependent variable: LAI_v6)

Table 47: Contribution of basal area, shrub richness, tree species richness, plant species richness along the entire study area and tree species abundance (BA_log = log transformed basal area, Abund_4^{th} = 4^{th} root transformed tree species abundance)

Model	Unstand_Coef		Stand_Coef			
	B	SE	Beta	t	P	VIF
Constant	0.305	0.34		0.909	0.373	
BA_log	0.404	0.13	0.64	3.225	0.004	5.15
Shrubs	-0.046	0.11	-0.088	-0.412	0.684	5.987
Trees	0.019	0.01	0.328	1.642	0.114	5.208
Richness	0.002	0.01	0.076	0.28	0.782	9.763
Abun_4th	0.045	0.25	0.036	0.177	0.861	5.478

Dependent variable: LAI_v6

Table 48: Analysis of variance test for the prediction of LAI_v5 by the explanatory variables –Tree species abundance, basal area, richness, shrub species richness and richness across the entire transect

Model		SS	df	MS	F	P
1	Regression	5.042	5	1.008	19.703	0.00
	Residual	1.177	23	0.051		
	Total	6.219	28			

Dependent variable: LAI_v5

Table 49: Contribution of basal area, shrub richness, tree species richness, plant species richness along the entire study area and tree species abundance (BA_log = log transformed basal area, Abun_4th = 4th root transformed tree species abundance)

	Unstand_Coef		Stand_Coef			
Model	**B**	**SE**	**Beta**	**t**	**p**	**VIF**
Constant	0.293	0.351		0.84	0.41	
BA_log	0.416	0.131	0.652	3.17	0	5.15
Shrubs	-0.031	0.116	-0.059	-0.27	0.79	5.987
Trees	0.021	0.012	0.35	1.69	0.1	5.208
Richness	0.001	0.006	0.033	0.12	0.91	9.763
Abun_4th	0.007	0. 263	0.006	0.03	0.98	5.478

Dependent variable: LAI_v5

4.4.3. LAI, edaphic and topographic factors

Topographic (elevation and slope) and edaphic factors (soil organic carbon (SOC), cation exchange capacity (CEC), soil texture (silt, sand, clay) and BD) were tested for linear relationships with LAI_true_v6 and LAI_true_v5 (Table 50). All topographic and some of the edaphic factors (SOC and BD) did not show significant linear relationships with both LAI_true_v6 and LAI_true_v5. The relationships between LAI_true_v6 and soil CEC, sand and clay was significant. LAI_true_v5 also showed significant linear relationships with CEC, sand and clay.

The explanatory variables (CEC, sand, clay) which showed significant linear relationships with both LAI _true_v6 and v5 were tested for collinearity before

conducting multiple regressions. All of them were found to have VIF < 10 (Tables 52 and 54). Multiple regression analysis (Tables 51–54) showed combined effect of the three explanatory variables. Combined, the three variables explained about 45% (R^2 = 0.45, R^2_{adj} = 0.39, SE = 0.37) of the variation in LAI _true_v6 and about 42% (R^2 = 0.42, R^2_{adj} = 0.35, SE = 0.38) of the variation in LAI_true_v5. In LAI_true_v6, sand has significant contribution to the model (Table 53), while in LAI_true_v5 all the three variables did not show significant contribution to the model separately (Table 54).

Table 50: Linear relationships between LAI_true indices and topographic factors (elevation and slope) and edaphic factors (SOC, CEC, silt, sand, clay and BD)

LAI type	**Pearson**	**Elev**	**SOC**	**CEC**	**slope**	**silt**	**sand**	**clay**	**BD**
	Cor.	0.36	-0.03	-0.41	-0.05	0.00	0.64	-0.55	-0.35
	P	0.06	0.87	0.03	0.79	1.00	0.00	0.00	0.06
LAI_true_v6	N	29	29	29	29	29	29	29	29
	Cor.	0.35	0.00	-0.41	-0.03	0.02	0.62	-0.54	-0.35
	P	0.06	1.00	0.03	0.88	0.92	0.00	0.00	0.07
LAI_true_v5	N	29	29	29	29	29	29	29	29

Table 51: Analysis of variance test for the prediction of LAI_true_v6 by the explanatory variables (clay, CEC and sand across the entire transect)

Model		SS	df	MS	F	P
1	Regression	2.758	3	0.919	6.835	.002
	Residual	3.362	25	0.134		
	Total	6.121	28			

Preidctors: Constant, Clay, CEC, Sand; Dependent variable: LAI_true_v6

Table 52: Contribution of CEC, sand and clay to the model

	Unstand_Coef		Stand_Coef			Collinearity
Model	**B**	**SE**	**Beta**	**t**	**P**	**VIF**
Constant	-2.474	4.173		-0.59	0.559	
CEC	-0.047	0.037	-0.21	-1.27	0.214	1.22
Sand	0.141	0.064	0.548	2.204	0.037	2.809
Clay	-0.006	0.058	-0.03	-0.1	0.924	2.997

Dependent variable: LAI_v6

Table 53: Analysis of variance test for the prediction of LAI_true_v5 by the explanatory variables- clay, CEC and sand across the transect

Model		SS	df	MS	F	P
1	Regression	2.613	3	0.871	6.04	0.003
	Residual	3.606	25	0.144		
	Total	6.219	28			

Predictors: Constant, Clay, ECE, Sand; Dependent variable: LAI_v5

Table 54: Contribution of CEC, sand and clay to the model

	Unstand_Coef		Stand_Coef			Collinearity
Model	**B**	**SE**	**Beta**	**t**	**P**	**VIF**
(Constant)	-1.772	4.322		-0.41	0.685	
CEC	-0.046	0.038	-0.21	-1.22	0.234	1.22
Sand	0.129	0.066	0.494	1.936	0.064	2.809
Clay	-0.014	0.06	-0.06	-0.23	0.82	2.997

Dependent variable: LAI_v5

4.4.4. LAI, enhanced vegetation index and normalized difference vegetation index

Enhanced vegetation index (EVI) and normalized vegetation index (NDVI) respectively showed significant linear relationships with LAI_true_v6 and LAI_true_v5 (Table 55). Both NDVI and EVI were used as predictor variables in multiple regressions with LAI_v6 and LAI_v5 (Tables 56–59). NDVI and EVI combined together have explained about 61% (R^2 = 0.611, R^2_{adj} = 0.581, RSE = 0.30275, F = 20.387, P = 0.00) of the variation in LAI_true_v6 and 60% (R^2 = 0.599, R^2_{adj} = 0.568, RSE = 0.3097, F = 19. 416, P = 0.00) of the variation in LAI_true _v5. In both LAI_true_v6 and LAI_true_v5, NDVI has significant contribution to the model, while EVI was not singly (Tables 57 and 59). In both LAI_v6 and LAI_v5, the analysis of variance showed significant result (Tables 56 and 58).

Table 55: Linear relationships between LAI_true indices and NDVI and EVI

LAI Type	Bivariate	NDVI	EVI
LAI_true_v6_sqrt	Pearson Correlation	0.77	0.69
	P	0.00	0.00
	N	29	29
LAI_true_v5_sqrt	Pearson Correlation	0.75	0.69
	P	0.00	0.00
	N	29	29

Table 56: Analysis of variance test for the prediction of LAI_true_v6 by the explanatory variables –EVI and NDVI

Model		SS	df	MS	F	P
1	Regression	3.737	2	1.869	20.387	0.00
	Residual	2.383	26	0.092		
	Total	6.121	28			

Predictors: Constant, EVI, NDVI; Dependent variable: LAI_v6

Table 57: Contribution of NDVI and EVI separately to the model

	Unstand_Coef		Stand_Coef			
Model	B	SE	Beta	t	p	VIF
Constant	-0.229	0.421		-0.544	0.591	
NDVI	1.612	0.527	0.585	3.061	0.005	2.435
EVI	0	0	0.237	1.242	0.225	2.435

Dependent variable: LAI_true_v6

Table 58: Analysis of variance test for the prediction of LAI_true_v5 by the explanatory variables- EVI and NDVI

Model		SS	df	MS	F	P
1	Regression	3.725	2	1.863	19.416	0.00
	Residual	2.494	26	0.096		
	Total	6.219	28			

Predictors: Constatnt, EVI, NDVI; Dependent variable: LAI_true_v5_sqrt

Table 59: Contribution of NDVI and EVI to the model

	Unstand_Coef		Stand_Coef			
Model	B	SE	Beta	t	P	VIF
Constant	-0.36	0.43		-0.82	0.418	
NDVI	1.502	0.54	0.54	2.788	0.01	2.435
EVI	0	0	0.277	1.431	0.164	2.435

Dependent variable: LAI_true_v5_sqrt

4.4.5. LAI and AGC storage

Both LAI_true_v6 and LAI_true_v5 showed strong linear relationship with AGC t ha^{-1}(4^{th}-root transformed) across the land use types in the study transect (Table 60). Due to the effect of collinearity the LAI_true_v5 was avoided from the regression analysis and conducted with LAI_true_v6. The linear regression analysis (Table 61) and Figure 20) showed that LAI_true_v6 explained about 75% (R^2 = 0.754, R^2_{adj} =

0.745, RSE = 0.166, F = 82.87, P = 00) of the variation in AGC t ha^{-1} along the study transect.

Table 60: Linear relationship between LAI_true indices and AGC

	Peason Correlation	**AGC t ha^{-1} (4^{th}_Root)**
LAI_true_v6_sqrt	R	0.87
	P	0
	N	29
LAI_true_v5_sqrt	R	0.86
	P	0
	N	29

Table 61: Analysis of variance test for the prediction of AGC by the explanatory variable –LAI_true_v6

Model		**SS**	**df**	**MS**	**F**	**P**
1	Regression	2.294	1	2.294	82.87	0
	Residual	0.747	27	0.028		
	Total	3.041	28			

Predictors: constant, LAI_true_v6_sqrt; Dependent variable: AGCt ha^{-1}

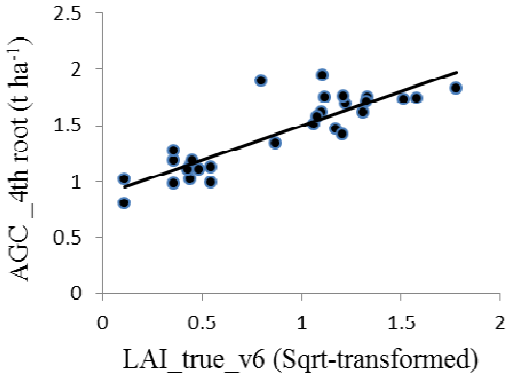


Figure 20: Prediction of above ground live carbon storage from leaf area index

4.4.6. LAI and climate variables

The linear correlation analysis (Appendix 18) showed significant linear relationships between LAI and most climate variables, while the relationships with some other climate variables were not statistically significant. LAI_true_v6 showed significant linear relationships with most climate variables, while the relationships with some other variables were not statistically significant. Almost half of the climate variables showed significant linear relationship with LAI_true_v5, while the relationships of LAI_true_v5 with the remaining half of the climate variables were not significant (Appendix 18).

All the climate variables with a significant linear relationship with LAI from both versions of the CAN-EYE showed strong collinearity in the multiple regression analysis. The least collinearity value was calculated for mean annual temperature (VIF = ~11) and annual temperature range (VIF = ~11) and these two variables were used in multiple regression analysis to determine the amount of variation explained in LAI. The two variables combined have explained about 21% (R^2 = 0.207, R^2_{adj} =

0.146, F = 3.401, P = 0.049) of the variation with LAI. The analysis of variance also showed significant result (Table 62). The contribution of the two variables was not significant separately (Table 63).

Table 62: Analysis of variance test for the prediction of AGC by the explanatory variables (bio1 = mean annual temperature and abio7 = nnual temperature range)

Model		**SS**	**df**	**MS**	**F**	**P**
1	Regression	1.290	2	0.645	3.401	0.049
	Residual	4.930	26	0.190		
	Total	6.219	28			

Predictors: Constant, bio1, bio7; Dependent variable: LAI_v5

Table 63: Contribution of mean annual temperature and annual temperature range to the model

		Unstand_Coef		**Stand_Coef**			
		B	**SE**	**Beta**	**T**	**p**	**VIF**
Model	Constant	11.319	5.739	-0.636	1.972	0.059	
1	bio7	-0.064	0.058	0.194	-1.107	0.278	10.837
	bio1	0.011	0.033		0.337	0.738	10.837

Dependent variable: LAI_v5

4.4.7. LAI above and below coffee canopies

LAI above and below the canopy of coffee shrubs/trees was taken from 29 sample plots of size 400 m^2 in the SFC along the transect. The box plot (Figure 21) shows the distribution of LAI data which were taken under two different conditions (above the coffee canopy (ab) and under the coffee canopy (uc)) along the study transect. The distribution of the data was also analysed under two varying versions of CAN-EYE software. In both versions of CAN-EYE, and under both presence and absence of vegetation clumping the mean ± standard error of the LAI taken below the canopy of coffee is higher than the mean ± standard error of the LAI taken above the coffee canopy (Table 64). The mean of LAI_true (where the vegetation clumping was accounted for) is higher than the mean LAI_effective (where the vegetation clumping was not considered). Even the mean for LAI_true below the coffee canopy is higher than the LAI_true for above coffee canopy.

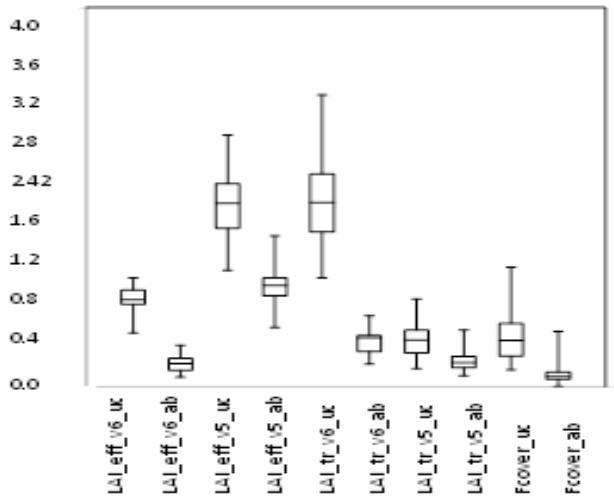


Figure 21: Boxplot analysis showing more LAI value for the under coffee canopy than those taken above the coffee canopy

Table 64: Mean of LAI under and above the coffee canopy (uc = under coffee canopy, ab = above coffee canopy)

Pairs	Mean ± SE	N
LAI_eff_v6_uc vs LAI_eff_v6_ab	0.93±0.03; 0.26±0.02	29
LAI_eff_v5_uc vs LAI_eff_v5_ab	1.05±0.04; 0.29±0.02	29
LAI_true_v6_uc vs LAI_true_v6_ab	1.93±0.07; 0.51±0.04	29
LAI_true_v5_uc vs LAI_true_v5_ab	1.98±0.09; 0.53±0.05	29

4.4.8. Normality test

Before testing for significance of the variation of LAI which was taken under the coffee canopy and above the coffee canopy, normality test was conducted, which confirmed that except for LAI_eff_v5 (above the coffee canopy) all the rest do not significantly deviate from the normal distribution (Table 65). Except for the two, Shapiro-Wilk normality test did not show significant difference of the data from normal distribution at P = 0.05 significant level.

4.4.9. Significance test

Paired sample t-test was applied (Table 66) to evaluate whether the LAI taken above and under the coffee canopy could show significant statistical difference or not. The t-test showed that there was statistically significant difference between LAI_eff_v6_un and LAI_eff_v6_ab (t_{28} = 20.15, P = 0.00), LAI_true_v6_uc and

LAI_true_v6_ab (t_{28} = 18.68, P = 0.00) and LAI_true_v5_uc and LAI_true_v5_ab (t_{28} = 15.27, P = 0.00).

Table 65: Shapiro-Wilk normality test for the LAI data taken above and below the coffee canopy

LAI	**N**	**Shapiro-Wilk W**	**P**
LAI_eff_v6_uc	29	0.95	0.17
LAI_eff_v6_ab	29	0.97	0.43
LAI_true_v6_uc	29	0.98	0.80
LAI_eff_v5_uc	29	0.96	0.28
LAI_true_v5_uc	29	0.97	0.64
LAI_true_v6_ab	29	0.96	0.31
LAI_eff_v5_ab	29	0.93	0.04
LAI_true_v5_ab	29	0.93	0.07

Table 66: Paired sample t-test for the true and eff_LAI taken above and below the coffee canopy

LAI under and above coffee canopies	**Mean ± SE**	**95% CI**		**t**	**df**	**P**
		lower	upper			
LAI_eff_v6_uc vs LAI_eff_v6_ab	0.67±0.03	0.6	0.73	20.2	28	0
LAI_eff_uc vsLAI_eff_ab	0.76±0.04	0.66	0.85	16.8	28	0
LAI_true_v6_uc vs LAI_true_v6_ab	1.41±0.08	1.26	1.57	18.7	28	0
LAI_true_v5_uc vs LAI_true_v5_ab	1.45±0.01	1.26	1.65	15.3	28	0

4.5. Habitat Suitability Model

The present and future distribution of *Acacia abyssinica*, *Cordia africana*, *Millettia ferruginea*, *Phytolacca dodecandra* and *Schefflera abyssinica* was modelled using Maximum Entropy modelling aross Ethiopia. The model performance under both present and future climate change scenarios is given in Table 67 and habitat suitability map for each of them is given in Appendix 19. The variable contribution and jackknife test for each of them is addressed below.

4.5.1. *Acacia abyssinica*

The model performance was tested and the test showed good performance for both training (AUC = 0.89) and test data (AUC = 0.86) sets. The model performance was also evaluated under the projected climate and found that it performed well for both training (AUC = 0.88) and test data (AUC = 0.82) sets (Table 67).

Table 67: Model performance under baseline (^{b}) and projected (^{p}) climate change scenarios for five plant species in Ethiopia

Species	**Training AUC^{b}**	**Test AUC^{b}**	**Training AUC^{p}**	**Test AUC^{p}**
Acacia abyssinica	0.89	0.86	0.88	0.82
Cordia africana	0.87	0.84	0.87	0.83
Millettia ferruginea	0.91	0.88	0.91	0.89
Phytolacca dodecandra	0.93	0.91	0.92	0.90
Schefflera abyssinica	0.91	0.90	0.91	0.87

4.5.1.1. Analysis of variable importance

Mean annual temperature has contributed more to the model compared to all the remaining variables under both the baseline climate change scenario (Table 68) and projected climate (Table 69). Rainfall seasonality has least contribution to the model under the baseline climate change scenario, while temperature seasonality contributed the least under the projected climate.

The jackknife test showed that the mean annual temperature was with the highest gain when used in isolation and hence has the most useful information by itself. It is also the variable that has the information which is not present in the remaining four variables. This is true under both present (Appendix 20A1, A3) and future (Appendix 20A2, A4) climate change scenarios. Most of the areas which are suitable for the distribution of *A.abyssinica* under the current climate (Appendix 19A) will turn unsuitable under the projected climate (Appendix 19B).

Table 68: Contribution of each five climate variables to the distribution *of Acacia abyssinica* under the baseline climate scenario

Variable	**% contribution**	**Perm. importance**
Mean annual Temperature	80.5	77
Isothermality	8.6	11.8
Mean annual rainfall	5.4	4.3
Temperature seasonality	3.9	4.9
Rainfall seasonality	1.6	2.1

Table 69: Contribution of each five climate variables to the distribution *of Acacia abyssinica* under the projected climate

Variable	% contribution	Perm. importance
Mean annual temperature	84	73.5
Isothermality	5.2	6.8
Mean annual rainfall	4	5.5
Rainfall seasonality	3.5	4.4
Temperature seasonality	3.3	9.7

4.5.2. *Cordia africana*

The present and future distribution of *C. africana* across Ethiopia was modelled using Maximum Entropy modelling algorithm. Five climate variables were selected to avoid the effect of collinearity. The model showed good performance under both the current scenarios and future climate projections. The receiver operating characteristic (ROC) curve (under the baseline scenario) showed better performance of the model. The area under curve for training data (under the baseline scenario) (AUC = 0.87), for test data (AUC = 0.84) which is higher than random distribution (AUC = 0.5) (Table 67). The model also showed good performance under the future climate change projections in which the ROC attained 0.87 for training data 0.83 for test data (Table 67).

Under the current climate change scenario, the areas of southwest highlands of Ethiopia (Jimma, Kaffa, Bench-Maji, Illubabbor, Shaka); central Oromia (east Shewa

and western part of Arsi) and southern Oromia (northern Borana, western and central parts of Bale), Eastern Ethiopia (eastern Hararghie Highlands) are climatically the most suitable areas for the distribution of *C. africana* (Appendix 19B1).The habitat suitability decreases towards the lowlands on the northeastern, eastern and western parts of Ethiopia.

Most of the areas in Borana and Bale zones of Oromia Region, which are currently suitable for the distribution of *C. africana* will lose their suitability for the species under the projected climate change scenario (Appendix 19B2). Areas in northern Ethiopia which are suitable for the distribution of *C. africana* under the baseline climate scenario will turn unsuitable under the projected climate.

4.5.2.1. Analysis of variable contributions

The contribution of mean annual temperature to the model under the current and projected climate was 52.3% and 64.7% respectively followed by mean annual rainfall with contribution of 33% and 22.6 respectively (Tables 70 and 71). Rainfall seasonality contributed only 4% and 4.1% to the model under the current and projected climates respectively.

The jackknife test of variable importance showed that mean annual temperature has got the highest gain when used in isolation under both the current (Appendix 20B1 & B3) and future climates (Appendix 20B2 & B4). This variable has the most useful

information by itself. The variable that reduces the gain when omitted was also mean annual temperature in both models (present and future). Mean annual temperature is also the most important variable of jackknife test of test data under the current and future climates. It has the highest gain when used in isolation and the variable which affects the model most when omitted.

Table 70: Contribution of each five climate variables to the distribution of *Cordia africana* underthe baseline climate scenarios in Ethiopia

Variable	**% contribution**	**Perm. importance**
Mean annual temperature	51.3	32.5
Mean annual rainfall	33	41.8
Temperature seasonality	6.1	13.2
Isothermality	5.6	2.1
Rainfall seasonality	4	10

Table 71: Contribution of each five climate variables to the distribution *of Cordia africana* under the projected climate

Variable	% contribution	Perm.importance
Mean annual temperature	64.7	55.7
Mean annual rainfall	22.6	24.9
Temperature seasonality	5.7	10.1
Rainfall seasonality	4.1	8.1
Isothermality	2.9	1.2

4.5.3. *Millettia ferruginea*

The distribution of *Millettia ferruginea* under the current and future climate change scenarios was modelled using five climate variables, while other climate variables were excluded due to collinearity. The model showed good performance under both the current scenarios and future climate projections. The ROC curve (under the baseline scenario) showed good performance of the model. The area under curve for training data (under the baseline scenario) (AUC = 0.91), for test data (AUC = 0.88) which is higher than random distribution (AUC = 0.5) (Table 67). The model also showed good performance under the future climate change projections in which the ROC attained 0.91 for training data 0.89 for test data (Table 67).

In general, southwest Ethiopia, particularly the highlands of Jimma, Kaffa, Shaka, most parts of Illuababor Zone, some areas of East Wellega Zone, and eastern part of West Wellega Zone, northern Borana Zone, Sidama and Gedeo Zones in south

Ethiopia, some parts of Awi and Metekel Zones are some of the most suitable areas for the distribution of *M. ferruginea* under the current climate change Scenario (Appendix 19C1).

The entire Awi Zone, most parts of Metekel, most parts of southwest Illubabor Zone and Shaka Zone will lose their suitability for the distribution of *M. ferruginea* under the future climate change scenarios (Appendix 19C2). Most highlands of Jimma and Bench-Maji Zone will be suitable for the distribution of *M. ferruginea* under the projected climate change.

Western and central highlands of Jimma, central and eastern part of Kaffa, central and northwestern parts of Bench-Maji remain suitable areas for the distribution of *M. ferruginea*. The habitat suitability declines in Shaka and western parts of Illubabor Zone. The expansion of suitable areas under the projected climate was predicted in the northern parts of Illubabor Zone, in the northern part of Borana and western part of Bale, northwestern parts of Gamo Gofa and South Omo, central Arsi and eastern Hararghe highlands (Appendix 19C2).

4.5.3.1. Analysis of variable contributions

Under the current climate, mean annual temperature is the most important variable with the percent contribution of 48.8% followed by mean annual rainfall (44.9%) (Table 72). The variable with the least contribution under same climate was rainfall seasonality (0.2%). Both mean annual temperature and mean annual rainfall are more impoartant predictors under the projected climate change scenarios (Table 73).

Table 72: Contribution of each five climate variables to the distribution *of Millettia ferruginea* under the baseline climate scenario

	***Millettia*_baseline**	
Variable	**% contribution**	**Perm. importance**
Mean annual temperature	48.8	77.4
Mean annual rainfall	44.9	16.3
Temperature seasonality	4.1	4.7
Isothermality	2	1.2
Rainfall seasonality	0.2	0

Table 73: Contribution of each five climate variables to the distribution *of Millettia ferruginea* under the projected climate

	***Millettia* _future**	
Variable	**% contribution**	**Perm. importance**
Mean annual temperature	52.5	76.9
Mean annual rainfall	37.9	12.1
Temperature seasonality	8.2	10.2
Isothermality	1.1	0.3
Rainfall seasonality	0.4	0.6

The importance of the variable was also shown by the Jackknife test (Appendix 20C1–C4). Mean annual rainfall was the most impoartant in the training data set, under the current climate (Appendix 20C1), while mean annual temperature was the most impoartant in test data (Appendix 20C2). Mean annual temperature is the variable that impacts the most when it is omitted in both training and test data under the current climate change scenarios. Under the projected climate, the variable with the highest gain in both training and test data was the mean annual rainfall (Appendix 20C3 & C4). The variable that decreases the gain the most when omitted was mean annual temperature.

4.5.4. *Phytolacca dodecandra*

The habitat suitability for the distribution of *P.dodecandra* under the current climate change scenarios and future projection was modelled using Maximum Entropy modelling. Five climate variables (mean annual temperature, mean annual precipitation, temperature seasonality, rainfall seasonality and isothermality) were used. The model performance was tested and the test showed good performance for both training (AUC = 0.93) and test data (AUC = 0.91) sets. The model performance was also evaluated under the projected climate and found that it performed better than it could be by random for both training (AUC = 0.92) and test data (AUC = 0.90) sets (Table 67).

Southwest highlands of Ethiopia (highlands of Kaffa, Jimma, Bench-Maji zones); central Ethiopia (highlands of West Shewa and Guragie zones); the eastern

escarpments of Rift Valley (Arsi, Sidama, northern Borana and Gedeo zones, north and western Bale) and Harargie highlands are currently the most suitable areas for the distribution of *P. dodecandra* (Appendix 19D1). The suitability decreases as one moves from the areas mentioned above towards the lowlands in all sides of Ethiopia. The western edges (from Gambella to western Tigray), the eastern edges from Ogaden to eastern Tigray) are the areas which are not suitable for the distribution of the species under the current climate change scenarios.

From the northwestern highlands, the areas of southwest Ethiopia (Jimma, Kaffa); central Ethiopia (West Shewa and Guraghe zones) will lose their suitability for the distribution of the species under the projected climate. The areas of southeastern highlands (most areas of northern and northwestern Bale; Sidama and Gedeo zones; central Arsi and eastern Hararghe highlands will be suitable for the distribution of the species under the projected climate (Appendix 19D2).

4.5.4.1. Analysis of variable importance

Temperature variables have contributed more to the model than the variables related to precipitation (Table 74). Mean annual temperature has contributed more to the model performance compared to all the remaining four variables under both the current and future climate projections (Tables 74 and 75). Mean annual rainfall contributed the least to the model under both climate change scenarios (Tables 74 and 75).

Table 74: Contribution of each five climate variables to the distribution *of Phytolacca dodecandra* under the baseline climate scenario

Variable	**% contribution**	**Perm. importance**
Mean annualtemperature	59.9	59.1
Isothermality	24.3	13.5
Temperature seasonality	10.4	24.1
Rainfall seasonality	3.9	2.9
Mean annual rainfall	1.6	0.4

Table 75: Contribution of each five climate variables to the distribution *of Phytolacca dodecandra* under the projected climate

Variable	**% contribution**	**Perm. importance**
Mean annual temperature	67.8	70.4
Isothermality	15.1	5.2
Temperature seasonality	12	18.8
Rainfall seasonality	3.7	4.8
Mean annual rainfall	1.3	0.7

The jackknife test showed that the mean annual temperature was with the highest gain when used in isolation and hence has the most useful information by itself. It is also the variable that has the information which is not present in the remaining four

variables. This is true under both present (Appendix 20D1 & D2) and future (Appendix 20D3 & D4) climate change scenarios.

4.5.5. *Schefflera abyssinica*

The model performed well under both present and future climate projections. Under the current climate change scenarios, the predicted area under curve was 0.91 for the training data and 0.90 for the test data. Under the projected climate, the AUC was 0.91 for the training data and 0.87 for the test data (Table 67)

4.5.5.1. Analysis of variable importance

Mean annual temperature is with the highest contribution followed by mean annual rainfall and hence it is the variable with the most impact on predicting the habitat suitability for *Schefflera abyssinica* under the current climate change scenario, while rainfall seasonality is with less impact on predicting suitable areas under the current climate (Table 76). Almost a similar condition was obtained for the habitat suitability of *S. abyssinica* under the future climate change scenarios. In the projected climate change scenarios too, the mean annual temperature contributed more and the least contributor was rainfall seasonality (Table 77). The second contributor to the model was mean annual rainfall. Some areas in south, southwest Ethiopia and Arsi highlands are suitable for the distribution of the species (Appendix 19E1). Some of these areas lose their suitability under the projected climate (Appendix 19E2).

Table 76: Contribution of the five climate variables to the distribution *of Schefflera abyssinica* under the baseline climate scenario

Variable	**% contribution**	**Perm. importance**
Mean annual temperature	60.3	70.2
Mean annual rainfall	23.3	19.3
Temperature seasonality	8.4	4.3
Isothermality	6.1	1.5
Rainfall seasonality	1.9	4.7

Table 77: Contribution of the five climate variables to the distribution *of Schefflera abyssinica* under the projected climate

Variable	**% contribution**	**Perm. importance**
Mean annual temperature	59.7	74.5
Mean annual rainfall	22.9	16.2
Temperature seasonality	9.9	5.4
Isothermality	4.6	0.7
Rainfall seasonality	2.9	3.

The jackknife test of variable importance for both training and test data showed that the mean annual temperature was the variable with the most useful information by itself and at the same time it was found to be the variable that decreases the gain the most when it was omitted (Appendix19E1 & E2). This was under the current climate

change scenarios. This variable remained the most important even under the projected climate change scenarios (Appendix 19E3 & E4).

CHAPTER FIVE

5. Discussion, Conclusion and Recommendations

5.1. Discussion

5.1.1. Land use /land cover change

The 2008 LULC map revealed that the transect was covered by cropland, natural forest, plantation forest, woodland and pasture. The information obtained from the Agricultural Office of Setema District and some elder people in the transect, the ubiquitous and extensive conversion of natural vegetation (grassland and forest) to agriculture and plantation forests started since 1975 in the lower part of the transect. These sources confirmed that agriculture was expanded to the upper part of the transect from 1985 onwards. This coincides with the time when people from norther Ethiopia were brought to resettle in the study area (one of the fertile parts of southwest Ethiopia selected at that time) as the remedy to combat the 1984 famine in northern Ethiopia. Since then, due to the wide spread of agricultural expansion, larger areas of the forest and grassland has been converted to croplands. This agrees with several reports that addressed the decline of forest cover in Ethiopia (Breitenbach, 1961; EFAP, 1994; Hylander *et al.*, 2013) and expansion of agriculture lands (Tadesse Woldemariam and Masresha Fetene, 2007). Due to human activities, the transect has been converted to a mosaic of different land use types such as cropland, pasture, plantation forest, SFC and DNF and woodland. This agrees with Landon (1996) and Konemund *et al.* (2002) who respectively addressed the annual loss of closed forests and natural vegetation in Ethiopia respectively. This study also agrees with a study on closed forest decline in Shaka Zone of Ethiopia by Tadesse

Woldemariam and Masresha Fetene (2007) and with net forest cover decline in Bonga and Goma-Gera area (Hylander *et al.*, 2013).

5.1.2. Species richness

The species area curve became flat after five plots in DNF, ten plots in woodland, five plots in cropland, ten plots in SFC, ten plots in pasture and four plots in planation forests showing that the sampling effort to incorporate all species occurring in different land use types was exhaustive.

The result of the study showed that the transect was rich in plant species richness and diversity. About 287 species belonging to 220 genera and 82 families were documented. As part of the Eastern Afromontane Biodiversity Hotspot area (Mittermeier *et al.*, 2004), the study transect in the Jimma Highlands has been endowed with plant species richness. This agrees with Coetzee (1978) who conducted a study on plant diversity and richness in East African Mountains. Among the 82 families recorded from the entire transect, Asteraceae was the most species rich family with total number of species (n = 33) followed by Fabaceae (n = 25). Asteraceae is the most species rich family in almost all land use types along the transect. Most floristic studies conducted in Ethiopia showed high number of plant species belonging to family Asteraceae (Dereje Denu, 2007; Dereje Denu and Tamene Belude, 2012; Ermias Lulekal, 2014) on Bibita Forest (Guraferda), sacred landscapes in Bedele District and Dense Forest in Ankober, respectively. Three of

the forty one families were represented by introduced species (Cupressaceae, Pinaceae and Proteaceae). According to the Setema District agricultural office, most of the exotic species were planted in the transect in late 1970's.

The six land use types of the transect vary in plant species richness, abundance and diversity. From this study it is apparent that the plant species richness decreases from woodland to the cropland. The chi-square test conducted indicated the impact of land use on the plant species richness. The plant species richness per hectare decreased from the relatively less modified (natural vegetation) to the highly modified landscapes (cropland, monoculture plantation and pasture). This agrees with most studies on the impact of land use change on plant species richness and diversity (Bobo *et al.*, 2005; Bremer and Farley, 2010; Getachew Tadesse *et al.*, 2014). More species per hectare was recorded from the woodland and followed by the DNF. The SFC was in the third place in terms of plant species richness per hectare. The SFC are high in plant species richness per hectare compared to the monoculture plantations, pasture and cropland. Plant species richness declined from the degraded natural vegetation to the monoculture plantation forests, to the cropland and pasture.

Different land use types have different number of plant species richness per hectare. Natural vegetation (forest, woodland and grassland) have been converted to cropland, pasture and manmade monoculture plantation forests by compromising the plant species richness and abundance. In this study, the cropland was relatively species poor per hectare compared to all other land use types. This agrees with Bobo

et al. (2005) in which the conversion of forest to cropland affected the plant species diversity and richness. Following the cropland, least species richness was recorded from the manmade monoculture plantations of exotic species. The site occupied by the manmade monoculture plantations of exotic species today, were occupied by natural vegetation in the past. The manmade plantations were introduced in the area in late 1970s by clearing the existing dense natural forests of the area. This was revealed from the land use map and personal communications with the local elders who have good knowledge about the vegetation change in the area and from the District agricultural office. The finding agrees with Bremer and Farley (2010). According to these authers plantation forests help in conservation of biodiversity when applied on degraded land, but not when they replace the natural vegetation.

Land use change affected not only the plant species richness, but also abundance of the tree species. The highest abundance was recorded from the plantation forests (798.25 ha^{-1}) followed by DNF (236 ha^{-1}) and SFC (129.7 ha^{-1}). The motive behind the plantation forests was commercial benefit and as a result the trees have been planted at regular intervals and have been protected until they mature for the planned purpose. The plantation forests in the study transect was owned by the state that is protecting the forests from exploitation by the local community. The abundance in the plantation forests was attributed by the management inputs and the protection provided to maximize the income up on selling the trees for timber.

The natural forests in the transect have been used as a common pool for different purposes such as poles and vines for construction purposes, fire wood for fuel and other ecosystem goods and services. There are frequent illegal felling of trees for logging, fuel and house contrustruction; this impact is compounded by cattle grazing due to shortage of pastureland for the communities around the natural forest. The combined effect of illegal felling and grazing by animals has greatly affected the germination and recruitment of plant species to the adult stage that has highly affected the abundance of trees and shrubs in the natural forest.

SFC is modified natural forest with wild coffee beneath the canopy. In the modifications of natural forests to the SFC, some individual trees have been removed, while others are retained for shade provision for the coffee shrubs/trees beneath. Less abundance of trees in the SFC compared to the DNFs was attributed by purposive removal of some individual trees as to maximize the growth of and yield obtained from coffee. This agrees with Demel Teketay (1999b; Kitessa Hundera *et al.* (2013). Woodland occupied the forth place in the tree species abundance whereas the cropland and pasture were least abundant in woody species due to the clearing of natural vegetation for the expansion of agriculture and livestock farming. Clearing of natural vegetation affected the diversity and abundance of plant species.

5.1.3. Basal area

Compared to all land use types in the transect, the plantation forests were the most important land use types in terms of basal area per hectare and this was attributed mainly by management inputs. The basal area for both DNF and SFC in the study

area are less than the normal basal area value for virgin tropical forests in Africa (Lamprecht, 1989). Compared to other studies conducted in different natural forests of Ethiopia (Tamrat Bekele, 1993; Tamrat Bekele, 1994; Abate Ayalew, 2003; Kitessa Hundera, 2003; Kumelachew Yeshitela and Taye Bekele, 2003; Simon Shibru and Girma Balcha, 2004; Ermias Lulekal, 2005; Genene Bekele, 2005; Dereje Denu, 2007), the basal areas for DNF and SFC in the transect are the least. This is due to degradation of the natural forest and selective removal of some trees during the conversion of natural forest to the SFC systems.

The most important tree species contributing higher basal area in the SFC are *Albizia gummifera*, *Croton macrostachyus*, *Ficus mucuso* and *Cordia africana*. *Croton macrostachyus* and *Albizia gummifera* have also been reported as important canopy trees in SFC (Driba Mulleta *et al.*, 2007; Aerts *et al.*, 2011). Driba Mulleta *et al.* (2007) also reported *C. africana* as important coffee shade tree. The most important tree species contributing higher basal area in the DNFs were *Ficus sur*, *Apodytes dimidiata*, *Schefflera abyssinica*, *Syzygium guineense*, *Albizia gummifera* and *Celtis africana*. As it was indicated in Dereje Denu (2007), *Ficus sur* was also one of the top ten tree species with high basal area in Bibita Forest.

5.1.4. Plant growth forms

Of the four plant growth forms herb was the richest in species composition compared to shrub, tree and liana across the transect and this agrees with Tadesse Woldemariam (2003) in Yayu forest, Schmitt (2006) in Bonga Forest, Dereje Denu

(2007) in Bibita Forest– all in southwest Ethiopia. Trees ranked second in species richness across the transect. This disagrees with Dereje Denu (2007) and Dereje Denu and Tamene Belude (2012) in which the tree species ranked third, while the shrub ranked second in Bibita Forest and had the same rank with herbaceous species in sacred forests of Bedele District, but it agrees with Schmitt (2006).

The herbs dominated all land use types in the study transect except the plantation forests where its richness follows the tree growth form. The herbaceous species distribution in the DNFs (n = 36, ~32%), woodlands (n = 56, ~41.18%), cropland (n = 50, ~55%), SFC (n = 64, ~44%), pasture (n = 51, ~45%) and in plantation forests (n = 27, ~34%). The number of herbaceous species per hectare was the least in DNF, while it was the highest in cropland. Compared to all land use types, except in the DNF, the number of herbaceous species per hectare was the least in plantation forests. The number of herbaceous species is less in plantation forests than in pasture or woodland and higher than in the natural forests. This disagrees with Kamo *et al*. (2002), which could be due to the degradation of the natural forest by anthropogenic activities.

The richness of liana species across the transect was lowest compared to herbs, shrubs and tree species richness. This agrees with Tadesse Woldemariam (2003) in Yayu Forest, Getaneh Belachew (2006) in Beshilo and Abay riverine vegetation, Dereje Denu (2007) in Bibita Forest. The least number of liana species richness per hectare was recorded from the cropland followed by the SFC with 0.29 and 0.34 ha^{-1}

respectively. The lianas were highly compromised in the conversion of natural vegetation to the cropland and SFC. When the forest is converted to cropland, the lianas are also removed with the trees and shrubs. In the conversion of forest to SFC, where the canopy trees are recruited, lianas have no chance to be recruited for shade provision by the coffee growers. Lianas are removed during the thinning activities due to their negative impact on the growth of coffee shrubs/trees and blocking access during harvesting of the ripe coffee berries. The highest record of lianas was in the DNF where it was highly successful than in any land use types along the transect. The impact of human induced disturbances on liana success was also shown somewhere by other authors (Schnitzer *et al.*, 2004; Addo-Fordjour, 2009; Rutishauser, 2011). The illegal felling favors the expansion of lianas which completely or partially covers the passage of light to the forest floor and the open sites are affected by the grazing animals. In the pasturelands, the number of herbaceous species was higher, while the woody species including the trees are rare. A study on pasturelands (Tracy and Sanderson, 2000) in America also showed a similar result with the finding of this study.

Of the 287 plant species recorded from the transect, nine were the most frequent ones occurring in about 50% of the study plots. Five of them were trees, three herbs and one shrub. Among the trees, *Albizia gummifera* and *Acacia abyssinica* are protected by the community for their shade provision for the coffee shrubs; *Cordia africana* has been protected for its various uses such as raw material for making household furniture and as coffee shade tree as it was indicated in Diriba Muleta *et al.* (2011). Species with rare occurrence in the study transect were *Eucalyptus camaldulensis*,

Grevillea robusta, *Kosteletzkya begoniifolia*, *Nuxia congesta*, *Pinus patula, Schrebera alata* and *Sesbania sesban*. *Eucalyptus camaldulensis*, *Grevillea robusta*, *Pinus patula* and *Sesbania sesban* are exotic species and they all are in manmade plantations except *Sesbania sesban* which has escaped from the home gardens and naturalized in the wild. *Kosteletzkya begoniifolia*, *Nuxia congesta* and *Schrebera alata* are indigenous species and have rare occurrence in the study area.

The SFC was classified in DNFs into lower storey, middle storey and upper storey using the classification scheme of IUFRO (Lamprecht, 1989). The number of tree species with the canopy remaining in the lower storey is greater than the number of tree species reaching the middle and upper storeys in the SFC. This disagrees with Getaneh Belachew (2006) and Dereje Denu (2007). The coffee growers retain some tree species in the coffee plot not only for shade provision, but also for other purposes such as house construction, building fences around their home garden and source of fire wood. They maintain the trees until they reach the stage that could help them for the mentioned purposes. In the DNF, where the canopy is highly dominated by lianas and the passage of light to the forest floor is blocked, the tree species richness is lower in the lower storey than in the middle. The forest is degraded due to uncontrolled human activities, which also facilitated the domination of the lianas as a canopy cover. In such liana dominated canopies, the germination and recruitment of the seedlings into saplings and then into trees is compromised. It allows only the germination and growth of shade loving species, while those light seeking species are unfavored. The tree species abundance in the middle storey is greater than that in the lower and upper storeys both in SFC and in DNF. This is in agreement with Getaneh

Belachew (2006), even though, the comparison is not a direct one due to spatial and temporal variations and also variability of other underlying environmental factors; it is to give some indication about the similarity and differences with other studies. Among the most dominant canopy tree species in SFC, *Albizia gummifera* and *Croton macrostachyus* are at forefront and this agrees with Aerts *et al.* (2011).

Few species dominated the upper storey compared to the middle and lower storey. The dominance is high when few species dominate the canopy and the dominance is low when several species are evenly distributed. The storey with high species richness is less in dominance, while the upper storey with less diversity is more dominant. This is because; few species dominated the upper story, while the lower storey is with several species with relatively even distribution. In general, in SFC, the diversity increased from the lower to the upper story via the middle storey. In DNF, the diversity is higher in the middle which is followed by the lower storey.

The upper storey in DNF is relatively with more diversity (12 species) compared to the diversity (3 species) in upper storey of SFC. The cluster analysis using Jaccard similarity index as distance measurer grouped the study plots into three. All plots of forests (SFC, DNF and planation forests) were grouped together because they share more common traits with each other than with the other remaining land use types.

5.1.5. Above ground live carbon storage

LULC changes are among the anthropogenic contributors to the global carbon emissions (Friedlingstein *et al*., 2010; Houghton, 1999). All land use types are not equally important in AGC storage. In this study, AGC storage (AGC t ha^{-1}) varies from land use to land use across the study transect in the Jimma Highlands. The highest AGC was recorded in the plantation forest followed by DNF and the least was in the cropland and pasture.

The management input which increased the tree species density in the plantation forests also contributed to the relatively higher AGC storage. The conversion of natural forests to DNF along the transect affected the amount of AGC in the above ground tree biomass. The AGC in DNF in this study was lower than the amount of AGC reported by Tadesse *et al*. (2014); Yohannes *et al*. (2015); Brown (1997) and WBISPP (2005). This is mainly due to the anthropogenic activities exerted on the DNF from the surrounding villages.

The human land use change affected forests which are important in the global carbon balance. As it was indicated in FAO (2010) Global forest resources store about 289 Gt of carbon. This very important global resource is affected by human land use change. The woodlands followed SFC in the amount of AGC stored in the above ground woody species biomass. Compared to the carbon storage in woodlands reported by WBISPP (2005) in Ethiopia, the amount of AGC calculated in the woodlands of this study area was lower. This difference actually emanates from the

methodologies and tools applied and the level of anthropogenic activities exerted on the woodlands. As indicated by Asner *et al*. (2003) land cover change is the most important factor that impacts on the AGC storage in woody vegetation.

Compared to croplands and pasture, SFCs are very important in their AGC storage. In this system, the natural forests have been modified through thinning by coffee growers for better coffee yield. It is one of the coffee management systems in Ethiopia (Demel Teketay, 1999b; Wiersum *et al*., 2008; Feyera Senebeta *et al*., 2009; Schmitt *et al*., 2010; Kitessa Hundera *et al*., 2013). More AGC t ha^{-1} storage was calculated for SFC than in croplands and pastures. This agrees with WBISPP (2005). The amount of carbon stored in SFC varies depending on management intensity, which in turn varies by region and tradition. For example, compared to carbon storage in nearby natural forests, coffee agro-forests have been reported to retain 42% of AGC carbon in Panama (Kirby and Potvin, 2007), 49% in Indonesia (Kessler *et al*., 2012) and 50-62% in Yeki and Decha of Ethiopia (Getachew Tadesse *et al*., 2014).

The most important tree species in AGC storarge in the SFC are *Acacia abyssinica*, *Albizia gummifera*, *Cordia africana*, *Croton macrostachyus*, *Dracaena steudneri*, *Ficus mucuso* and *Millettia ferruginea*. Among these tree species, *Acacia abyssinica*, *Albizia gummifera*, *Cordia africana* and *Millettia ferruginea* were reported by Diriba Mulleta *et al*. (2011) as important coffee shade trees in southwest Ethiopia. These species are also the first four tree species in farmers' preference as coffee shade trees

in this study. *Cordia africana* is also retained on farm for its good quality timber. The coffee farmers look after these tree species in their coffee farm for many years and as a result the trees are relatively with high DBH and stem density. The higher AGC storage was attributed by the management inputs in the conservation of the selected coffee shade trees. *Albizia gummifera* and *Croton macrostachyus* were also reported by Aerts *et al*. (2010) as important coffee shade trees forming the dominant canopies in some areas of southwest Ethiopia. *Ficus mucuso* was not among the top tree species of choice by the farmers for shade provision. This species dominated the coffee forest along Didessa River and was not recoded from other plots. The species is characterised by its large trunk diameter which has contributed to the highest carbon storage in its above ground biomass.

The five most important plant families in AGC in the SFC of the study area were Fabaceae, Moraceae, Euphorbiaceae, Boraginaceae and Dracaenaceae. These are the families to which the above most important coffee shade trees belong. In the conversion of natural vegetation to agriculture, most trees, shrubs and lianas are cleared, while some trees are retained on farm for different purposes. The least AGC in tree biomass was calculated for the croplands covered by annual crops and pasturelands. The AGC calculated for cropland in this study is within the range of AGC calculated for croplands (1.78–2.47 t ha^{-1}) in Ethiopia (WBISPP, 2005). The most important tree species in the cropland was *Cordia africana* which the farmers purposely retained on farm for its good timber. The species was also ecologically important in improving soil fertility (Abebe Yadessa *et al*., 2009). Pasture and

croplands are characterised by small number of individual trees sparsely scattered and retained for different purposes.

Experience accumulated over decades living and working in southwest Ethiopia tells us that the profitability of traditional coffee farming is finely balanced: when the market price of coffee drops, there often follows a wave of conversion from SFC to cropland. If such livelihood pressures were to cause the coffee growers along our study transect to similarly convert their land, then we estimate that 59.5 t ha^{-1} (conversion to cropland) or 59.0 t ha^{-1} (pasture) would be released as greenhouse gas emissions into the atmosphere. This is in agreement with Achard *et al*. (2004); Houghton (1999); Friedlingstein *et al*. (2010); Kaplan, *et al*. (2010) in which the impact of LULC change in carbon emission was addressed.

AGC storage has significant linear relationships with tree species richness and abundance. These two varibales (richness and abundance) explained about 82% of the variation in carbon storage. AGC storage was calculated from woody species with DBH $\geq$ 10 cm. Most of the woody species in the transect with this DBH are trees. That is why tree species abundance and richness were highly correlated with AGC storage. This agrees with Strassburg *et al*. (2010).

AGC storage also showed significant linear relationships with some climate variables such as mean temperature warmest quarter, mean temperature coolest quarter, mean

annual rainfall, rainfall driest quarter, potential evapotranspiration, moisture index moist quarter, annual moisture index, mean diurnal range in temperature, mean annual temperature, min temperature coolest month, annual temperature range and maximum temperature warmest month. Potential evapotranspiration explained about 21% of the variation in carbon storage when all other variables were excluded due to collinearity. Net primary productivity (the basis for carbon storage in the woody species biomass) decreases by dry weather and warmer temperatures (Tian, *et al*., 1998).

Among the edaphic variables, CEC, sand and pH showed significant linear relationship with AGC. Cation exchange capacity and pH negatively correlated to AGC, while sand showed positive relationship with AGC. AGC decreases with increasing CEC and soil pH, but increases with increasing percentage of sand particle. In the regression analysis, combined together, soil pH, CEC and sand significantly explained the variation in AGC t ha^{-1} across different land use types along the transect.

5.1.6. Leaf area index (LAI)

LAI under both Version 5 and 6 of CAN-EYE were influenced by human land use change. The decreasing order of land use types in LAI values includes DNF, SFC, plantation forests, woodland, cropland and pasture. This agrees with Kozlowski *et al*. (1991), Mass *et al*. (1995) who addressed the variation in LAI among ecosystems and within ecosystems respectively. The three forest types (SFC, DNFs and

plantation forests) and woodlands were not statistically different in LAI_true_v5 and v6. In the same way cropland and pasture were not statistically different in LAI. Almost all canopy trees have been removed in the conversion of forests and woodlands to croplands and pasture in the study transect. Few scattered trees have been retained in the croplands and pastures. This has contributed to relatively lower. LAI values for the canopy trees in these land use types. There were also slight differences in LAI between cropland and pasture. Trees with more canopies were found in the croplands than in the pasture contributing to more LAI in the cropland. The three forest types (DNF, SFC and plantation) are different in LAI. The DNFs were relatively higher in LAI compared to SFC and plantation forests. SFC is the result of modification of natural forest through thinning activities in the conversion to SCFs. Lianas and shrubs are totally removed in the modification of natural forests to the SFC. In addition to lianas and shrubs, the individual trees are removed as to allow enough light to the coffee shrubs. Therefore; though it is degraded, the natural forest in the study transect has relatively more tree density and lianas than the SFC and all other land use types in the transect. This has contributed to more LAI in the DNF than in the SFC. The DNF is composed of broad leaved indigenous tree species, while the plantation forests are all with exotic species and are mostly needle leaved. The LAI in DNF is higher than the LAI in the plantation forests most probably attributed by the variation in the leaf morphology. In the DNF, the lianas climbing to the canopy of trees also have contribution to the LAI, while lianas as canopy component are absent from the plantation forests. The woodlands are composed of short trees, shrubs and grasses. The canopies are not closed as it has been observed in the DNF and are also relatively less dense. This has contributed to

lower LAI value compared to the three forest types. Though there were variations in the three forest types and woodlands in terms of LAI, the variations were not statistically significant, most probably due to the similarity in the canopy cover. In the woodlands, shrubs, taller herbaceous species contributed to the canopy.

LAI_true was strongly correlated with tree species basal area, richness and abundance. Leaf area is a very important biophysical factor that plays an important role in photosynthesis and primary productivity. The biomass accumulated in the trees and other woody species is the result of this primary productivity. The growth in basal area is the result of biomass accumulation as a result of primary productivity. The strong linear relationship between LAI and woody species basal area, most probably, emanates from the physiological relationships they have. When the abundance of tree species is compromised due to the conversion of natural forest- as in the SFC and croplands, the LAI is also compromised. This indicates the importance of density in its contribution to the LAI.

Herbaceous species richness was not significantly related to both LAI_true_v6 and LAI_true_v5. In the DNF where the LAI was relatively higher, the herbaceous species richness was poor. The growth of light loving herbaceous species is compromised under the canopies of natural and plantation forests. The management inputs in SFC and plantation forests also impacted the herbaceous species growth.

Topographic factors such as elevation and slope have no strong relationship with the LAI. In the study transect, land use was found more important than topographic factors. The natural vegetation has been changed to different land use types irrespective of elevation and slope. The areas where more species richness and abundance are expected may have less number of species abundance due to the human land use change. At the same time, at elevations where less number of species and abundance are expected, you may come up with more species than at the elevation with more theoretical species richness and abundance.

Among the edaphic factors, soil cation exchange capacity, sand and clay have significant relationship with the LAI. CEC and clay were negatively related with LAI, while the sand was positively related. These three edaphic factors have also significantly explained the variation in LAI. EVI and NDVI are significantly related to the LAI. This agrees with Goswami *et al*. (2015) that showed strong correlation between LAI and NDVI. In the multiple regression analysis, the two variables combined, significantly explained the variation in LAI. NDVI has significant contribution to the model, while the contribution of EVI was not significant singly.

LAI and AGC storage: Both LAI_true_v6 and LAI_true_v5 have strong linear relationship with the above ground carbon storage across the land use types in the study transect. LAI_true_v6 has explained about 75% of the variation in AGC t ha^{-1}. Land use types have significant variation in AGC t ha^{-1}. The LAI which is influenced

by human land use change has significantly explained the variation in AGC, which is also influenced by human land use change.

LAI and climate variables: As very important biophysical element, leaf acts as an interface between the plant canopy and the atmosphere. It is a very important site for absorption of energy from the sun, for gas exchange and regulation of water loss. Leaf area has a direct role to play in this important biological process in green plants. The significant linear relationships between LAI and climate variables are attributed to these natural interactions. LAI showed significant linear relationships with climate variables such as mean temperature warmest quarter, mean annual rainfall, maximum temperature warmest month, mean annual temperature, annual temperature range, mean temperature coolest quarter, moisture index moist quarter,mean diurnal range in temp, rainfall driest quarter, annual moisture index and potential evapotranspiration. This agrees with Jin and Zhang (2001), Xavier and Vettorazzi (2003) and Luo *et al*. (2004) also showed the existence of linear relationship between LAI and precipitation. All the above climate variables showed strong collinearity in the multiple regression analysis. The two climate variables with relatively low collinearity value were mean annual temperature and annual temperature range. These two variables combined, have significantly explained the variation in LAI across the land use types in the study transect.

The LAI data taken below and above coffee canopy (taken above the canopy of coffee shrubs/trees and below the canopy of coffee shrubs/trees) are important to

determine the contribution of coffee canopy to the LAI across the coffee agro-forestry in the transect. In the LAI data taken below the coffee canopy, it is obvious that the contribution of coffee canopy to the LAI was included, while, in the LAI data taken above the coffee canopy, the contribution of coffee canopy to the LAI was excluded. The LAI taken below the coffee canopy was higher than the LAI taken above the coffee canopy due to the inclusion and exclusion of the coffee canopy respectively. The significant variation between the LAI taken above the coffee canopy and LAI taken below the coffee canopy showed a significant contribution of coffee canopy to the LAI. Therefore; it is possible to deduce that the coffee canopy, in addition to the canopy of shade trees, has contribution in regulating the microclimates under the canopy. Hardwick *et al*. (2015) also showed the importance of LAI in regulating the microclimate beneath the canopy. According to him, the air under the canopies having high LAI is cooler and has high relative humidity during the day. The canopy below the coffee canopy could have cooler climate than the canopy above the coffee canopy.

5.1.7. Species distribution

The model output showed that the lowlands of Ethiopia are not suitable for the distribution of *Cordia africana*. This agrees with the description of elevational distribution of the species by Riedl and Edwards (2006). The areas which are climatically most suitable for the distribution of *C.africana* are parts of southwest highlands such as Jimma, Kaffa, Bench-Maji, Illubabbor, Shaka; central and southern Oromia and eastern Hararghe Highlands. These areas are within the range

of elevations reported by Riedl and Edwards (2006) for the distribution of the species. Most areas of Borana and Bale zones in Oromia, which are climatically suitable under the current climate change scenarios for the distribution of *C. africana*, will lose their suitability for the distribution of the species in the future. The suitable areas in northern Ethiopia for the distribution of *C. africana* under the baseline climate scenario will turn unsuitable under the projected climate.

The two climate variables contributing more to the model are mean annual temperature and mean annual rainfall. The lowlands of Ethiopia which are not suitable for the distribution of the species are the areas where the temperature is high and rainfall is low (Daniel Gemechu, 1977). The southwest Ethiopian highlands which are climatically suitable for the distribution of *C. africana* are characterised by relatively high rainfall and low temperature (Daniel Gemechu, 1977). This shows how the temperature and rainfall influence the distribution of *C. africana*. The areas which are suitable for the distribution of the species under the current climate change scenario will lose their suitability under the projected climate. This may be due to the rise in temperature. As it was indicated by Platts *et al.* (2014) the temperature increases in sub-Sahara Africa under both IPCC concentration pathways by 2100. The mean annual temperature for the occurrence locations of *C. africana* will increase by 4.3 to 5.1°C by late century (data from Platts *et al.*, 2014).

Millettia ferruginea is one of the endemic species of Ethiopia with least concern in IUCN Red list category (Vivero *et al.*, 2005). The species is distributed in upland forests and rainforests covering the elevational range from 1000–2500m above sea

level. The lowlands around Ethiopian highlands are not suitable for the distribution of *M. ferruginea* under the baseline and projected climate scenarios. Southwest highlands of Ethiopia, particularly the highlands of Jimma, Kaffa, Shaka, most parts of Illuababor zones; some areas of East Wellega zone, and eastern part of West Wellega and northern Borana zones, Sidama and Gedeo zones in south Ethiopia, and some parts of Awi and Metekel zones are some of the most suitable areas for the distribution of *Millettia ferruginea* under the baseline scenario. Under the projected climate change scenarios, the entire Awi Zone, most parts of Metekel, most parts of southwest Illubabor and Shaka zones will lose their suitability for the distribution of *Millettia ferruginea* under the future climate change scenarios.

Western and central highlands of Jimma, central and eastern parts of Kaffa, central and northwestern parts of Bench-Maji, south and southeastern parts of Illubabor remain suitable areas for the distribution of *Millettia ferruginea*. These are the areas with high rainfall and low temperature compared to the surrounding areas (Daniel Gemechu, 1977; Platts *et al*., 2014). They are characterized by low average annual water deficit, low temperature and high rainfall (Daniel Gemechu, 1977; Platts *et al*., 2014). They are the wettest regions of the country (Daniel Gemechu, 1977). Similarly, mean annual temperature and mean annual rainfall are the variables with the highest contribution to the model. The rise in temperature for the points of occurrence of *M. ferruginea* ranges from 4.4–5.0°C by the year 2100 (Platts *et al*., 2014). Under the baseline scenario, the mean annual rainfall for the occurrence localities of *M. ferruginea* ranges from 714–1868 mm. This shifts to 724–1862 mm under the projected climate by the year 2100 (Platts *et al.*, 2014). From this one can

deduce that change in temperature is more important than the change in rainfall for the distribution of *M. ferruginea*.

Phytolacca dodecandra is distributed in an elevation range of 1500–3000 m above sea level (Polhill, 2000). Elevation and temperature have inverse relationship where the temperature decreases with increasing altitude. Mean annual temperature for the occurrence localities of the species ranges from 10.8–21.8°C under the current climate change scenarios (Platts *et al.,* 2014). This temperature range is suitable for the distribution of *P. dodecandra* under the baseline scenario. The mean annual temperature ranges from 15.4–26°C under the projected climate for the occurrence localities of *P. dodecandra* with rise in temperature by 4.6°C and 4.2°C for the higher and lower elevations respectively. The areas with mean annual temperature higher than 21.8°C are not suitable for the distribution of the species. The lower mean annual temperature for occurrence localities of *P .dodecandra* shifts from 10.8°C (under baseline) to 15.4°C (under the projected climate) for the higher elevations, while the mean annual temperature for the lower elevations shifts from 21.8–26°C (Platts *et al*., 2014). Based on the temperature and elevation relationship, it is possible to deduce the elevational shift in spatial distribution of *P. dodecandra* if the current climate change scenario continues. This agrees with Parmesa and Yohe (2003).

Highlands of Kaffa, Jimma, Bench-Maji (parts of southwest highlands of Ethiopia); west Shewa and Guragie zones (central Ethiopia); Arsi, Sidama, Borena and Gedeo highlands, north and western Bale;and Harargie highlands are currently the most suitable areas for the distribution of *P.dodecandra.* The areas with the mean annual

temperature above 21.8°C lost their suitability for the distribution of the species. From the northwestern highlands, the areas of southwest Ethiopia (Jimma, Kaffa); central Ethiopia (west Shewa and Guraghe zones) will lose their suitability for the distribution of the species under the projected climate due to the shift of mean annual temperature above 21.8°C. The areas of southeastern highlands (most areas of northern and northwestern Bale; Sidama and Gedeo zones; Central Arsi and eastern Hararghe highlands will be suitable for the distribution of the species under the projected climate

Mean annual temperature for occurrence locations of *Schefflera abyssinica* under the baseline climate change scenarios ranges from 13.8–21.5°C. This shifts to 18.4–26.3°C under the projected climate change scenarios with a minimum change of 4.6°C and a maximum of 4.8°C.

5.2. Conclusion

1. Land use/land cover change affected plat species richness, abundance and diversity across the study transect. The richness decreases from less modified to highly modified land use types in the trasect.
2. Plant spcies richness and abundance showed significant linear relationships with some climate variables across the transect. Therefore, climate has impacts on the richness and abundance of plant species.
3. In all land use types, except in planation forests, herbaceous species dominate the species composition.

4. Land use/land cover change affected the above ground live carbon storage with the maximum in the planation forests followed by DNF and SFC and the minimum in cropland.
5. The linear relationship between above ground live carbon storage and climate variables shows that climate affects its storage.
6. Tree species richness and abundance vary along the vertical stratification in SFC and DNF. In both cases, the middle storey is with the highest species abundance followed by the lower storey.
7. As in plant richness and carbon storage, LAI also varies with land use types and the differences were statistically significant. This shows how the land use types influence the distribution of LAI. The three forests (SFC, DNF and plantation forests) and woodlands were not significantly differed in LAI.
8. Leaf area index highly influenced the above ground live carbon storage. It explains about 75% of the variation in carbon storage across the land use types.
9. Leaf area index has linear relationships with climate variables such as mean annual rainfall, max temp warmest month, mean annual temperature and potential evapotranspiration. These climate variables could affect LAI directly or indirectly.
10. SFC is significantly different from pasture and cropland in LAI, while the difference with DNF, plantation forest and woodland was not significant.
11. Topographic variables did not significantly explain the variation in LAI across the study transect, while land use types did well.

12. Significant statistical variation was obtained between the LAI taken above the coffee canopy and the LAI taken below the coffee canopy. This shows the importance of coffee canopy in the contribution to the total leaf area index when taken below the coffee canopy.
13. The distribution model of five plant species across Ethiopia showd how the climate change affects their distribution both under the present and projected scenarios.
14. Most of the areas which are suitable for the distribution of these species under the current climate will turn unsuitable under the most extreme representative concentration pathways (RCP8.5).

5.3. Recommendations

1. In the transect, most of the grasslands and some areas of forests have been converted to farm lands of annual crops by the small holder subsistence agriculture. Each year, new areas have been added to agricultural land. This is to get more yields to satisfy the increasing family members. To combat this problem, new agricultural technologies by which the farmers could get sufficient yield from small areas of land should be introduced in the area.
2. Most of the areas in the transect are covered by SFC, while the DNF is confined to smaller areas located above 2000 m elevation. Farmers tend to convert coffee forests to alternative land use types like croplands during yield loss and failure in coffee price. This compromises the plant species richness, diversity, carbon storage, leaf

area index and other ecosystem services from which the community could benefit. To make the SFC sustainable in provision of ecosystem goods and services, there should be a mechanism by which the farmers could be supported during the yield loss and failure in market price.

3. SFC is in the third place in carbon storage in the biomass of the coffee shade trees. They are important sinks of carbon because the coffee shade trees are looked after by the coffee farmers and stay longer in the coffee plot providing shade for the coffee trees/shrubs beneath. The SFC forests satisfy the forest definition for REDD+ mechanism. Therefore, SFC should be considered in any climate debates and the coffee growers should be benefited from the carbon funds.
4. The DNF is confined to the upper part of the transect and is used as a common pool for provison of materials for construction, timber and non-timber forest products and other ecosystem goods and services for the surrounding community. There is also a pressure from the community to convert the forest to croplands which strongly compromises the species richness, diversity, carbon storage, leaf area index and other ecosystem goods and services. Therefore, there should be a mechanism by which the community around the forest could get sustainable benefit from the forest around them. Non-timber forest products like honey production could sustainably benefit the community and also conserve the forest.

5. Climate change affects the distribution of plant species. Most of the areas which are currently suitable for the distribution of the species may become unsuitable in the future if the current climate change scenario continues. Climate has no boundary and the measure to be taken needs integrated effort across the world. Therefore, humanity across the world should agree to fight the climate change through reduction in greenhouse gas emissions.

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Appendices

Appendix 1: Soil and Potential evapotranspiration data for the study plots in the Jimma Highlands (CEC = cation exchange capacity, OC = organic carbon, BLD = bulk density, PET = potential evapotranspiration)

Land Use	Sand	Clay	Silt	PH	CEC (ds/m)	OC (kg)	BLD (kg)	PET (mm)
SFC 1	33.500	37.667	28.667	5.067	0.202	18.667	1138.500	1674
SFC 2	36.167	37.333	26.833	5.617	0.222	16.833	1133.333	1759
SFC 3	35.000	37.833	27.000	5.467	0.225	16.167	1127.167	1811
SFC 4	35.500	40.333	23.833	5.517	0.233	18.833	1134.167	1818
SFC 5	34.833	38.833	26.500	5.567	0.235	17.500	1108.500	1726
SFC 6	32.167	43.667	24.167	5.267	0.253	21.667	1158.500	1814
SFC 7	32.333	41.167	26.667	5.433	0.233	18.667	1195.833	1715
DNF1	32.167	43.667	24.167	5.317	0.253	21.667	1158.500	1755
DNF 2	34.167	37.667	27.667	4.983	0.192	17.833	1164.167	1655
DNF 3	34.333	38.167	27.667	5.017	0.198	18.833	1124.167	1650
DNF 4	33.500	41.333	25.333	4.983	0.193	18.667	1147.667	1655
Pasture 1	30.167	42.333	27.167	5.567	0.242	22.000	1161.833	1748
Pasture 2	28.333	43.333	27.833	5.483	0.263	22.000	1152.000	1785
Pasture 3	31.500	42.500	25.833	5.517	0.223	17.833	1157.833	1826
Pasture 4	30.833	43.500	25.667	5.367	0.253	18.667	1186.833	1823
Pasture 5	32.000	42.167	25.833	5.683	0.243	22.500	1159.833	1785
Woodland 1	36.167	37.333	26.833	5.283	0.222	16.833	1133.333	1663
Woodland 2	33.000	39.833	26.833	5.533	0.243	17.167	1084.667	1674
Woodland 3	32.333	41.000	26.667	5.567	0.210	20.167	1226.833	1718
Woodland 4	33.500	39.500	26.667	5.467	0.238	18.833	1095.833	1715
Cropland 1	32.167	42.333	25.333	5.067	0.200	17.333	1128.167	1674
Cropland 2	32.333	41.167	26.667	5.433	0.233	18.667	1195.833	1807
Cropland 3	33.667	41.167	25.333	5.567	0.232	19.333	1136.333	1795
Cropland 4	30.833	43.500	25.667	5.633	0.253	18.667	1186.833	1826
Cropland 4	30.667	41.333	27.833	5.383	0.203	20.167	1178.333	1795
Cropland 6	33.010	39.833	26.833	5.533	0.243	17.167	1084.667	1718
Cropland 7	32.510	43.657	24.000	5.257	0.261	23.001	1119.657	1748
Plantation 1	33.000	42.167	24.667	5.017	0.203	18.833	1137.833	1759
Plantation 2	32.167	42.333	25.333	5.067	0.200	17.333	1128.167	1816
Plantation 3	31.167	42.167	26.667	5.266	0.220	22.167	1249.833	1814
Plantation 4	32.500	43.667	24.000	5.267	0.262	23.000	1119.667	1795

Appendix 2: Species list, percent and relative frequencies in the DNF

S.N	Species name (in DNF)	Family	Growth form	Freq	%Freq	R.F
1	*Acanthus eminens*	Acanthaceae	S	3	75	0.011
2	*Achyranthes aspera*	Amaranthaceae	H	3	75	0.011
3	*Adiantum poiretii*	Adiantaceae	H	4	100	0.014
4	*Ageratum conyzoides*	Asteraceae	H	2	50	0.007
5	*Albizia gummifera*	Fabaceae	T	4	100	0.014
6	*Albizia schimperiana*	Fabaceae	T	2	50	0.007
7	*Allophylus abyssinicus*	Sapindaceae	T	4	100	0.014
8	*Allophylus macrobotrys*	Sapindaceae	S	2	50	0.007
9	*Apodytes dimidiata*	Icacinaceae	T	3	75	0.011
10	*Arthraxon micans*	Poaceae	H	2	50	0.007
11	*Asparagus racemosus*	Asparagaceae	S	3	75	0.011
12	*Asplenium aethiopicum*	Aspleniaceae	H	3	75	0.011
13	*Asplenium formosum*	Aspleniaceae	H	3	75	0.011
14	*Bersama abyssinica*	Melianthaceae	T	4	100	0.014
15	*Bidens pilosa*	Asteraceae	H	2	50	0.007
16	*Brucea antidysenterica*	Simaroubaceae	S	2	50	0.007
17	*Calpurnia aurea*	Fabaceae	T	1	25	0.004
18	*Canthium oligocarpum*	Rubiaceae	T	2	50	0.007
19	*Carissa spinarum*	Apocynaceae	S	3	75	0.011
20	*Cassipourea malosana*	Rhizophoraceae	T	1	25	0.004
21	*Celtis africana*	Ulmaceae	T	4	100	0.014
22	*Chionanthus mildbraedii*	Oleaceae	S	2	50	0.007
23	*Cissus petiolata*	Vitaceae	L	2	50	0.007
24	*Clausena anisata*	Rutaceae	S	2	50	0.007
25	*Coffea arabica*	Rubiaceae	S	2	50	0.007
26	*Combretum paniculatum*	Combretaceae	L	2	50	0.007
27	*Conyza bonariensis*	Asteraceae	H	2	50	0.007
28	*Cordia africana*	Boraginaceae	T	2	50	0.007
29	*Crassocephalum rubens*	Asteraceae	H	2	50	0.007
30	*Croton macrostachyus*	Euphorbiaceae	T	4	100	0.014
31	*Cynodon aethiopicus*	Poaceae	H	2	50	0.007
32	*Cyphostemma cyphopetalum*	Vitaceae	H	2	50	0.007
33	*Dalbergia lactea*	Fabaceae	S	2	50	0.007
34	*Desmodium repandum*	Fabaceae	H	4	100	0.014
35	*Dichrocephala integrifolia*	Asteraceae	H	3	75	0.011
36	*Doryopteris concolor*	Sinopteridaceae	H	2	50	0.007
37	*Dracaena afromontana*	Dracaenaceae	S	2	50	0.007
38	*Dracaena steudneri*	Dracaenaceae	T	2	50	0.007

S.N	Species name (in DNF)	Family	Growth form	Freq	%Freq	R.F
39	*Droguetia iners*	Urticaceae	H	3	75	0.011
40	*Ehretia cymosa*	Boraginaceae	T	2	50	0.007
41	*Ekebergia capensis*	Meliaceae	T	2	50	0.007
42	*Embelia schimperi*	Myrsinaceae	S	2	50	0.007
43	*Eremomastax speciosa*	Acanthaceae	H	2	50	0.007
44	*Erythrococca trichogyne*	Euphorbiaceae	S	2	50	0.007
45	*Ficus sur*	Moraceae	T	3	75	0.011
46	*Flacourtia indica*	Flacourtiaceae	T	2	50	0.007
47	*Galiniera saxifraga*	Rubiaceae	T	3	75	0.011
48	*Geranium aculeolatum*	Geraniaceae	H	2	50	0.007
49	*Gouania longispicata*	Rhamnaceae	L	3	75	0.011
50	*Grewia ferruginea*	Proteaceae	S	2	50	0.007
51	*Hippocratea goetzei*	Celastraceae	L	2	50	0.007
52	*Hypoestes forskaullii*	Acanthaceae	H	2	50	0.007
53	*Impatiens aethiopica*	Balsaminaceae	H	2	50	0.007
54	*Isoglossa somalensis*	Acanthaceae	S	2	50	0.007
55	*Jasminum abyssinicum*	Oleaceae	L	4	100	0.014
56	*Jasminum repandum*	Oleaceae	L	3	75	0.011
57	*Laggera crispata*	Asteraceae	H	2	50	0.007
58	*Landolphia buchananii*	Apocynaceae	L	4	100	0.014
59	*Loxogramme abyssinica*	Polypodiaceae	H	3	75	0.011
60	*Macaranga capensis*	Euphorbiaceae	T	2	50	0.007
61	*Maesa lanceolata*	Myrsinaceae	T	2	50	0.007
62	*Maytenus arbutifolia*	Celastraceae	T	3	75	0.011
63	*Maytenus gracilipes*	Celastraceae	S	2	50	0.007
64	*Maytenus undata*	Celastraceae	S	2	50	0.007
65	*Microsorium scolopendria*	Polypodiaceae	H	2	50	0.007
66	*Mikaniopsis clematoides*	Asteraceae	H	2	50	0.007
67	*Millettia ferruginea*	Fabaceae	T	2	50	0.007
68	*Myrsine africana*	Myrsinaceae	S	2	50	0.007
69	*Nuxia congesta*	Loganiaceae	T	1	25	0.004
70	*Ocimum urticifolium*	Lamiaceae	S	2	50	0.007
71	*Olea welwitschii*	Oleaceae	T	2	50	0.007
72	*Oplismenus compositus*	Poaceae	H	3	75	0.011
73	*Oplismenus hirtellus*	Poaceae	H	2	50	0.007
74	*Oxyanthus speciosus*	Rubiaceae	S	2	50	0.007
75	*Passiflora edulis*	Passifolraceae	L	2	50	0.007
76	*Paullinia pinnata*	Sapindaceae	L	2	50	0.007
77	*Peperomia abyssinica*	Piperaceae	H	4	100	0.014

S.N	Species name (in DNF)	Family	Growth form	Freq	%Freq	R.F
78	*Peperomia tetraphyla*	Piperaceae	H	4	100	0.014
79	*Pergularia daemia*	Asclepiadaceae	H	2	50	0.007
80	*Periploca linearifolia*	Asclepiadaceae	L	2	50	0.007
81	*Phoenix reclinata*	Arecaceae	T	3	75	0.011
82	*Phyllanthus mooneyi*	Euphorbiaceae	H	2	50	0.007
83	*Phytolacca dodecandra*	Phytolacaeae	S	2	50	0.007
84	*Piper capense*	Pinaceae	S	3	75	0.011
85	*Podocarpus falcatus*	Lamiaceae	T	4	100	0.014
86	*Polyscias fulva*	Podocarpaceae	T	2	50	0.007
87	*Pouzolzia mixta*	Araliaceae	S	2	50	0.007
88	*Prunus africana*	Lamiaceae	T	2	50	0.007
89	*Psychotria orophila*	Myrtaceae	T	2	50	0.007
90	*Rhamnus prinoides*	Ranunculaceae	S	3	75	0.011
91	*Rothmannia urcelliformis*	Capparidaceae	T	2	50	0.007
92	*Rubus steudneri*	Rosaceae	S	3	75	0.011
93	*Rumex natalensis*	Rosaceae	H	2	50	0.007
94	*Rytigynia neglecta*	Polygonaceae	S	3	75	0.011
95	*Sanicula elata*	Rubiaceae	H	3	75	0.011
96	*Schefflera abyssinica*	Lamiaceae	T	2	50	0.007
97	*Senna didymobotrya*	Oleaceae	S	2	50	0.007
98	*Setaria megaphylla*	Fabaceae	H	3	75	0.011
99	*Setaria verticillata*	Poaceae	H	2	50	0.007
100	*Solanecio gigas*	Malvaceae	S	3	75	0.011
101	*Solanecio mannii*	Asteraceae	T	3	75	0.011
102	*Solanum anguivi*	Asteraceae	S	2	50	0.007
103	*Solanum giganteum*	Solanaceae	S	2	50	0.007
104	*Stephania abyssinica*	Caryophyllaceae	H	2	50	0.007
105	*Syzygium guineense*	Bignoniaceae	T	4	100	0.014
106	*Teclea nobilis*	Asteraceae	T	2	50	0.007
107	*Tectaria gemmifera*	Rutaceae	H	2	50	0.007
108	*Tragia cinerea*	Ranunculaceae	H	2	50	0.007
109	*Trichilia dregeana*	Euphorbiaceae	T	2	50	0.007
110	*Urera hypselodendron*	Tiliaceae	L	2	50	0.007
111	*Vangueria apiculata*	Urticaceae	T	2	50	0.007
112	*Vepris dainellii*	Rubiaceae	T	3	75	0.011
113	*Vernonia auriculifera*	Asteraceae	S	2	50	0.007
114	*Vernonia biafrae*	Asteraceae	S	2	50	0.007

Appendix 3: Species list, family, growth form (GF) percent and relative frequencies (%freq, R.F) in the woodland

S.N	Species name (in woodland)	Family	GF	Freq	%Freq	R.F
1	*Acacia abyssinica*	Fabaceae	T	4	100	0.35
2	*Acacia lahai*	Fabaceae	T	2	50	0.17
3	*Acalypha racemosa*	Euphorbiaceae	H	2	50	0.17
4	*Acanthus pubescens*	Acanthaceae	S	4	100	0.35
5	*Achyranthes aspera*	Amaranthaceae	H	3	75	0.26
6	*Aeschynomene schimperi*	Fabaceae	H	2	50	0.17
7	*Ageratum conyzoides*	Asteraceae	H	2	50	0.17
8	*Ajuga integrifolia*	Lamiaceae	H	2	50	0.17
9	*Albizia gummifera*	Fabaceae	T	2	50	0.17
10	*Amphicarpa africana*	Fabaceae	H	2	50	0.17
11	*Arthropteris monocarpa*	Oleandraceae	H	2	50	0.17
12	*Aspilia mossambicensis*	Asteraceae	S	2	50	0.17
13	*Asplenium formosum*	Aspleniaceae	H	2	50	0.17
14	*Berkheya spekeana*	Asteraceae	H	2	50	0.17
15	*Bidens pilosa*	Asteraceae	H	4	100	0.35
16	*Bidens prestinaria*	Asteraceae	H	2	50	0.17
17	*Bridelia micrantha*	Euphorbiaceae	T	2	50	0.17
18	*Buchnera hispida*	Scrophulariaceae	H	2	50	0.17
19	*Caesalpinia decapetala*	Fabaceae	S	1	25	0.09
20	*Calpurnia aurea*	Fabaceae	T	2	50	0.17
21	*Cardiospermum halicacabum*	Sapindaceae	H	2	50	0.17
22	*Carissa spinarum*	Apocynaceae	S	2	50	0.17
23	*Cissus petiolata*	Vitaceae	L	2	50	0.17
24	*Clausena anisata*	Rutaceae	S	2	50	0.17
25	*Clematis cadatus*	Ranunculaceae	L	2	50	0.17
26	*Clematis longicauda*	Ranunculaceae	L	2	50	0.17
27	*Clematis simensis*	Ranunculaceae	L	2	50	0.17
28	*Clerodendron myricoides*	Lamiaceae	S	2	50	0.17
29	*Coelorhachis afraurita*	Poaceae	H	2	50	0.17
30	*Coffea arabica*	Rubiaceae	S	1	25	0.09
31	*Combretum collinum*	Combretaceae	T	2	50	0.17
32	*Combretum molle*	Combretaceae	T	2	50	0.17
33	*Combretum paniculatum*	Combretaceae	L	2	50	0.17
34	*Commelina diffusa*	Commelinaceae	H	2	50	0.17
35	*Cordia africana*	Boraginaceae	T	3	75	0.26
36	*Croton macrostachyus*	Euphorbiaceae	T	3	75	0.26
37	*Cuscuta campestris*	Cuscutaceae	H	2	50	0.17

S.N	Species name (in woodland)	Family	GF	Freq	%Freq	R.F
38	*Cyathula uncinulatA*	Amaranthaceae	H	2	50	0.17
39	*Cycnium herzfeldianum*	Scrophulariaceae	H	2	50	0.17
40	*Cynodon aethiopicus*	Poaceae	H	2	50	0.17
41	*Cyperus welwitschii*	Cyperaceae	H	2	50	0.17
42	*Cyphostemma cyphopetalum*	Vitaceae	H	3	75	0.26
43	*Cyprus triceps*	Cyperaceae	H	2	50	0.17
44	*Desmodium repandum*	Fabaceae	H	2	50	0.17
45	*Desmodium salisifolium*	Fabaceae	H	2	50	0.17
46	*Dichondra repens*	Convolvulaceae	H	3	75	0.26
47	*Dicliptera laxata*	Acanthaceae	H	2	50	0.17
48	*Dioscorea bulbifera*	Dioscoreaceae	H	2	50	0.17
49	*Entada abyssinica*	Fabaceae	T	4	100	0.35
50	*Erythrina brucei*	Fabaceae	T	1	25	0.09
51	*Euphorbia cyparissioides*	Euphorbiaceae	H	2	50	0.17
52	*Euphorbia tirucalli*	Euphorbiaceae	T	2	50	0.17
53	*Ficus mucuso*	Moraceae	T	2	50	0.17
54	*Ficus sp.*	Moraceae	T	1	25	0.09
55	*Ficus sur*	Moraceae	T	2	50	0.17
56	*Ficus sycamoras*	Moraceae	T	2	50	0.17
57	*Ficus thonningii*	Moraceae	T	2	50	0.17
58	*Ficus vasta*	Moraceae	T	2	50	0.17
59	*Flacourtia indica*	Flacourtiaceae	T	2	50	0.17
60	*Galinsoga parviflora*	Asteraceae	H	2	50	0.17
61	*Gardenia volkensii*	Rubiaceae	S	3	75	0.26
62	*Girardinia diversifolia*	Urticaceae	H	2	50	0.17
63	*Gnidia glauca*	Thymelaeaceae	S	2	50	0.17
64	*Grewia ferruginea*	Proteaceae	S	2	50	0.17
65	*Guizotia schimperi*	Asteraceae	H	2	50	0.17
66	*Helinus mystacinus*	Rhamnaceae	L	2	50	0.17
67	*Helychrysum forskaulii*	Asteraceae	H	1	25	0.09
68	*Hibiscus berberidifolius*	Malvaceae	S	2	50	0.17
69	*Hibiscus dongolensis*	Malvaceae	S	2	50	0.17
70	*Hippocratea goetzei*	Celastraceae	L	2	50	0.17
71	*Hyparrhenia rufa*	Poaceae	H	3	75	0.26
72	*Hypericum peplidifolium*	Hypericaceae	H	2	50	0.17
73	*Hypericum revolutum*	Hypericaceae	S	2	50	0.17
74	*Hypolepis glandulifera*	Dennstaedtiaceae	H	2	50	0.17
75	*Indigofera spicata*	Fabaceae	S	2	50	0.17
76	*Justicia ladanoides*	Acanthaceae	H	2	50	0.17
77	*Keetia guiinzii*	Rubiaceae	S	2	50	0.17

S.N	Species name (in woodland)	Family	GF	Freq	%Freq	R.F
78	*Laggera crispata*	Asteraceae	H	2	50	0.17
79	*Lantana trifolium*	Verbenaceae	S	2	50	0.17
80	*Leucas martinicensis*	Lamiaceae	H	2	50	0.17
81	*Lippia adoensis*	Verbenaceae	S	3	75	0.26
82	*Maesa lanceolata*	Myrsinaceae	T	2	50	0.17
83	*Mikaniopsis clematoides*	Asteraceae	H	2	50	0.17
84	*Millettia ferruginea*	Fabaceae	T	2	50	0.17
85	*Momordica foetida*	Cucurbitaceae	H	2	50	0.17
86	*Ocimum lamiifolium*	Lamiaceae	S	2	50	0.17
87	*Ocimum urticifolium*	Lamiaceae	S	2	50	0.17
88	*Oplismenus compositus*	Poaceae	H	2	50	0.17
89	*Otostegia tomentosa*	Lamiaceae	S	2	50	0.17
90	*Passiflora edulis*	Passifolraceae	L	1	25	0.09
91	*Pavonia urens*	Malvaceae	S	3	75	0.26
92	*Pennisetum sphacelatum*	Poaceae	H	2	50	0.17
93	*Phoenix reclinata*	Arecaceae	T	2	50	0.17
94	*Phyllanthus ovalifolius*	Euphorbiaceae	S	2	50	0.17
95	*Premna schimperi*	Urticaceae	S	2	50	0.17
96	*Pseudarthria hookeri*	Rosaceae	H	2	50	0.17
97	*Psidium guajava*	Fabaceae	T	2	50	0.17
98	*Pychnostachys emini*	Fabaceae	H	2	50	0.17
99	*Pycnostachys abyssinica*	Lamiaceae	H	2	50	0.17
100	*Pycreus nitida*	Lamiaceae	H	2	50	0.17
101	*Rhamnus prinoides*	Ranunculaceae	S	2	50	0.17
102	*Rhoicissus tridentata*	Rhamnaceae	L	2	50	0.17
103	*Rhus natalensis*	Vitaceae	S	2	50	0.17
104	*Ricinus communis*	Anacardiaceae	H	2	50	0.17
105	*Rothmannia urcelliformis*	Capparidaceae	T	1	25	0.09
106	*Rubus steudneri*	Rosaceae	S	2	50	0.17
107	*Rumex natalensis*	Rosaceae	H	2	50	0.17
108	*Sapium ellipticum*	Apiaceae	T	2	50	0.17
109	*Satureja paradoxa*	Euphorbiaceae	H	2	50	0.17
110	*Senna didymobotrya*	Oleaceae	S	2	50	0.17
111	*Senna occidentalis*	Fabaceae	H	2	50	0.17
112	*Senna petersiana*	Fabaceae	T	3	75	0.26
113	*Sesbania sesban*	Malvaeae	T	1	25	0.09
114	*Sicyos polyacanthus*	Poaceae	H	1	25	0.09
115	*Sida schimperiana*	Cucurbitaceae	S	2	50	0.17
116	*Sida tenuicarpa*	Malvaceae	S	2	50	0.17
117	*Sida ternata*	Malvaceae	H	2	50	0.17

S.N	Species name (in woodland)	Family	GF	Freq	%Freq	R.F
118	*Solanum capsicoides*	Solanaceae	S	2	50	0.17
119	*Solanum giganteum*	Solanaceae	S	2	50	0.17
120	*Solanum incanum*	Solanaceae	S	3	75	0.26
121	*Stachys albigena*	Poaceae	H	2	50	0.17
122	*Stereospermum kunthianum*	Menispermaceae	T	3	75	0.26
123	*Syzygium guineense*	Bignoniaceae	T	2	50	0.17
124	*Terminalia schimperiana*	Tectariaceae	T	4	100	0.35
125	*Tragia cinerea*	Ranunculaceae	H	2	50	0.17
126	*Triumfetta pilosa*	Moraceae	H	2	50	0.17
127	*Vangueria apiculata*	Urticaceae	T	2	50	0.17
128	*Vernonia adoensis*	Rutaceae	S	2	50	0.17
129	*Vernonia amygdalina*	Asteraceae	T	2	50	0.17
130	*Vernonia auriculifera*	Asteraceae	S	4	100	0.35
131	*Vernonia hochstetteri*	Asteraceae	S	2	50	0.17
132	*Vernonia ischnophylla*	Asteraceae	S	3	75	0.26
133	*Vernonia karaguensis*	Asteraceae	S	2	50	0.17
134	*Vernonia theophrastifolia*	Asteraceae	S	2	50	0.17
135	*Vernonia thomsoniana*	Asteraceae	S	2	50	0.17
136	*Veronica abyssinica*	Asteraceae	H	2	50	0.17

Appendix 4: Species list, family, growth form (GF) percent and relative frequencies (%freq, R.F) in the cropland

S.N	Species name (in cropland)	Family	GF	Freq	%Freq	R.F
1	*Acacia abyssinica*	Fabaceae	T	5	71	0.022
2	*Acanthus pubescens*	Acanthaceae	S	2	29	0.009
3	*Achyranthes aspera*	Amaranthaceae	H	3	43	0.013
4	*Ageratum conyzoides*	Asteraceae	H	7	100	0.030
5	*Ajuga integrifolia*	Lamiaceae	H	2	29	0.009
6	*Albizia gummifera*	Fabaceae	T	4	57	0.017
7	*Alchemila pedata*	Rosaceae	H	3	43	0.013
8	*Alectra sessiliflora*	Scrophulariaceae	H	2	29	0.009
9	*Amaranthus hybridus*	Amaranthaceae	H	2	29	0.009
10	*Amaranthus sparganiocephalus*	Amaranthaceae	H	2	29	0.009
11	*Arthraxon micans*	Poaceae	H	2	29	0.009
12	*Bersama abyssinica*	Melianthaceae	T	3	43	0.013
13	*Bidens pilosa*	Asteraceae	H	3	43	0.013
14	*Bidens prestinaria*	Asteraceae	H	4	57	0.017
15	*Brassica carinata*	Brassicaceae	H	3	43	0.013
16	*Brucea antidysenterica*	Simaroubaceae	S	3	43	0.013
17	*Calpurnia aurea*	Fabaceae	T	3	43	0.013
18	*Caylusea abyssinica*	Resedaceae	H	3	43	0.013
19	*Celtis africana*	Ulmaceae	T	2	29	0.009
20	*Chenopodium ambrosioides*	Chenopodiaceae	H	3	43	0.013
21	*Cirsium dender*	Asteraceae	H	2	29	0.009
22	*Cissampelos mucronata*	Menispermaceae	H	2	29	0.009
23	*Clematis cadatus*	Ranunculaceae	L	2	29	0.009
24	*Clematis simensis*	Ranunculaceae	L	2	29	0.009
25	*Coelorhachis afraurita*	Poaceae	H	2	29	0.009
26	*Combretum collinum*	Combretaceae	T	2	29	0.009
27	*Commelina diffusa*	Commelinaceae	H	3	43	0.013
28	*Commelina imberbis*	Commelinaceae	H	2	29	0.009
29	*Conyza bonariensis*	Asteraceae	H	2	29	0.009
30	*Cordia africana*	Boraginaceae	T	5	71	0.022
31	*Crassocephalum macropappum*	Asteraceae	H	2	29	0.009
32	*Croton macrostachyus*	Euphorbiaceae	T	2	29	0.009
33	*Cuscuta campestris*	Cuscutaceae	H	3	43	0.013
34	*Cyathula uncinulatA*	Amaranthaceae	H	5	71	0.022
35	*Cycnium herzfeldianum*	Scrophulariaceae	H	2	29	0.009
36	*Cynodon aethiopicus*	Poaceae	H	5	71	0.022
37	*Dalbergia lactea*	Fabaceae	S	2	29	0.009

S.N	Species name (in cropland)	Family	GF	Freq	%Freq	R.F
38	*Datura stramonium*	Solanaceae	H	3	43	0.013
39	*Dichondra repens*	Convolvulaceae	H	2	29	0.009
40	*Dioscorea bulbifera*	Dioscoreaceae	H	2	29	0.009
41	*Echium plantagineum*	Boraginaceae	H	2	29	0.009
42	*Ehretia cymosa*	Boraginaceae	T	2	29	0.009
43	*Erythrina brucei*	Fabaceae	T	1	14	0.004
44	*Euphorbia tirucalli*	Euphorbiaceae	T	2	29	0.009
45	*Ficus mucuso*	Moraceae	T	2	29	0.009
46	*Ficus sp.*	Moraceae	T	1	14	0.004
47	*Ficus sur*	Moraceae	T	2	29	0.009
48	*Galinsoga parviflora*	Asteraceae	H	3	43	0.013
49	*Glycine wightii*	Fabaceae	H	2	29	0.009
50	*Guizotia schimperi*	Asteraceae	H	5	71	0.022
51	*Hibiscus dongolensis*	Malvaceae	S	2	29	0.009
52	*Hygrophila asteracanthoide*	Acanthaceae	H	2	29	0.009
53	*Hyparrhenia rufa*	Poaceae	H	2	29	0.009
54	*Indigofera spicata*	Fabaceae	S	2	29	0.009
55	*Justicia ladanoides*	Acanthaceae	H	2	29	0.009
56	*Laggera crispata*	Asteraceae	H	2	29	0.009
57	*Leucas martinicensis*	Lamiaceae	H	2	29	0.009
58	*Lippia adoensis*	Verbenaceae	S	2	29	0.009
59	*Maesa lanceolata*	Myrsinaceae	T	2	29	0.009
60	*Maytenus gracilipes*	Celastraceae	S	3	43	0.013
61	*Millettia ferruginea*	Fabaceae	T	2	29	0.009
62	*Momordica foetida*	Cucurbitaceae	H	4	57	0.017
63	*Nicandra physaloides*	Solanaceae	H	2	29	0.009
64	*Ocimum urticifolium*	Lamiaceae	S	2	29	0.009
65	*Pavonia glechomifolia*	Malvaceae	H	2	29	0.009
66	*Pavonia urens*	Malvaceae	S	2	29	0.009
67	*Pennisetum nubicum*	Poaceae	H	2	29	0.009
68	*Phyllanthus mooneyi*	Euphorbiaceae	H	2	29	0.009
69	*Physalis peruviana*	Solanaceae	H	2	29	0.009
70	*Phytolacca dodecandra*	Phytolacaeae	S	4	57	0.017
71	*Plantago lanceolata*	Pittosporaceae	H	4	57	0.017
72	*Ritchiea albersii*	Euphorbiaceae	T	1	14	0.004
73	*Rumex natalensis*	Rosaceae	H	3	43	0.013
74	*Sapium ellipticum*	Apiaceae	T	2	29	0.009
75	*Satureja paradoxa*	Euphorbiaceae	H	2	29	0.009
76	*Schefflera abyssinica*	Lamiaceae	T	2	29	0.009
77	*Senna didymobotrya*	Oleaceae	S	3	43	0.013

S.N	Species name (in cropland)	Family	GF	Freq	%Freq	R.F
78	*Sida schimperiana*	Cucurbitaceae	S	2	29	0.009
79	*Sida tenuicarpa*	Malvaceae	S	3	43	0.013
80	*Solanecio gigas*	Malvaceae	S	2	29	0.009
81	*Solanum incanum*	Solanaceae	S	3	43	0.013
82	*Soncus asper*	Solanaceae	H	3	43	0.013
83	*Stereospermum kunthianum*	Menispermaceae	T	2	29	0.009
84	*Tagetes minuta*	Myrtaceae	H	2	29	0.009
85	*Terminalia schimperiana*	Tectariaceae	T	2	29	0.009
86	*Tragia cinerea*	Ranunculaceae	H	2	29	0.009
87	*Triumfetta rhomboidea*	Tiliaceae	H	2	29	0.009
88	*Vernonia amygdalina*	Asteraceae	T	2	29	0.009
89	*Vernonia auriculifera*	Asteraceae	S	4	57	0.017
90	*Vernonia ischnophylla*	Asteraceae	S	2	29	0.009
91	*Veronica abyssinica*	Asteraceae	H	2	29	0.009

Appendix 5: Species list, Growth form (GF), percent and relative frequencies (%freq, R.F) of plant species in the SFC

S.N	Species name (in SFC)	Family	GF	Freq	%Freq	R.F
1	*Celtis africana*	Ulmaceae	T	7	100	0.017
2	*Coffea arabica*	Rubiaceae	S	7	100	0.017
3	*Ehretia cymosa*	Boraginaceae	T	7	100	0.017
4	*Achyranthes aspera*	Amaranthaceae	H	6	86	0.015
5	*Albizia gummifera*	Fabaceae	T	6	86	0.015
6	*Cordia africana*	Boraginaceae	T	6	86	0.015
7	*Croton macrostachyus*	Euphorbiaceae	T	6	86	0.015
8	*Desmodium repandum*	Fabaceae	H	6	86	0.015
9	*Vepris dainellii*	Rubiaceae	T	6	86	0.015
10	*Vernonia amygdalina*	Asteraceae	T	6	86	0.015
11	*Vernonia auriculifera*	Asteraceae	S	6	86	0.015
12	*Clausena anisata*	Rutaceae	S	5	71	0.012
13	*Maesa lanceolata*	Myrsinaceae	T	5	71	0.012
14	*Oplismenus compositus*	Poaceae	H	5	71	0.012
15	*Vangueria apiculata*	Urticaceae	T	5	71	0.012
16	*Acacia abyssinica*	Fabaceae	T	4	57	0.010
17	*Acanthus eminens*	Acanthaceae	S	4	57	0.010
18	*Ageratum conyzoides*	Asteraceae	H	4	57	0.010
19	*Allophylus abyssinicus*	Sapindaceae	T	4	57	0.010
20	*Bidens pilosa*	Asteraceae	H	4	57	0.010
21	*Cyathula uncinulatA*	Amaranthaceae	H	4	57	0.010
22	*Erythrococca trichogyne*	Euphorbiaceae	S	4	57	0.010
23	*Girardinia diversifolia*	Urticaceae	H	4	57	0.010
24	*Millettia ferruginea*	Fabaceae	T	4	57	0.010
25	*Pentas lanceolata*	Rubiaceae	S	4	57	0.010
26	*Peperomia abyssinica*	Piperaceae	H	4	57	0.010
27	*Rytigynia neglecta*	Polygonaceae	S	4	57	0.010
28	*Sapium ellipticum*	Apiaceae	T	4	57	0.010
29	*Allophylus macrobotrys*	Sapindaceae	S	3	43	0.007
30	*Bersama abyssinica*	Melianthaceae	T	3	43	0.007
31	*Bidens prestinaria*	Asteraceae	H	3	43	0.007
32	*Calpurnia aurea*	Fabaceae	T	3	43	0.007
33	*Clematis hirsuta*	Ranunculaceae	L	3	43	0.007
34	*Diospyros abyssinica*	Ebenaceae	T	3	43	0.007
35	*Dracaena steudneri*	Dracaenaceae	T	3	43	0.007
36	*Ficus thonningii*	Moraceae	T	3	43	0.007
37	*Ficus vasta*	Moraceae	T	3	43	0.007

S.N	Species name (in SFC)	Family	GF	Freq	%Freq	R.F
38	*Flacourtia indica*	Flacourtiaceae	T	3	43	0.007
39	*Hypoestes aristata*	Acanthaceae	H	3	43	0.007
40	*Impatiens aethiopica*	Balsaminaceae	H	3	43	0.007
41	*Justicia schimperiana*	Acanthaceae	S	3	43	0.007
42	*Maytenus arbutifolia*	Celastraceae	T	3	43	0.007
43	*Maytenus gracilipes*	Celastraceae	S	3	43	0.007
44	*Ocimum lamiifolium*	Lamiaceae	S	3	43	0.007
45	*Pavonia urens*	Malvaceae	S	3	43	0.007
46	*Pergularia daemia*	Asclepiadaceae	H	3	43	0.007
47	*Phyllanthus ovalifolius*	Euphorbiaceae	S	3	43	0.007
48	*Phytolacca dodecandra*	Phytolacaeae	S	3	43	0.007
49	*Pittosporum viridiflorum*	Piperaceae	T	3	43	0.007
50	*Prunus africana*	Lamiaceae	T	3	43	0.007
51	*Ritchiea albersii*	Euphorbiaceae	T	3	43	0.007
52	*Rubus steudneri*	Rosaceae	S	3	43	0.007
53	*Sicyos polyacanthus*	Poaceae	H	3	43	0.007
54	*Sida tenuicarpa*	Malvaceae	S	3	43	0.007
55	*Stephania abyssinica*	Caryophyllaceae	H	3	43	0.007
56	*Tragia cinerea*	Ranunculaceae	H	3	43	0.007
57	*Acalypha racemosa*	Euphorbiaceae	H	2	29	0.005
58	*Achyrospermum schimperi*	Lamiaceae	H	2	29	0.005
59	*Adenostemma perottettii*	Asteraceae	H	2	29	0.005
60	*Albizia schimperiana*	Fabaceae	T	2	29	0.005
61	*Ampelocissus bombycina*	Vitaceae	H	2	29	0.005
62	*Arthropteris monocarpa*	Oleandraceae	H	2	29	0.005
63	*Asparagus racemosus*	Asparagaceae	S	2	29	0.005
64	*Aspilia mossambicensis*	Asteraceae	S	2	29	0.005
65	*Asplenium aethiopicum*	Aspleniaceae	H	2	29	0.005
66	*Asplenium formosum*	Aspleniaceae	H	2	29	0.005
67	*Bridelia micrantha*	Euphorbiaceae	T	2	29	0.005
68	*Caesalpinia decapetala*	Fabaceae	S	2	29	0.005
69	*Celosia anthelminthica*	Amaranthaceae	H	2	29	0.005
70	*Celosia trigyna*	Amaranthaceae	H	2	29	0.005
71	*Ceropegia racemosa*	Asclepiadaceae	H	2	29	0.005
72	*Chenopodium ambrosioides*	Chenopodiaceae	H	2	29	0.005
73	*Chionanthus mildbraedii*	Oleaceae	S	2	29	0.005
74	*Cissampelos mucronata*	Menispermaceae	H	2	29	0.005
75	*Commelina diffusa*	Commelinaceae	H	2	29	0.005
76	*Crassocephalum macropappum*	Asteraceae	H	2	29	0.005
77	*Crotalaria emarginella*	Fabaceae	H	2	29	0.005

S.N	Species name (in SFC)	Family	GF	Freq	%Freq	R.F
78	*Cyphostemma cyphopetalum*	Vitaceae	H	2	29	0.005
79	*Dalbergia lactea*	Fabaceae	S	2	29	0.005
80	*Desmodium dichotomum*	Fabaceae	H	2	29	0.005
81	*Dicliptera laxata*	Acanthaceae	H	2	29	0.005
82	*Doryopteris concolor*	Sinopteridaceae	H	2	29	0.005
83	*Dracaena afromontana*	Dracaenaceae	S	2	29	0.005
84	*Droguetia iners*	Urticaceae	H	2	29	0.005
85	*Ekebergia capensis*	Meliaceae	T	2	29	0.005
86	*Ensete ventricosum*	Musaceae	H	2	29	0.005
87	*Eremomastax speciosa*	Acanthaceae	H	2	29	0.005
88	*Euphorbia candelabrum*	Euphorbiaceae	T	2	29	0.005
89	*Ficus sp.*	Moraceae	T	2	29	0.005
90	*Ficus sur*	Moraceae	T	2	29	0.005
91	*Galiniera saxifraga*	Rubiaceae	T	2	29	0.005
92	*Galinsoga parviflora*	Asteraceae	H	2	29	0.005
93	*Geranium aculeolatum*	Geraniaceae	H	2	29	0.005
94	*Grewia ferruginea*	Proteaceae	S	2	29	0.005
95	*Guizotia schimperi*	Asteraceae	H	2	29	0.005
96	*Hibiscus berberidifolius*	Malvaceae	S	2	29	0.005
97	*Hippocratea goetzei*	Celastraceae	L	2	29	0.005
98	*Indigofera spicata*	Fabaceae	S	2	29	0.005
99	*Isoglossa somalensis*	Acanthaceae	S	2	29	0.005
100	*Justicia ladanoides*	Acanthaceae	H	2	29	0.005
101	*Laggera crispata*	Asteraceae	H	2	29	0.005
102	*Leucas martinicensis*	Lamiaceae	H	2	29	0.005
103	*Loxogramme abyssinica*	Polypodiaceae	H	2	29	0.005
104	*Microsorium scolopendria*	Polypodiaceae	H	2	29	0.005
105	*Momordica foetida*	Cucurbitaceae	H	2	29	0.005
106	*Ocimum urticifolium*	Lamiaceae	S	2	29	0.005
107	*Pavonia glechomifolia*	Malvaceae	H	2	29	0.005
108	*Pennisetum nubicum*	Poaceae	H	2	29	0.005
109	*Peperomia tetraphyla*	Piperaceae	H	2	29	0.005
110	*Phoenix reclinata*	Arecaceae	T	2	29	0.005
111	*Physalis peruviana*	Solanaceae	H	2	29	0.005
112	*Podocarpus falcatus*	Lamiaceae	T	2	29	0.005
113	*Polyscias fulva*	Podocarpaceae	T	2	29	0.005
114	*Premna schimperi*	Urticaceae	S	2	29	0.005
115	*Pseudarthria hookeri*	Rosaceae	H	2	29	0.005
116	*Psydrax schimperiana*	Rubiaceae	T	2	29	0.005
117	*Pteris pteridioides*	Rubiaceae	H	2	29	0.005

S.N	Species name (in SFC)	Family	GF	Freq	%Freq	R.F
118	*Pterolobium stellatum*	Pteridaceae	S	2	29	0.005
119	*Pycnostachys abyssinica*	Lamiaceae	H	2	29	0.005
120	*Ranunculus multifidus*	Pyperaceae	H	2	29	0.005
121	*Ricinus communis*	Anacardiaceae	H	2	29	0.005
122	*Rothmannia urcelliformis*	Capparidaceae	T	2	29	0.005
123	*Sanicula elata*	Rubiaceae	H	2	29	0.005
124	*Schefflera abyssinica*	Lamiaceae	T	2	29	0.005
125	*Senna occidentalis*	Fabaceae	H	2	29	0.005
126	*Senna petersiana*	Fabaceae	T	2	29	0.005
127	*Senra incana*	Fabaceae	H	2	29	0.005
128	*Setaria verticillata*	Poaceae	H	2	29	0.005
129	*Sida schimperiana*	Cucurbitaceae	S	2	29	0.005
130	*Solanecio gigas*	Malvaceae	S	2	29	0.005
131	*Solanum anguivi*	Asteraceae	S	2	29	0.005
132	*Solanum incanum*	Solanaceae	S	2	29	0.005
133	*Soncus asper*	Solanaceae	H	2	29	0.005
134	*Stellaria mannii*	Lamiaceae	H	2	29	0.005
135	*Syzygium guineense*	Bignoniaceae	T	2	29	0.005
136	*Teclea nobilis*	Asteraceae	T	2	29	0.005
137	*Tectaria gemmifera*	Rutaceae	H	2	29	0.005
138	*Thalictrum rhynchocarpum*	Combretaceae	H	2	29	0.005
139	*Trichilia dregeana*	Euphorbiaceae	T	2	29	0.005
140	*Trilepisium madagascariense*	Meliaceae	T	2	29	0.005
141	*Triumfetta pilosa*	Moraceae	H	2	29	0.005
142	*Triumfetta rhomboidea*	Tiliaceae	H	2	29	0.005
143	*Urera hypselodendron*	Tiliaceae	L	2	29	0.005
144	*Vernonia karaguensis*	Asteraceae	S	2	29	0.005
145	*Apodytes dimidiata*	Icacinaceae	T	1	14	0.002
146	*Cassipourea malosana*	Rhizophoraceae	T	1	14	0.002
147	*Ficus mucuso*	Moraceae	T	1	14	0.002
148	*Gouania longispicata*	Rhamnaceae	L	1	14	0.002
149	*Kosteletzkya begoniifolia*	Malvaceae	H	1	14	0.002
150	*Olea welwitschii*	Oleaceae	T	1	14	0.002
151	*Psidium guajava*	Fabaceae	T	1	14	0.002
152	*Schrebera alata*	Araliaceae	T	1	14	0.002

Appendix 6: Species list, Growth form (GF) percent and relative frequencies (%freq, R.F) of plant species in pastureland

S.N	Species name (in pasture land)	Family	GF	Freq	%Freq	R.F
1	*Acacia abyssinica*	Fabaceae	T	2	40	0.163
2	*Acanthus pubescens*	Acanthaceae	S	2	40	0.163
3	*Achyranthes aspera*	Amaranthaceae	H	3	60	0.244
4	*Aeschynomene schimperi*	Fabaceae	H	2	40	0.163
5	*Ageratum conyzoides*	Asteraceae	H	5	100	0.407
6	*Albizia gummifera*	Fabaceae	T	2	40	0.163
7	*Allophylus macrobotrys*	Sapindaceae	S	2	40	0.163
8	*Amaranthus hybridus*	Amaranthaceae	H	2	40	0.163
9	*Amaranthus sparganiocephalus*	Amaranthaceae	H	2	40	0.163
10	*Apodytes dimidiata*	Icacinaceae	T	1	20	0.081
11	*Asplenium formosum*	Aspleniaceae	H	2	40	0.163
12	*Bauhinia tomentosa*	Fabaceae	T	2	40	0.163
13	*Becium verticillifolium*	Lamiaceae	S	2	40	0.163
14	*Berkheya spekeana*	Asteraceae	H	2	40	0.163
15	*Bersama abyssinica*	Melianthaceae	T	2	40	0.163
16	*Bidens pilosa*	Asteraceae	H	2	40	0.163
17	*Bridelia micrantha*	Euphorbiaceae	T	3	60	0.244
18	*Buchnera hispida*	Scrophulariaceae	H	2	40	0.163
19	*Cardiospermum halicacabum*	Sapindaceae	H	2	40	0.163
20	*Cirsium dender*	Asteraceae	H	2	40	0.163
21	*Clausena anisata*	Rutaceae	S	2	40	0.163
22	*Clematis hirsuta*	Ranunculaceae	L	2	40	0.163
23	*Clematis longicauda*	Ranunculaceae	L	2	40	0.163
24	*Clematis simensis*	Ranunculaceae	L	2	40	0.163
25	*Combretum collinum*	Combretaceae	T	3	60	0.244
26	*Combretum paniculatum*	Combretaceae	L	2	40	0.163
27	*Commelina imberbis*	Commelinaceae	H	2	40	0.163
28	*Conyza bonariensis*	Asteraceae	H	2	40	0.163
29	*Crossopteryx febrifuga*	Rubiaceae	T	2	40	0.163
30	*Croton macrostachyus*	Euphorbiaceae	T	2	40	0.163
31	*Cyathula uncinulatA*	Amaranthaceae	H	2	40	0.163
32	*Cynodon aethiopicus*	Poaceae	H	2	40	0.163
33	*Cyperus digitatus*	Cyperaceae	H	3	60	0.244
34	*Cyprus triceps*	Cyperaceae	H	3	60	0.244
35	*Desmodium dichotomum*	Fabaceae	H	2	40	0.163
36	*Desmodium repandum*	Fabaceae	H	2	40	0.163
37	*Dichondra repens*	Convolvulaceae	H	4	80	0.325

S.N	Species name (in pasture land)	Family	GF	Freq	%Freq	R.F
38	*Digitaria abyssinica*	Poaceae	H	2	40	0.163
39	*Digitaria ternata*	Poaceae	H	2	40	0.163
40	*Doryopteris concolor*	Sinopteridaceae	H	2	40	0.163
41	*Ehretia cymosa*	Boraginaceae	T	2	40	0.163
42	*Entada abyssinica*	Fabaceae	T	2	40	0.163
43	*Euphorbia cyparissioides*	Euphorbiaceae	H	2	40	0.163
44	*Euphorbia schimperiana*	Euphorbiaceae	H	2	40	0.163
45	*Ficus thonningii*	Moraceae	T	2	40	0.163
46	*Ficus vasta*	Moraceae	T	3	60	0.244
47	*Flacourtia indica*	Flacourtiaceae	T	3	60	0.244
48	*Galinsoga parviflora*	Asteraceae	H	2	40	0.163
49	*Gardenia volkensii*	Rubiaceae	S	3	60	0.244
50	*Glycine wightii*	Fabaceae	H	2	40	0.163
51	*Gnidia glauca*	Thymelaeaceae	S	2	40	0.163
52	*Grewia ferruginea*	Proteaceae	S	2	40	0.163
53	*Guizotia schimperi*	Asteraceae	H	2	40	0.163
54	*Helinus mystacinus*	Rhamnaceae	L	2	40	0.163
55	*Helychrysum forskaulii*	Asteraceae	H	2	40	0.163
56	*Hygrophila asteracanthoide*	Acanthaceae	H	3	60	0.244
57	*Hyparrhenia rufa*	Poaceae	H	2	40	0.163
58	*Hypericum peplidifolium*	Hypericaceae	H	2	40	0.163
59	*Justicia ladanoides*	Acanthaceae	H	2	40	0.163
60	*Keetia guiinzii*	Rubiaceae	S	1	20	0.081
61	*Keetia zanzibarica*	Rubiaceae	S	2	40	0.163
62	*Laggera alata*	Asteraceae	H	2	40	0.163
63	*Laggera crispata*	Asteraceae	H	2	40	0.163
64	*Lantana trifolium*	Verbenaceae	S	2	40	0.163
65	*Lippia adoensis*	Verbenaceae	S	2	40	0.163
66	*Maesa lanceolata*	Myrsinaceae	T	3	60	0.244
67	*Maytenus arbutifolia*	Celastraceae	T	2	40	0.163
68	*Maytenus senegalensis*	Celastraceae	T	2	40	0.163
69	*Micractis bojeri*	Asteraceae	H	2	40	0.163
70	*Nephrolepis undulata*	Nephrolepidaceae	H	2	40	0.163
71	*Ocimum urticifolium*	Lamiaceae	S	2	40	0.163
72	*Oplismenus compositus*	Poaceae	H	2	40	0.163
73	*Oplismenus hirtellus*	Poaceae	H	2	40	0.163
74	*Otostegia tomentosa*	Lamiaceae	S	2	40	0.163
75	*Paullinia pinnata*	Sapindaceae	L	2	40	0.163
76	*Pavonia urens*	Malvaceae	S	3	60	0.244
77	*Pennisetum sphacelatum*	Poaceae	H	2	40	0.163

S.N	Species name (in pasture land)	Family	GF	Freq	%Freq	R.F
78	*Pentas lanceolata*	Rubiaceae	S	2	40	0.163
79	*Persicaria setosula*	Polygonaceae	H	2	40	0.163
80	*Phoenix reclinata*	Arecaceae	T	2	40	0.163
81	*Phyllanthus mooneyi*	Euphorbiaceae	H	2	40	0.163
82	*Phyllanthus ovalifolius*	Euphorbiaceae	S	2	40	0.163
83	*Plectranthus punctatus*	Plantaginaceae	H	2	40	0.163
84	*Premna schimperi*	Urticaceae	S	2	40	0.163
85	*Prunus africana*	Lamiaceae	T	1	20	0.081
86	*Pterolobium stellatum*	Pteridaceae	S	2	40	0.163
87	*Pychnostachys emini*	Fabaceae	H	2	40	0.163
88	*Pycreus nitida*	Lamiaceae	H	2	40	0.163
89	*Ranunculus multifidus*	Pyperaceae	H	2	40	0.163
90	*Rhamnus prinoides*	Ranunculaceae	S	2	40	0.163
91	*Rhoicissus tridentata*	Rhamnaceae	L	2	40	0.163
92	*Rhus natalensis*	Vitaceae	S	3	60	0.244
93	*Rubus apetalus*	Rubiaceae	S	2	40	0.163
94	*Rubus steudneri*	Rosaceae	S	2	40	0.163
95	*Rytigynia neglecta*	Polygonaceae	S	2	40	0.163
96	*Sapium ellipticum*	Apiaceae	T	3	60	0.244
97	*Satureja paradoxa*	Euphorbiaceae	H	4	80	0.325
98	*Senna petersiana*	Fabaceae	T	2	40	0.163
99	*Sida schimperiana*	Cucurbitaceae	S	4	80	0.325
100	*Sida ternata*	Malvaceae	H	2	40	0.163
101	*Solanum anguivi*	Asteraceae	S	2	40	0.163
102	*Solanum dasyphyllum*	Solanaceae	H	2	40	0.163
103	*Solanum incanum*	Solanaceae	S	2	40	0.163
104	*Sporobolus africanus*	Asteraceae	H	2	40	0.163
105	*Syzygium guineense*	Bignoniaceae	T	2	40	0.163
106	*Vangueria apiculata*	Urticaceae	T	2	40	0.163
107	*Vernonia adoensis*	Rutaceae	S	2	40	0.163
108	*Vernonia auriculifera*	Asteraceae	S	3	60	0.244
109	*Vernonia hochstetteri*	Asteraceae	S	2	40	0.163
110	*Vernonia ischnophylla*	Asteraceae	S	2	40	0.163
111	*Vernonia ituriensis*	Asteraceae	S	2	40	0.163
112	*Vernonia theophrastifolia*	Asteraceae	S	2	40	0.163
113	*Xanthium strumanium*	Scrophulariaceae	H	2	40	0.163

Appendix 7: Species list, family, growth form (GF) percent and relative frequencies (%freq, R.F) of plant species in plantation forests of Jimma Highlands

S.N	Species name (in plantation forest)	Family	GF	Freq	%Freq	R.F
1	*Acacia abyssinica*	Fabaceae	T	1	25	0.006
2	*Achyranthes aspera*	Amaranthaceae	H	3	75	0.018
3	*Ageratum conyzoides*	Asteraceae	H	3	75	0.018
4	*Albizia gummifera*	Fabaceae	T	3	75	0.018
5	*Apodytes dimidiata*	Icacinaceae	T	1	25	0.006
6	*Bersama abyssinica*	Melianthaceae	T	3	75	0.018
7	*Bidens pilosa*	Asteraceae	H	2	50	0.012
8	*Brucea antidysenterica*	Simaroubaceae	S	2	50	0.012
9	*Calpurnia aurea*	Fabaceae	T	4	100	0.024
10	*Celtis africana*	Ulmaceae	T	2	50	0.012
11	*Cirsium dender*	Asteraceae	H	2	50	0.012
12	*Clausena anisata*	Rutaceae	S	3	75	0.018
13	*Clutia lanceolata Forssk.*	Euphorbiaceae	S	2	50	0.012
14	*Commelina diffusa*	Commelinaceae	H	2	50	0.012
15	*Cordia africana*	Boraginaceae	T	2	50	0.012
16	*Croton macrostachyus*	Euphorbiaceae	T	3	75	0.018
17	*Cupressus lucitanica*	Cupressaceae	T	1	25	0.006
18	*Cyathula uncinulatA*	Amaranthaceae	H	2	50	0.012
19	*Dalbergia lactea*	Fabaceae	S	2	50	0.012
20	*Dichondra repens*	Convolvulaceae	H	2	50	0.012
21	*Ehretia cymosa*	Boraginaceae	T	2	50	0.012
22	*Ekebergia capensis*	Meliaceae	T	2	50	0.012
23	*Erythrococca trichogyne*	Euphorbiaceae	S	2	50	0.012
24	*Eucalyptus camaldulensis*	Myrtaceae	T	1	25	0.006
25	*Euphorbia schimperiana*	Euphorbiaceae	H	2	50	0.012
26	*Ficus sur*	Moraceae	T	2	50	0.012
27	*Ficus thonningii*	Moraceae	T	2	50	0.012
28	*Flacourtia indica*	Flacourtiaceae	T	2	50	0.012
29	*Galinsoga parviflora*	Asteraceae	H	2	50	0.012
30	*Girardinia diversifolia*	Urticaceae	H	2	50	0.012
31	*Gouania longispicata*	Rhamnaceae	L	2	50	0.012
32	*Grevillea robusta*	Tiliaceae	T	1	25	0.006
33	*Guizotia schimperi*	Asteraceae	H	2	50	0.012
34	*Hippocratea goetzei*	Celastraceae	L	2	50	0.012
35	*Hypoestes forskaullii*	Acanthaceae	H	3	75	0.018
36	*Jasminum abyssinicum*	Oleaceae	L	2	50	0.012

S.N	Species name (in plantation forest)	Family	GF	Freq	%Freq	R.F
37	*Justicia ladanoides*	Acanthaceae	H	3	75	0.018
38	*Kalanchoe petitiana*	Crassulaceae	H	3	75	0.018
39	*Laggera alata*	Asteraceae	H	4	100	0.024
40	*Laggera crispata*	Asteraceae	H	2	50	0.012
41	*Lantana trifolium*	Verbenaceae	S	1	25	0.006
42	*Leucas martinicensis*	Lamiaceae	H	2	50	0.012
43	*Macaranga capensis*	Euphorbiaceae	T	2	50	0.012
44	*Maesa lanceolata*	Myrsinaceae	T	4	100	0.024
45	*Maytenus gracilipes*	Celastraceae	S	2	50	0.012
46	*Myrsine africana*	Myrsinaceae	S	2	50	0.012
47	*Ocimum lamiifolium*	Lamiaceae	S	2	50	0.012
48	*Ocimum urticifolium*	Lamiaceae	S	2	50	0.012
49	*Olea welwitschii*	Oleaceae	T	1	25	0.006
50	*Oplismenus compositus*	Poaceae	H	3	75	0.018
51	*Pentas lanceolata*	Rubiaceae	S	3	75	0.018
52	*Peperomia abyssinica*	Piperaceae	H	3	75	0.018
53	*Peperomia tetraphyla*	Piperaceae	H	2	50	0.012
54	*Pergularia daemia*	Asclepiadaceae	H	2	50	0.012
55	*Phoenix reclinata*	Arecaceae	T	2	50	0.012
56	*Phyllanthus mooneyi*	Euphorbiaceae	H	3	75	0.018
57	*Phyllanthus ovalifolius*	Euphorbiaceae	S	2	50	0.012
58	*Pinus patula*	Asteraceae	T	1	25	0.006
59	*Pittosporum viridiflorum*	Piperaceae	T	1	25	0.006
60	*Plantago lanceolata*	Pittosporaceae	H	2	50	0.012
61	*Premna schimperi*	Urticaceae	S	2	50	0.012
62	*Pterolobium stellatum*	Pteridaceae	S	2	50	0.012
63	*Rothmannia urcelliformis*	Capparidaceae	T	2	50	0.012
64	*Rubus steudneri*	Rosaceae	S	3	75	0.018
65	*Rytigynia neglecta*	Polygonaceae	S	3	75	0.018
66	*Sapium ellipticum*	Apiaceae	T	2	50	0.012
67	*Satureja paradoxa*	Euphorbiaceae	H	3	75	0.018
68	*Senna didymobotrya*	Oleaceae	S	2	50	0.012
69	*Sida schimperiana*	Cucurbitaceae	S	2	50	0.012
70	*Solanecio mannii*	Asteraceae	T	1	25	0.006
71	*Solanum incanum*	Solanaceae	S	2	50	0.012
72	*Syzygium guineense*	Bignoniaceae	T	1	25	0.006
73	*Tagetes minuta*	Myrtaceae	H	2	50	0.012
74	*Tectaria gemmifera*	Rutaceae	H	2	50	0.012
75	*Thalictrum rhynchocarpum*	Combretaceae	H	2	50	0.012

S.N	Species name (in plantation forest)	Family	GF	Freq	%Freq	R.F
76	*Vangueria apiculata*	Urticaceae	T	2	50	0.012
77	*Vepris dainellii*	Rubiaceae	T	1	25	0.006
78	*Vernonia auriculifera*	Asteraceae	S	4	100	0.024
79	*Vernonia ituriensis*	Asteraceae	S	2	50	0.012

Appendix 8: List of plant species in all study plots along the transect in the Jimma Highlands

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
1	*Acacia abyssinica*	Fabaceae	T	DD1	16	51. 61	0. 032
2	*Acacia lahai*	Fabaceae	T	DD2	2	6. 45	0. 004
3	*Acalypha racemosa*	Euphorbiaceae	H	DD3	4	12. 90	0. 008
4	*Acanthus pubescens*	Acanthaceae	S	DD4	8	25. 81	0. 016
5	*Acanthus eminens*	Acanthaceae	S	DD5	7	22. 58	0. 014
6	*Achyranthes aspera*	Amaranthaceae	H	DD6	21	67. 74	0. 042
7	*Achyrospermum schimperi*	Lamiaceae	H	DD7	2	6. 45	0. 004
8	*Adenostemma perottettii*	Asteraceae	H	DD8	2	6. 45	0. 004
9	*Adiantum poiretii*	Adiantaceae	H	DD9	4	12. 90	0. 008
10	*Aeschynomene schimperi*	Fabaceae	H	DD10	4	12. 90	0. 008
11	*Ageratum conyzoides*	Asteraceae	H	DD11	23	74. 19	0. 046
12	*Ajuga integrifolia*	Lamiaceae	H	DD12	4	12. 90	0. 008
13	*Albizia gummifera*	Fabaceae	T	DD13	21	67. 74	0. 042
14	*Albizia schimperiana*	Fabaceae	T	DD14	4	12. 90	0. 008
15	*Alchemila pedata*	Rosaceae	H	DD15	3	9. 68	0. 006
16	*Alectra sessiliflora*	Scrophulariaceae	H	DD16	2	6. 45	0. 004
17	*Allophylus abyssinicus*	Sapindaceae	T	DD17	8	25. 81	0. 016
18	*Allophylus macrobotrys*	Sapindaceae	S	DD18	7	22. 58	0. 014
19	*Amaranthus hybridus*	Amaranthaceae	H	DD19	4	12. 90	0. 008
20	*Amaranthus sparganiocephalus*	Amaranthaceae	H	DD20	4	12. 90	0. 008
21	*Ampelocissus bombycina*	Vitaceae	H	DD21	2	6. 45	0. 004
22	*Amphicarpa africana*	Fabaceae	H	DD22	2	6. 45	0. 004
23	*Apodytes dimidiata*	Icacinaceae	T	DD23	6	19. 35	0. 012
24	*Arthraxon micans*	Poaceae	H	DD24	4	12. 90	0. 008
25	*Arthropteris monocarpa*	Oleandraceae	H	DD25	4	12. 90	0. 008
26	*Asparagus racemosus*	Asparagaceae	S	DD26	5	16. 13	0. 010
27	*Aspilia mossambicensis*	Asteraceae	S	DD27	4	12. 90	0. 008
28	*Asplenium aethiopicum*	Aspleniaceae	H	DD28	5	16. 13	0. 010
29	*Asplenium formosum*	Aspleniaceae	H	DD29	9	29. 03	0. 018
30	*Bauhinia tomentosa*	Fabaceae	T	DD30	2	6. 45	0. 004
31	*Becium verticillifolium*	Lamiaceae	S	DD31	2	6. 45	0. 004
32	*Berkheya spekeana*	Asteraceae	H	DD32	4	12. 90	0. 008
33	*Bersama abyssinica*	Melianthaceae	T	DD33	15	48. 39	0. 030
34	*Bidens pilosa*	Asteraceae	H	DD34	17	54. 84	0. 034

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
35	*Bidens prestinaria*	Asteraceae	H	DD35	9	29. 03	0. 018
36	*Brassica carinata*	Brassicaceae	H	DD36	3	9. 68	0. 006
37	*Bridelia micrantha*	Euphorbiaceae	T	DD37	7	22. 58	0. 014
38	*Brucea antidysenterica*	Simaroubaceae	S	DD38	7	22. 58	0. 014
39	*Buchnera hispida*	Scrophulariaceae	H	DD39	4	12. 90	0. 008
40	*Caesalpinia decapetala*	Fabaceae	S	DD40	3	9. 68	0. 006
41	*Calpurnia aurea*	Fabaceae	T	DD41	13	41. 94	0. 026
42	*Canthium oligocarpum*	Rubiaceae	T	DD42	2	6. 45	0. 004
43	*Cardiospermum halicacabum*	Sapindaceae	H	DD43	4	12. 90	0. 008
44	*Carissa spinarum*	Apocynaceae	S	DD44	5	16. 13	0. 010
45	*Cassipourea malosana*	Rhizophoraceae	T	DD45	2	6. 45	0. 004
46	*Caylusea abyssinica*	Resedaceae	H	DD46	3	9. 68	0. 006
47	*Celosia anthelminthica*	Amaranthaceae	H	DD47	2	6. 45	0. 004
48	*Celosia trigyna*	Amaranthaceae	H	DD48	2	6. 45	0. 004
49	*Celtis africana*	Ulmaceae	T	DD49	15	48. 39	0. 030
50	*Ceropegia racemosa*	Asclepiadaceae	H	DD50	2	6. 45	0. 004
51	*Chenopodium ambrosioides*	Chenopodiaceae	H	DD51	5	16. 13	0. 010
52	*Chionanthus mildbraedii*	Oleaceae	S	DD52	4	12. 90	0. 008
53	*Cirsium dender*	Asteraceae	H	DD53	6	19. 35	0. 012
54	*Cissampelos mucronata*	Menispermaceae	H	DD54	4	12. 90	0. 008
55	*Cissus petiolata*	Vitaceae	L	DD55	4	12. 90	0. 008
56	*Clausena anisata*	Rutaceae	S	DD56	14	45. 16	0. 028
57	*Clematis cadatus*	Ranunculaceae	L	DD57	4	12. 90	0. 008
58	*Clematis hirsuta*	Ranunculaceae	L	DD58	5	16. 13	0. 010
59	*Clematis longicauda*	Ranunculaceae	L	DD59	4	12. 90	0. 008
60	*Clematis simensis*	Ranunculaceae	L	DD60	6	19. 35	0. 012
61	*Clerodendron myricoides*	Lamiaceae	S	DD61	2	6. 45	0. 004
62	*Clutia lanceolata*	Euphorbiaceae	S	DD62	2	6. 45	0. 004
63	*Coelorhachis afraurita*	Poaceae	H	DD63	4	12. 90	0. 008
64	*Coffea arabica*	Rubiaceae	S	DD64	10	32. 26	0. 020
65	*Combretum collinum*	Combretaceae	T	DD65	7	22. 58	0. 014
66	*Combretum molle*	Combretaceae	T	DD66	2	6. 45	0. 004
67	*Combretum paniculatum*	Combretaceae	l	DD67	6	19. 35	0. 012
68	*Commelina diffusa*	Commelinaceae	H	DD68	9	29. 03	0. 018
69	*Commelina imberbis*	Commelinaceae	H	DD69	4	12. 90	0. 008
70	*Conyza bonariensis*	Asteraceae	H	DD70	6	19. 35	0. 012
71	*Cordia africana*	Boraginaceae	T	DD71	18	58. 06	0. 036

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
72	*Crassocephalum macropappum*	Asteraceae	H	DD72	4	12. 90	0. 008
73	*Crassocephalum rubens*	Asteraceae	H	DD73	2	6. 45	0. 004
74	*Crossopteryx febrifuga*	Rubiaceae	T	DD74	2	6. 45	0. 004
75	*Crotalaria emarginella*	Fabaceae	H	DD75	2	6. 45	0. 004
76	*Croton macrostachyus*	Euphorbiaceae	T	DD76	20	64. 52	0. 040
77	*Cupressus lusitanica*	Cupressaceae	T	DD77	1	3. 23	0. 002
78	*Cuscuta campestris*	Cuscutaceae	H	DD78	5	16. 13	0. 010
79	*Cyathula uncinulatA*	Amaranthaceae	H	DD79	15	48. 39	0. 030
80	*Cycnium herzfeldianum*	Scrophulariaceae	H	DD80	4	12. 90	0. 008
81	*Cynodon aethiopicus*	Poaceae	H	DD81	11	35. 48	0. 022
82	*Cyperus digitatus*	Cyperaceae	H	DD82	3	9. 68	0. 006
83	*Cyperus welwitschii*	Cyperaceae	H	DD83	2	6. 45	0. 004
84	*Cyphostemma cyphopetalum*	Vitaceae	H	DD84	7	22. 58	0. 014
85	*Cyprus triceps*	Cyperaceae	H	DD85	5	16. 13	0. 010
86	*Dalbergia lactea*	Fabaceae	S	DD86	8	25. 81	0. 016
87	*Datura stramonium*	Solanaceae	H	DD87	3	9. 68	0. 006
88	*Desmodium dichotomum*	Fabaceae	H	DD88	4	12. 90	0. 008
89	*Desmodium repandum*	Fabaceae	H	DD89	14	45. 16	0. 028
90	*Desmodium salisifolium*	Fabaceae	H	DD90	2	6. 45	0. 004
91	*Dichondra repens*	Convolvulaceae	H	DD91	11	35. 48	0. 022
92	*Dichrocephala integrifolia*	Asteraceae	H	DD92	3	9. 68	0. 006
93	*Dicliptera laxata*	Acanthaceae	H	DD93	4	12. 90	0. 008
94	*Digitaria abyssinica*	Poaceae	H	DD94	2	6. 45	0. 004
95	*Digitaria ternata*	Poaceae	H	DD95	2	6. 45	0. 004
96	*Dioscorea bulbifera*	Dioscoreaceae	H	DD96	4	12. 90	0. 008
97	*Diospyros abyssinica*	Ebenaceae	T	DD97	3	9. 68	0. 006
98	*Doryopteris concolor*	Sinopteridaceae	H	DD98	6	19. 35	0. 012
99	*Dracaena afromontana*	Dracaenaceae	S	DD99	4	12. 90	0. 008
100	*Dracaena steudneri*	Dracaenaceae	T	DD100	5	16. 13	0. 010
101	*Droguetia iners*	Urticaceae	H	DD101	5	16. 13	0. 010
102	*Echium plantagineum*	Boraginaceae	H	DD102	2	6. 45	0. 004
103	*Ehretia cymosa*	Boraginaceae	T	DD103	15	48. 39	0. 030
104	*Ekebergia capensis*	Meliaceae	T	DD104	6	19. 35	0. 012
105	*Embelia schimperi*	Myrsinaceae	S	DD105	2	6. 45	0. 004
106	*Ensete ventricosum*	Musaceae	H	DD106	2	6. 45	0. 004
107	*Entada abyssinica*	Fabaceae	T	DD107	6	19. 35	0. 012
108	*Eremomastax speciosa*	Acanthaceae	H	DD108	4	12. 90	0. 008

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
109	*Erythrina brucei*	Fabaceae	T	DD109	2	6. 45	0. 004
110	*Erythrococca trichogyne*	Euphorbiaceae	S	DD110	8	25. 81	0. 016
111	*Eucalyptus camaldulensis*	Myrtaceae	T	DD111	1	3. 23	0. 002
112	*Euphorbia candelabrum*	Euphorbiaceae	T	DD112	2	6. 45	0. 004
113	*Euphorbia cyparissioides*	Euphorbiaceae	H	DD113	4	12. 90	0. 008
114	*Euphorbia schimperiana*	Euphorbiaceae	H	DD114	4	12. 90	0. 008
115	*Euphorbia tirucalli*	Euphorbiaceae	T	DD115	4	12. 90	0. 008
116	*Ficus mucuso*	Moraceae	T	DD116	5	16. 13	0. 010
117	*Ficus sp.*	Moraceae	T	DD117	4	12. 90	0. 008
118	*Ficus sur*	Moraceae	T	DD118	11	35. 48	0. 022
119	*Ficus sycamoras*	Moraceae	T	DD119	2	6. 45	0. 004
120	*Ficus thonningii*	Moraceae	T	DD120	9	29. 03	0. 018
121	*Ficus vasta*	Moraceae	T	DD121	8	25. 81	0. 016
122	*Flacourtia indica*	Flacourtiaceae	T	DD122	12	38. 71	0. 024
123	*Galiniera saxifraga*	Rubiaceae	T	DD123	5	16. 13	0. 010
124	*Galinsoga parviflora*	Asteraceae	H	DD124	11	35. 48	0. 022
125	*Gardenia volkensii*	Rubiaceae	S	DD125	6	19. 35	0. 012
126	*Geranium aculeolatum*	Geraniaceae	H	DD126	4	12. 90	0. 008
127	*Girardinia diversifolia*	Urticaceae	H	DD127	8	25. 81	0. 016
128	*Glycine wightii*	Fabaceae	H	DD128	4	12. 90	0. 008
129	*Gnidia glauca*	Thymelaeaceae	S	DD129	4	12. 90	0. 008
130	*Gouania longispicata*	Rhamnaceae	L	DD130	6	19. 35	0. 012
131	*Grevillea robusta*	Proteaceae	T	DD131	1	3. 23	0. 002
132	*Grewia ferruginea*	Tiliaceae	S	DD132	8	25. 81	0. 016
133	*Guizotia schimperi*	Asteraceae	H	DD133	13	41. 94	0. 026
134	*Helinus mystacinus*	Rhamnaceae	L	DD134	4	12. 90	0. 008
135	*Helychrysum forskaulii*	Asteraceae	H	DD135	3	9. 68	0. 006
136	*Hibiscus berberidifolius*	Malvaceae	S	DD136	4	12. 90	0. 008
137	*Hibiscus dongolensis*	Malvaceae	S	DD137	4	12. 90	0. 008
138	*Hippocratea goetzei*	Celastraceae	L	DD138	8	25. 81	0. 016
139	*Hygrophila asteracanthoide*	Acanthaceae	H	DD139	5	16. 13	0. 010
140	*Hyparrhenia rufa*	Poaceae	H	DD140	7	22. 58	0. 014
141	*Hypericum peplidifolium*	Hypericaceae	H	DD141	4	12. 90	0. 008
142	*Hypericum revolutum*	Hypericaceae	S	DD142	2	6. 45	0. 004
143	*Hypoestes aristata*	Acanthaceae	H	DD143	3	9. 68	0. 006
144	*Hypoestes forskaullii*	Acanthaceae	H	DD144	5	16. 13	0. 010
145	*Hypolepis glandulifera*	Dennstaedtiaceae	H	DD145	2	6. 45	0. 004

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
146	*Impatiens aethiopica*	Balsaminaceae	H	DD146	5	16. 13	0. 010
147	*Indigofera spicata*	Fabaceae	S	DD147	6	19. 35	0. 012
148	*Isoglossa somalensis*	Acanthaceae	S	DD148	4	12. 90	0. 008
149	*Jasminum abyssinicum*	Oleaceae	L	DD149	6	19. 35	0. 012
150	*Jasminum repandum*	Oleaceae	L	DD150	3	9. 68	0. 006
151	*Justicia ladanoides*	Acanthaceae	H	DD151	11	35. 48	0. 022
152	*Justicia schimperiana*	Acanthaceae	S	DD152	3	9. 68	0. 006
153	*Kalanchoe petitiana*	Crassulaceae	H	DD153	3	9. 68	0. 006
154	*Keetia guiinzii*	Rubiaceae	S	DD154	3	9. 68	0. 006
155	*Keetia zanzibarica*	Rubiaceae	S	DD155	2	6. 45	0. 004
156	*Kosteletzkya begoniifolia*	Malvaceae	H	DD156	1	3. 23	0. 002
157	*Laggera alata*	Asteraceae	H	DD157	6	19. 35	0. 012
158	*Laggera crispata*	Asteraceae	H	DD158	12	38. 71	0. 024
159	*Landolphia buchananii*	Apocynaceae	L	DD159	4	12. 90	0. 008
160	*Lantana trifolium*	Verbenaceae	S	DD160	5	16. 13	0. 010
161	*Leucas martinicensis*	Lamiaceae	H	DD161	8	25. 81	0. 016
162	*Lippia adoensis*	Verbenaceae	S	DD162	7	22. 58	0. 014
163	*Loxogramme abyssinica*	Polypodiaceae	H	DD163	5	16. 13	0. 010
164	*Macaranga capensis*	Euphorbiaceae	T	DD164	4	12. 90	0. 008
165	*Maesa lanceolata*	Myrsinaceae	T	DD165	18	58. 06	0. 036
166	*Maytenus arbutifolia*	Celastraceae	T	DD166	8	25. 81	0. 016
167	*Maytenus gracilipes*	Celastraceae	S	DD167	10	32. 26	0. 020
168	*Maytenus senegalensis*	Celastraceae	T	DD168	2	6. 45	0. 004
169	*Maytenus undata*	Celastraceae	S	DD169	2	6. 45	0. 004
170	*Micractis bojeri*	Asteraceae	H	DD170	2	6. 45	0. 004
171	*Microsorium scolopendria*	Polypodiaceae	H	DD171	4	12. 90	0. 008
172	*Mikaniopsis clematoides*	Asteraceae	H	DD172	4	12. 90	0. 008
173	*Millettia ferruginea*	Fabaceae	T	DD173	10	32. 26	0. 020
174	*Momordica foetida*	Cucurbitaceae	H	DD174	8	25. 81	0. 016
175	*Myrsine africana*	Myrsinaceae	S	DD175	4	12. 90	0. 008
176	*Nephrolepis undulata*	Nephrolepidaceae	H	DD176	2	6. 45	0. 004
177	*Nicandra physaloides*	Solanaceae	H	DD177	2	6. 45	0. 004
178	*Nuxia congesta*	Loganiaceae	T	DD178	1	3. 23	0. 002
179	*Ocimum lamiifolium*	Lamiaceae	S	DD179	7	22. 58	0. 014
180	*Ocimum urticifolium*	Lamiaceae	S	DD180	12	38. 71	0. 024
181	*Olea welwitschii*	Oleaceae	T	DD181	4	12. 90	0. 008
182	*Oplismenus compositus*	Poaceae	H	DD182	15	48. 39	0. 030
183	*Oplismenus hirtellus*	Poaceae	H	DD183	4	12. 90	0. 008

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
184	*Otostegia tomentosa*	Lamiaceae	S	DD184	4	12. 90	0. 008
185	*Oxyanthus speciosus*	Rubiaceae	S	DD185	2	6. 45	0. 004
186	*Passiflora edulis*	Passifolraceae	L	DD186	3	9. 68	0. 006
187	*Paullinia pinnata*	Sapindaceae	L	DD187	4	12. 90	0. 008
188	*Pavonia glechomifolia*	Malvaceae	H	DD188	4	12. 90	0. 008
189	*Pavonia urens*	Malvaceae	S	DD189	11	35. 48	0. 022
190	*Pennisetum nubicum*	Poaceae	H	DD190	4	12. 90	0. 008
191	*Pennisetum sphacelatum*	Poaceae	H	DD191	4	12. 90	0. 008
192	*Pentas lanceolata*	Rubiaceae	S	DD192	9	29. 03	0. 018
193	*Peperomia abyssinica*	Piperaceae	H	DD193	11	35. 48	0. 022
194	*Peperomia tetraphyla*	Piperaceae	H	DD194	8	25. 81	0. 016
195	*Pergularia daemia*	Asclepiadaceae	H	DD195	7	22. 58	0. 014
196	*Periploca linearifolia*	Asclepiadaceae	L	DD196	2	6. 45	0. 004
197	*Persicaria setosula*	Polygonaceae	H	DD197	2	6. 45	0. 004
198	*Phoenix reclinata*	Arecaceae	T	DD198	11	35. 48	0. 022
199	*Phyllanthus mooneyi*	Euphorbiaceae	H	DD199	9	29. 03	0. 018
200	*Phyllanthus ovalifolius*	Euphorbiaceae	S	DD200	9	29. 03	0. 018
201	*Physalis peruviana*	Solanaceae	H	DD201	4	12. 90	0. 008
202	*Phytolacca dodecandra*	Phytolacaeae	S	DD202	9	29. 03	0. 018
203	*Pinus patula*	Pinaceae	T	DD203	1	3. 23	0. 002
204	*Piper capense*	Piperaceae	S	DD204	3	9. 68	0. 006
205	*Pittosporum viridiflorum*	Pittosporaceae	T	DD205	4	12. 90	0. 008
206	*Plantago lanceolata*	Plantaginaceae	H	DD206	6	19. 35	0. 012
207	*Plectranthus punctatus*	Lamiaceae	H	DD207	2	6. 45	0. 004
208	*Podocarpus falcatus*	Podocarpaceae	T	DD208	6	19. 35	0. 012
209	*Polyscias fulva*	Araliaceae	T	DD209	4	12. 90	0. 008
210	*Pouzolzia mixta*	Urticaceae	S	DD210	2	6. 45	0. 004
211	*Premna schimperi*	Lamiaceae	S	DD211	8	25. 81	0. 016
212	*Prunus africana*	Rosaceae	T	DD212	6	19. 35	0. 012
213	*Pseudarthria hookeri*	Fabaceae	H	DD213	4	12. 90	0. 008
214	*Psidium guajava*	Myrtaceae	T	DD214	3	9. 68	0. 006
215	*Psychotria orophila*	Rubiaceae	T	DD215	2	6. 45	0. 004
216	*Psydrax schimperiana*	Rubiaceae	T	DD216	2	6. 45	0. 004
217	*Pteris pteridioides*	Pteridaceae	H	DD217	2	6. 45	0. 004
218	*Pterolobium stellatum*	Fabaceae	S	DD218	6	19. 35	0. 012
219	*Pychnostachys emini*	Lamiaceae	H	DD219	4	12. 90	0. 008
220	*Pycnostachys abyssinica*	Lamiaceae	H	DD220	4	12. 90	0. 008
221	*Pycreus nitida*	Cyperaceae	H	DD221	4	12. 90	0. 008
222	*Ranunculus multifidus*	Ranunculaceae	H	DD222	4	12. 90	0. 008

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
223	*Rhamnus prinoides*	Rhamnaceae	S	DD223	7	22. 58	0. 014
224	*Rhoicissus tridentata*	Vitaceae	L	DD224	4	12. 90	0. 008
225	*Rhus natalensis*	Anacardiaceae	S	DD225	5	16. 13	0. 010
226	*Ricinus communis*	Euphorbiaceae	H	DD226	4	12. 90	0. 008
227	*Ritchiea albersii*	Capparidaceae	T	DD227	4	12. 90	0. 008
228	*Rothmannia urcelliformis*	Rubiaceae	T	DD228	7	22. 58	0. 014
229	*Rubus apetalus*	Rosaceae	S	DD229	2	6. 45	0. 004
230	*Rubus steudneri*	Rosaceae	S	DD230	13	41. 94	0. 026
231	*Rumex natalensis*	Polygonaceae	H	DD231	7	22. 58	0. 014
232	*Rytigynia neglecta*	Rubiaceae	S	DD232	12	38. 71	0. 024
233	*Sanicula elata*	Apiaceae	H	DD233	5	16. 13	0. 010
234	*Sapium ellipticum*	Euphorbiaceae	T	DD234	13	41. 94	0. 026
235	*Satureja paradoxa*	Lamiaceae	H	DD235	11	35. 48	0. 022
236	*Schefflera abyssinica*	Araliaceae	T	DD236	6	19. 35	0. 012
237	*Schrebera alata*	Oleaceae	T	DD237	1	3. 23	0. 002
238	*Senna didymobotrya*	Fabaceae	S	DD238	9	29. 03	0. 018
239	*Senna occidentalis*	Fabaceae	H	DD239	4	12. 90	0. 008
240	*Senna petersiana*	Fabaceae	T	DD240	7	22. 58	0. 014
241	*Senra incana*	Malvaeae	H	DD241	2	6. 45	0. 004
242	*Sesbania sesban*	Fabaceae	T	DD242	1	3. 23	0. 002
243	*Setaria megaphylla*	Poaceae	H	DD243	3	9. 68	0. 006
244	*Setaria verticillata*	Poaceae	H	DD244	4	12. 90	0. 008
245	*Sicyos polyacanthus*	Cucurbitaceae	H	DD245	4	12. 90	0. 008
246	*Sida schimperiana*	Malvaceae	S	DD246	12	38. 71	0. 024
247	*Sida tenuicarpa*	Malvaceae	S	DD247	8	25. 81	0. 016
248	*Sida ternata*	Malvaceae	H	DD248	4	12. 90	0. 008
249	*Solanecio gigas*	Asteraceae	S	DD249	7	22. 58	0. 014
250	*Solanecio mannii*	Asteraceae	T	DD250	4	12. 90	0. 008
251	*Solanum anguivi*	Solanaceae	S	DD251	6	19. 35	0. 012
252	*Solanum capsicoides*	Solanaceae	S	DD252	2	6. 45	0. 004
253	*Solanum dasyphyllum*	Solanaceae	H	DD253	2	6. 45	0. 004
254	*Solanum giganteum*	Solanaceae	S	DD254	4	12. 90	0. 008
255	*Solanum incanum*	Solanaceae	S	DD255	12	38. 71	0. 024
256	*Soncus asper*	Asteraceae	H	DD256	5	16. 13	0. 010
257	*Sporobolus africanus*	Poaceae	H	DD257	2	6. 45	0. 004
258	*Stachys albigena*	Lamiaceae	H	DD258	2	6. 45	0. 004
259	*Stellaria mannii*	Caryophyllaceae	H	DD259	2	6. 45	0. 004
260	*Stephania abyssinica*	Menispermaceae	H	DD260	5	16. 13	0. 010
261	*Stereospermum*	Bignoniaceae	T	DD261	5	16. 13	0. 010

S.N	Species name (All Plots)	Family	Growth form	Col.No.	Freq	% Freq	R. F
	kunthianum						
262	*Syzygium guineense*	Myrtaceae	T	DD262	11	35. 48	0. 022
263	*Tagetes minuta*	Asteraceae	H	DD263	5	16. 13	0. 010
264	*Teclea nobilis*	Rutaceae	T	DD264	4	12. 90	0. 008
265	*Tectaria gemmifera*	Tectariaceae	H	DD265	6	19. 35	0. 012
266	*Terminalia schimperiana*	Combretaceae	T	DD266	6	19. 35	0. 012
267	*Thalictrum rhynchocarpum*	Ranunculaceae	H	DD267	4	12. 90	0. 008
268	*Tragia cinerea*	Euphorbiaceae	H	DD268	9	29. 03	0. 018
269	*Trichilia dregeana*	Meliaceae	T	DD269	4	12. 90	0. 008
270	*Trilepisium madagascariense*	Moraceae	T	DD270	2	6. 45	0. 004
271	*Triumfetta pilosa*	Tiliaceae	H	DD271	4	12. 90	0. 008
272	*Triumfetta rhomboidea*	Tiliaceae	H	DD272	4	12. 90	0. 008
273	*Urera hypselodendron*	Urticaceae	L	DD273	4	12. 90	0. 008
274	*Vangueriaapiculata*	Rubiaceae	T	DD274	13	41. 94	0. 026
275	*Vepris dainellii*	Rutaceae	T	DD275	10	32. 26	0. 020
276	*Vernonia adoensis*	Asteraceae	S	DD276	4	12. 90	0. 008
277	*Vernonia amygdalina*	Asteraceae	T	DD277	10	32. 26	0. 020
278	*Vernonia auriculifera*	Asteraceae	S	DD278	23	74. 19	0. 046
279	*Vernonia biafrae*	Asteraceae	S	DD279	2	6. 45	0. 004
280	*Vernonia hochstetteri*	Asteraceae	S	DD280	4	12. 90	0. 008
281	*Vernonia ischnophylla*	Asteraceae	S	DD281	7	22. 58	0. 014
282	*Vernonia ituriensis*	Asteraceae	S	DD282	4	12. 90	0. 008
283	*Vernonia karaguensis*	Asteraceae	S	DD283	4	12. 90	0. 008
284	*Vernonia theophrastifolia*	Asteraceae	S	DD284	4	12. 90	0. 008
285	*Vernonia thomsoniana*	Asteraceae	S	DD285	2	6. 45	0. 004
286	*Veronica abyssinica*	Scrophulariaceae	H	DD286	4	12. 90	0. 008
287	*Xanthium strumanium*	Asteraceae	H	DD287	2	6. 45	0. 004

Appendix 9: Linear relationships between plant growth forms, richness and environmental variables

	Pearson	Elev	bio3	bio13	bio12	bio5	bio1	mi	pet	bio4	silt	pH	CEC	BD	sand	clay
Herb	Cor	-0.57	0.35	-0.01	-0.42	0.45	0.45	-0.45	0.48	0.35	0.07	0.41	0.22	-0.22	0.20	-0.22
	P	0.00	0.05	0.94	0.02	0.01	0.01	0.01	0.01	0.05	0.73	0.02	0.23	0.23	0.29	0.25
	N	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Shrub	Cor	-0.09	0.33	0.01	0.01	0.00	0.01	0.00	0.01	0.18	0.31	-0.05	-0.18	-0.21	0.27	-0.42
	P	0.64	0.07	0.94	0.97	0.99	0.97	0.99	0.94	0.35	0.09	0.80	0.34	0.26	0.14	0.02
	N	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Tree	Cor	0.11	0.04	0.07	0.26	-0.24	-0.25	0.25	-0.24	-0.03	0.15	-0.30	-0.22	-0.22	0.41	-0.42
	P	0.58	0.83	0.70	0.15	0.19	0.17	0.18	0.20	0.88	0.42	0.10	0.24	0.23	0.02	0.02
	N	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31

(Elev = elevation, bio3 = isothermality, bio13 = rainfall wettest month, bio12 = mean annual rainfall, bio5 = maximum temperature warmest month, bio1 = mean annual temperature, mi = annual moisture index, pet = potential evapotranspiration, bio4 = rainfall seasonality, CEC = cation exchange capacity, BD = bulk density)

Appendix 10: Synoptic Table for grouping canopy trees in SFC

Binomial	Group I	Group II	Group III	Group IV
Acacia abyssinica	0.00	**5.33**	**4.40**	0.00
Albizia gummifera	**7.40**	4.93	2.00	2.20
Allophylus abyssinica	4.20	0.47	0.00	0.00
Apodytes dimidiata	1.40	0.00	0.00	0.00
Bersama abyssinica	2.00	0.00	1.60	0.60
Bridelia micrantha	0.00	0.47	0.00	0.00
Celtis africana	1.20	3.33	0.00	3.40
Chionanthus mildbraedii	0.00	0.00	0.00	1.30
Clausena anisata	0.00	1.60	0.00	0.00
Cordia africana	4.80	**6.73**	2.80	4.60
Croton macrostachyus	**8.00**	3.53	3.20	**6.00**
Diospyros abyssinica	2.60	0.33	0.00	**5.70**
Dracaena steudneri	0.00	0.27	0.00	3.50
Ehreta cymosa	4.80	1.07	0.00	1.00
Ekebergia capensis	0.00	0.00	1.00	0.00
Ficus mucuso	0.00	0.00	0.00	4.10
Ficus sur	2.40	0.47	0.00	2.00
Ficus thonningi	0.00	2.40	0.00	1.30
Ficus vasta	0.00	0.47	0.00	1.80
Flacourtia indica	0.00	0.00	0.00	0.60
Galiniera saxifraga	1.00	0.00	0.00	0.00
Grewia ferruginea	0.00	0.13	0.00	0.00
Maesa lanceolata	0.00	0.53	0.40	0.20
Maytenus arbutifolia	0.00	0.00	0.40	0.00
Millettia ferruginea	0.00	0.00	**6.60**	4.80
phoenix reclinata	0.00	0.00	0.00	0.30
Pittosporum viridiflorum	0.60	0.00	0.00	0.00
Podocarpus falcatus	0.00	0.33	0.00	0.00
Polyscias fulva	0.00	0.47	0.60	0.00
Prunus africana	3.00	0.53	1.60	0.60
Rothmania urcelliformis	0.00	0.00	0.00	0.80
Sapium ellipticum	0.00	1.27	1.40	1.30
Schefflera abyssinica	4.20	0.00	1.20	0.00
Schrebera alata	0.00	0.33	0.00	0.00
Syzygium guineense	0.00	0.47	0.00	0.50
Terminalia schimperiana	0.00	0.00	0.00	0.40
Trichilia dregeana	0.00	0.33	0.00	1.20
Trilepisium madagascariense	0.00	0.00	0.00	1.90
Vangueria apiculata	0.00	0.67	0.00	0.50
Vepris dainellii	0.00	2.20	0.00	1.70
Vernonia amygdalina	0.80	1.33	0.00	0.00
Vernonia auriculifera	0.00	1.33	0.00	0.00

Appendix 11: Linear relationships between tree species abundance and environmental variables

		Elev	bio3	bio13	bio12	bio5	bio1	mi	pet	bio4	silt	pH	cec	bld	sand	clay
Abundance	Cor	0.41	-0.22	0.04	0.45	-0.46	-0.47	0.46	-0.48	-0.27	-0.15	-0.54	-0.40	-0.06	0.42	-0.27
	P	0.03	0.26	0.86	0.01	0.01	0.01	0.01	0.01	0.16	0.45	0.00	0.03	0.76	0.02	0.16
	N	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29

(Elev = elevation, bio13 = rainfall wettest month, bio3 = isothermality, bio1 = mean annual temperature, bio4 = rainfall seasonality, silt = soil silt, pH = soil pH, CEC = cation exchange capacity, bld = bulk density, bio12 = mean annual rainfall, PET = potential evapotranspiration, MI = annual moisture index, bio5 = maximum temperature warmest month, abund = tree species abundance)

Appendix 12: AGC in each tree species (A) and in each plant family (B) in SFC (C t ha^{-1}) (C t ha^{-1} = carbon ton per hectare)

A (in SFC)		**B (in SFC)**	
Species name	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Albizia gummifera	14.618	Fabaceae	22.017
Croton macrostachyus	9.682	Moraceae	12.073
Ficus mucuso	7.307	Euphorbiaceae	11.438
Acacia abyssinica	4.293	Boraginaceae	4.976
Dracaena steudneri	4.153	Dracaenaceae	4.153
Cordia africana	4.105	Ulmaceae	1.604
Millettia ferruginea	3.093	Ebenaceae	1.321
Ficus vasta	1.773	Rosaceae	1.214
Ficus sur	1.746	Araliaceae	0.755
Sapium ellipticum	1.714	Rutaceae	0.423
Celtis africana	1.604	Myrtaceae	0.294
Diospyros abyssinica	1.321	Iccacinaceae	0.270
Prunus africana	1.214	Meliaceae	0.224
Ficus thonningii	0.97	Sapindacea	0.193
Ehretia cymosa	0.873	Asteraceae	0.116
Schefflera abyssinica	0.665	Celastraceae	0.110
Vepris dainellii	0.394	Melianthaceae	0.075
Syzygium guineense	0.294	Oleaceae	0.071
Trilepisium madagascariense	0.277	Rubiaceae	0.054
Apodytes dimidiata	0.27	Flacourtiaceae	0.047
Trichilia dregeana	0.214	Myrsinaceae	0.041
Allophylus abyssinicus	0.193	Podocarpaceae	0.019
Maytenus arbutifolia	0.11	Combretaceae	0.016

A (in SFC)		**B (in SFC)**	
Species name	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Vernonia amygdalina	0.093	Arecaceae	0.015
Polyscias fulva	0.091	Pitosporaceae	0.002
Bersama abyssinica	0.075	Tiliaceae	0.002
Maesa lanceolata	0.051		
Flacourtia indica	0.047		
Bridelia micrantha	0.043		
Schrebera alata	0.037		
Chionanthus mildbraedii	0.034		
Clausena anisata	0.029		
Rothmania urcelliformis	0.027		
Vernonia auriculifera	0.023		
Vangueria apiculata	0.023		
Podocarpus falcatus	0.019		
Terminalia schimperiana	0.016		
Phoenix reclinata	0.015		
Ekebergia capensis	0.011		
Galiniera saxifraga	0.004		
Pittosporum viridiflorum	0.002		
Grewia ferruginea	0.002		
Total	**61.5**		

Appendix 13: AGC in each tree species (A) and in each plant family (B) in DNF

A (in DNF)		B (in DNF)	
Species name	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Ficus sur	19.752	Moraceae	19.978
Apodytes dimidiata	14.152	Icacinaceae	14.152
Syzygium guineense	8.085	Fabaceae	9.525
Celtis africana	6.609	Myrtaceae	8.085
Albizia gummifera	6.485	Ulmaceae	6.609
Schefflera abyssinica	5.842	Araliaceae	6.102
Olea welwitschii	3.203	Oleaceae	4.863
Millettia ferruginea	3.040	Euphorbiaceae	3.935
Prunus africana	2.464	Rosaceae	2.464
Macaranga capensis	2.307	Meliaceae	1.549
Chionanthus mildbraedi	1.660	Rutaceae	1.321
Croton macrostachyus	1.628	Melianthaceae	0.915
Ekebergia capensis	1.156	Rubiaceae	0.842
Bersama abyssinica	0.915	Sapindaceae	0.528
Galiniera saxifraga	0.892	Podocarpaceae	0.383
Vepris dainellii	0.723	Boraginaceae	0.358
Allophylus abyssinicus	0.528	Loganiaceae	0.212
Trichilia dregeana	0.393	Arecaceae	0.168
Podocarpus falcatus	0.383	Celastraceae	0.038
Cordia africana	0.358	Simaroubaceae	0.002
Teclea noblis	0.310		
Polysciasfulva	0.261		
Ficus sycamoras	0.226		
Nuxia congesta	0.212		

A (in DNF)		B (in DNF)	
Species name	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Phoenix reclinata	0.168		
Canthium oligocarpum	0.121		
Rothmania ulceriformis	0.071		
Maytenus arbutifolia	0.038		
Vangueria apiculata	0.027		
Psychotria orophila	0.013		
Oxyanthus speciosus	0.007		
Brucea antidysenterica	0.002		
Total	**82.029**		

Appendix 14: AGC in each tree species (A) and in each plant family (B) in woodland

A (in woodland)		**B (in woodland**	
Species name	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Acacia abyssinica	4.406	*Anacardiaceae*	0.016
Acacia lahai	0.094	*Arecaceae*	0.034
Albizia gummifera	0.116	*Asteraceae*	0.051
Bridelia micrantha	0.005	*Bignoniaceae*	0.555
Combretum collinum	0.586	*Boraginaceae*	0.834
Combretum molle	0.019	*Combretaceae*	1.374
Cordia africana	0.834	*Euphorbiaceae*	0.129
Croton macrostachyus	0.069	*Fabaceae*	5.532
Entada abyssinica	0.896	*Flacourtiaceae*	0.112
Euphorbia tirucalli	0.003	*Moraceae*	2.510
Ficus sur	0.512	*Myrsinaceae*	1.703
Ficus sycamoras	1.190	*Myrtaceae*	0.007
Ficus vasta	0.808	*Rubiaceae*	0.008
Flacourtia indica	0.112		
Gardenis volkensii	0.008		
Maesa lanceolata	1.703		
Millettia ferruginea	0.005		
Phoenix reclinata	0.034		
Psidium guajava	0.007		
Rhus natalensis	0.016		
Sapium ellipticum	0.051		
Senna petersiana	0.009		
Sesbania sesban	0.007		
Stereospermum kunthianum	0.555		
Terminalia schimperiana	0.769		
Vernonia amygdalina	0.051		
Total	**12.865**		

Appendix 15: AGC in each tree species (A) and in each plant family (B) in pasture

A		**B**	
Species	**C t ha^{-1}**	**Family**	**C t ha^{-1}**
Acacia abyssinica	0.073	Bignoniaceae	0.042
Bauhinia tomentosa	0.019	Boraginaceae	0.003
Combretum collinum	0.124	Combretaceae	0.124
Ehretia cymosa	0.003	Euphorbiaceae	0.243
Entada abyssinica	0.022	Fabaceae	0.113
Ficus vasta	1.932	Flacourtiaceae	0.008
Flacourtia indica	0.008	Moraceae	1.932
Gardenia volkensii	0.012	Myrsinaceae	0.002
Keetia zanzibarica	0.003	Myrtaceae	0.023
Maesa lanceolata	0.002	Rubiaceae	0.015
Sapium ellipticum	0.243		
Stereospermum kunthianum	0.042		
Syzygium guineense	0.023		
Total	**2.507**		

Appendix 16: AGC in each tree species (A) and in each plant family (B) in croplands

A		**B**	
Species	**C t ha^{-1}**	**Families**	**C t ha^{-1}**
Acacia abyssinica	0.191	Araliaceae	0.125
Albizia gummifera	0.002	Asteraceae	0.103
Combretum molle	0.123	Boraginaceae	1.171
Cordia africana	0.794	Combretaceae	0.122
Ficus vasta	0.114	Fabaceae	0.161
Ficus sycamoras	0.299	Moraceae	0.344
Prunus africana	0.611		
Scheffleria abyssinica	0.150		
Terminalia schimperiana	0.024		
Vernonia amygdalina	0.123		
Total	**2.432**		

Appendix 17: Linear relationships between AGC and climate variables

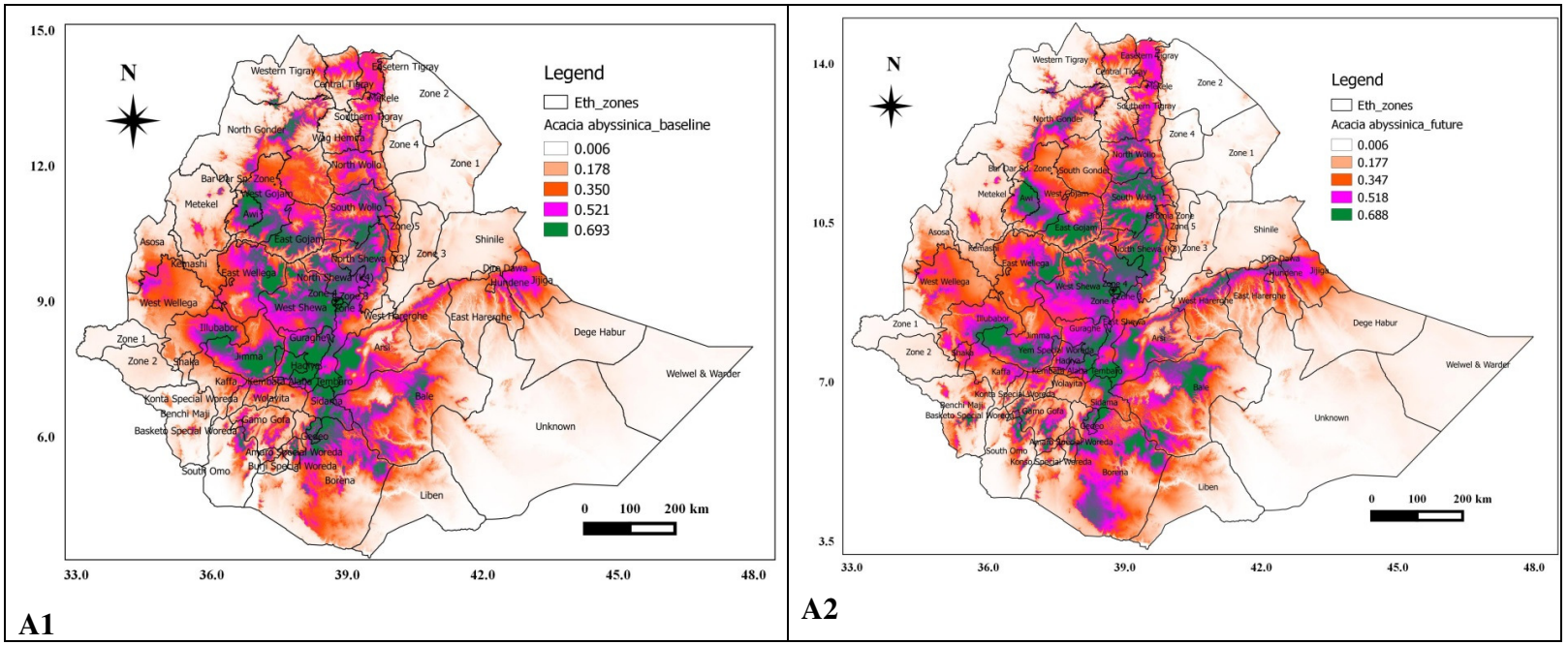
		bio10	**bio11**	**bio12**	**bio13**	**bio14**	**bio15**	**bio16**	**bio17**	**pet**	**mimq**	**mi**	**bio2**	**bio3**	**bio1**	**bio6**	**bio7**	**bio4**	**bio5**
AGC _4th root	Cor	-0.44	-0.44	0.42	-0.01	-0.25	0.30	0.20	0.45	-0.46	0.44	0.44	-0.45	-0.16	-0.45	-0.43	-0.44	-0.31	-0.44
	P	0.02	0.02	0.02	0.97	0.18	0.12	0.30	0.01	0.02	0.02	0.02	0.01	0.42	0.01	0.02	0.02	0.10	0.02
	N	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29

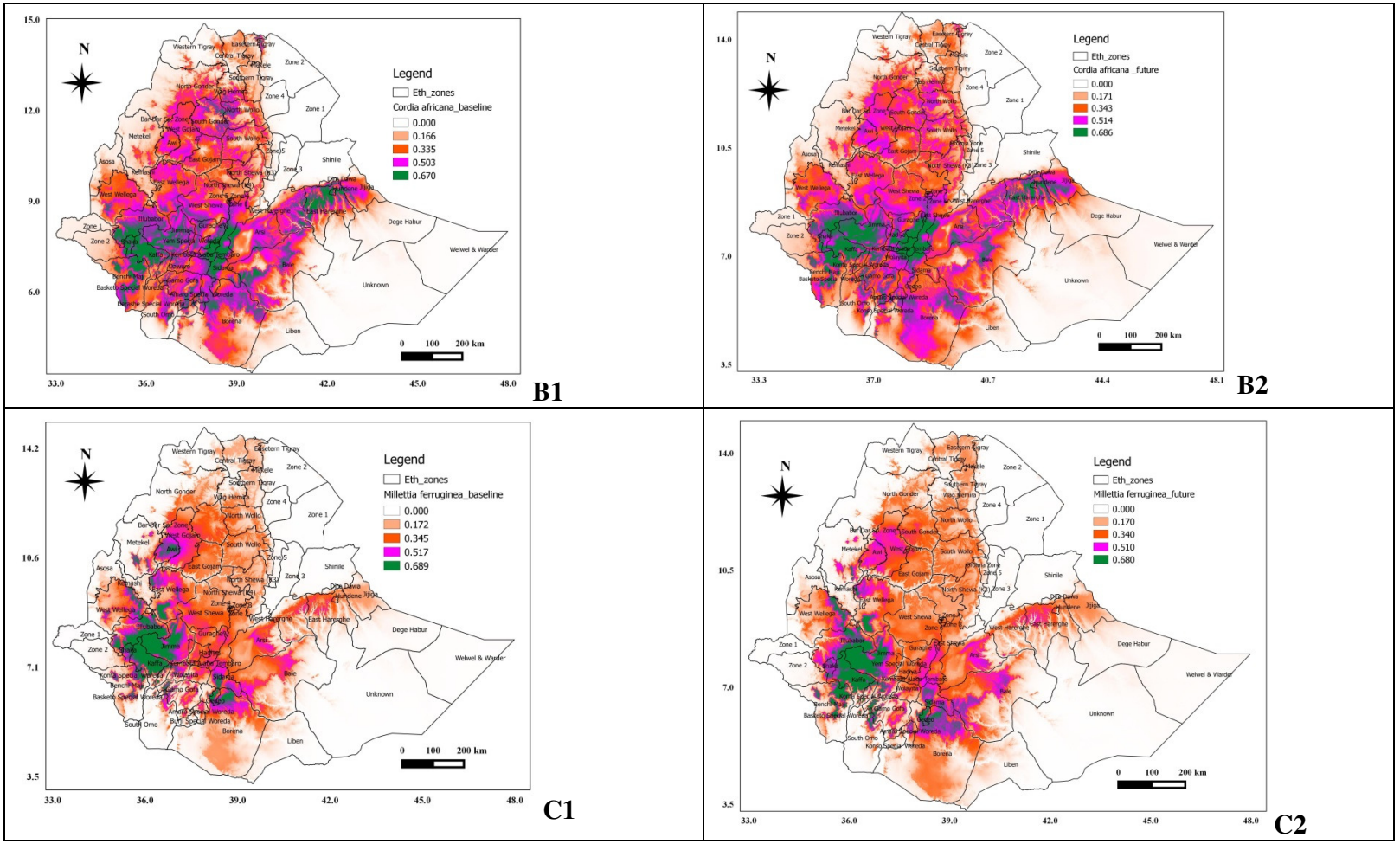
bio10 = mean temperature warmest quarter, bio11 = mean temperature coolest quarter, bio12 = mean annual rainfall, bio13 = rainfall wettest month, bio14 = Rainfall driest month, bio15 = Rainfall seasonality, bio16 = Rainfall wettest quarter, bio17 =Rainfall driest quarter, pet = potential evapotranspiration, mimq = Moisture index moist quarter, mi = Annual moisture index, 2 = Mean diurnal range in temperature, bio3 = Isothermality, bio1 = mean annual temperature, bio6 = Min temp coolest month, bio7 = Annual temperature range, bio4 =Temperature seasonality, bio5 = Max temp warmest month

Appendix 18: Linear relationships between true_LAI indices and climate variables

LAI Type	Pearson	bio3	bio10	bio13	bio12	bio5	mimq	bio1	bio16	bio7	bio14	bio6	bio11	bio2	bio17	mi	bio15	pet	bio4
LAI_v6	Cor.	0.043	-0.418	-0.121	0.375	-0.415	0.376	-0.423	0.093	-0.46	-0.132	-0.368	-0.41	-0.425	0.44	0.405	0.22	-0.419	-0.264
	P	0.823	0.024	0.532	0.045	0.025	0.044	0.022	0.633	0.012	0.496	0.05	0.027	0.022	0.017	0.029	0.252	0.024	0.167
	N	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
LAI_v5	Cor.	0.053	-0.406	-0.126	0.363	-0.405	0.365	-0.412	0.084	-0.452	-0.13	-0.357	-0.4	-0.414	0.423	0.394	0.212	-0.41	-0.255
	P	0.785	0.029	0.515	0.053	0.029	0.051	0.026	0.665	0.014	0.503	0.057	0.032	0.026	0.022	0.035	0.269	0.027	0.182
	N	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29

Appendix 19: Habitat suitability for the distribution of five plant species in Ethiopia under baseline and projected climate (A1, B1, C1, D1, E1 = baseline scenario, A2, B2, C2, D2, E2 = Projected climatescenario)




N
Legend
Eth_zones
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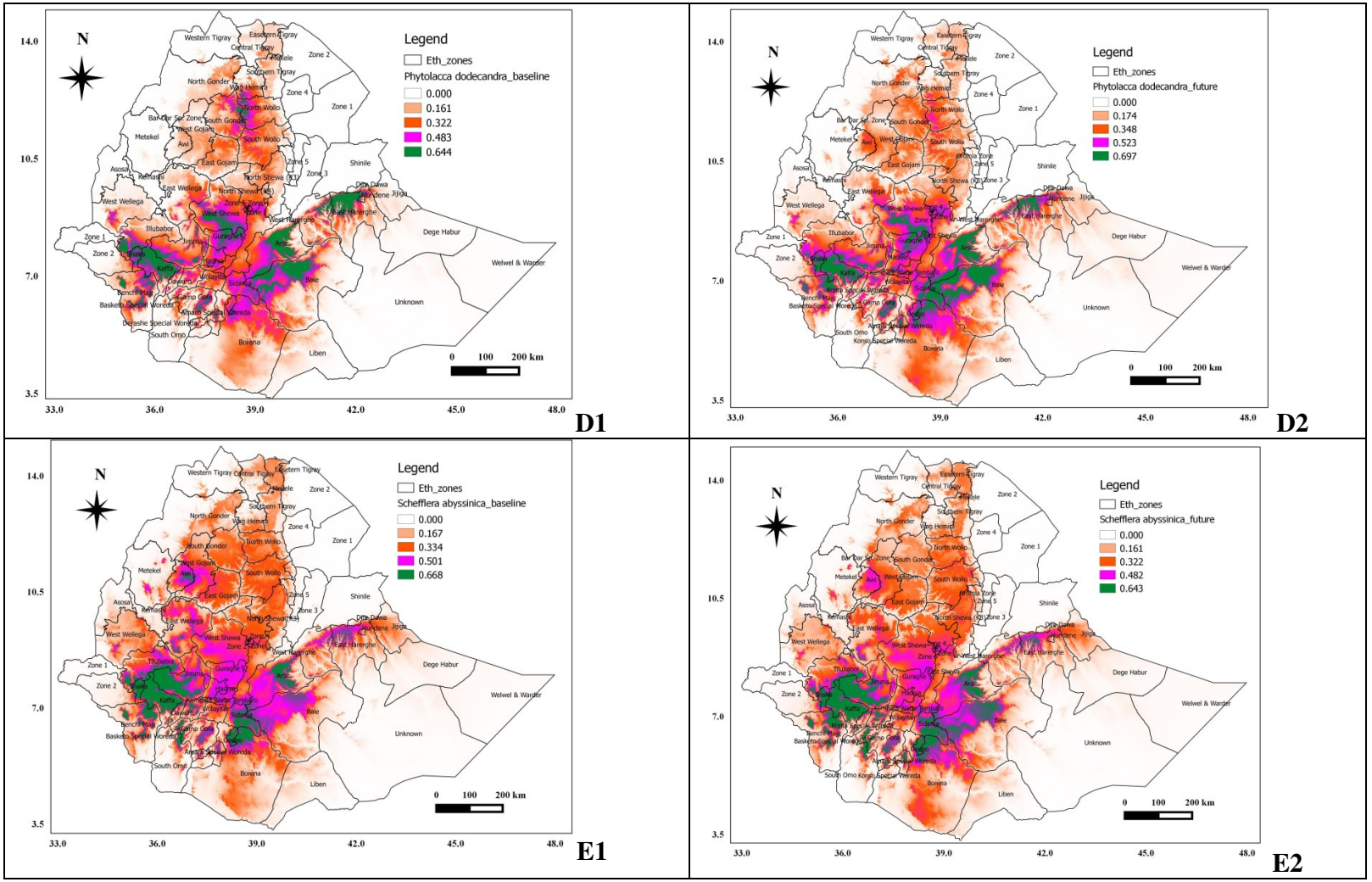
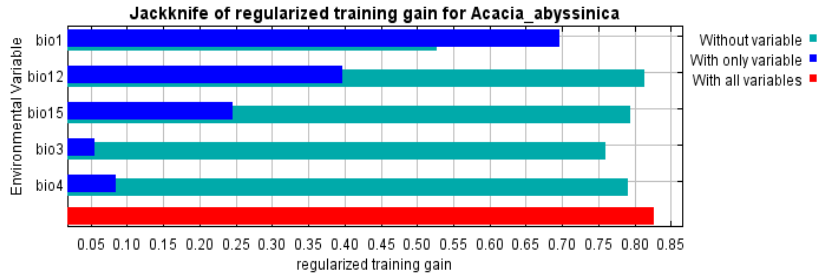
0.000
0.166
0.335
0.503
0.670
Cordia africana _future
0.171
0.343
0.514
0.686
Millettia ferruginea_baseline
0.172
0.345
0.517
0.689
Millettia ferruginea_future
0.170
0.340
0.510
0.680
Unknown
0 100 200 km
B1
B2
C1
C2

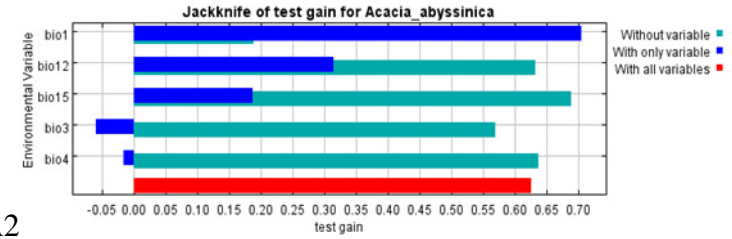

N
Legend
Eth_zones
Phytolacca dodecandra_baseline
0.000
0.161
0.322
0.483
0.644
Phytolacca dodecandra_future
0.000
0.174
0.348
0.523
0.697
Schefflera abyssinica_baseline
0.000
0.167
0.334
0.501
0.668
Schefflera abyssinica_future
0.000
0.161
0.322
0.482
0.643
0 100 200 km
14.0
10.5
7.0
3.5
33.0
36.0
39.0
42.0
45.0
48.0
D1
D2
E1
E2

Appendix 20: Jackknife test (training and test data) for the distribution of five plant species (A1, B1, C1, D1, E1 represent training gain under baseline scenario; A2, B2, C2, D2, E2 represent test gain under the baseline scenario; A3, B3, C3, D3, E3 represent training gain under the projected climate; A4, B4, C4, D4, E4 represent test gain under the projected climate

Jackknife test for the distribution of five species

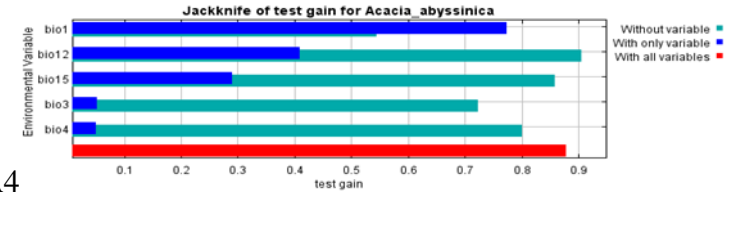


A1



A2

A3



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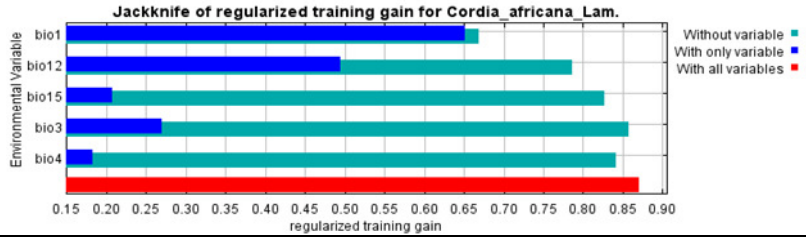
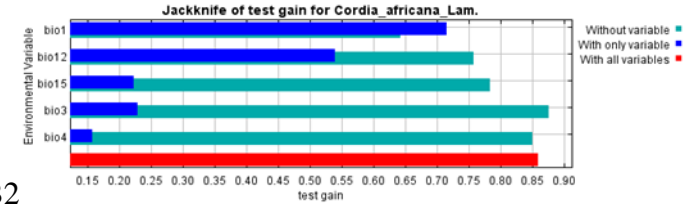
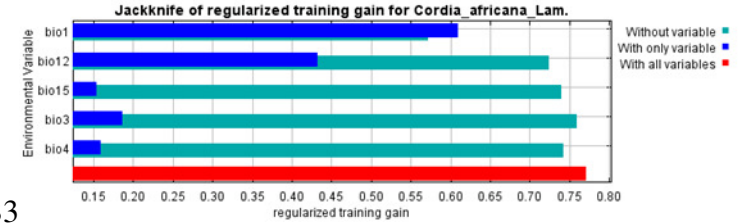




B2

B1



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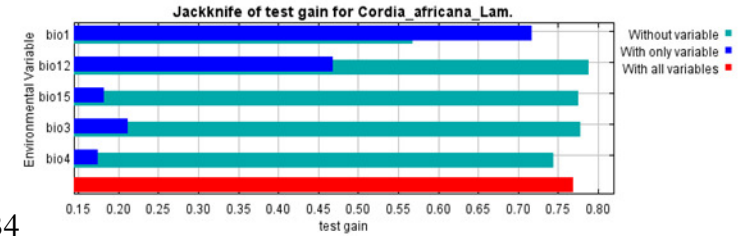
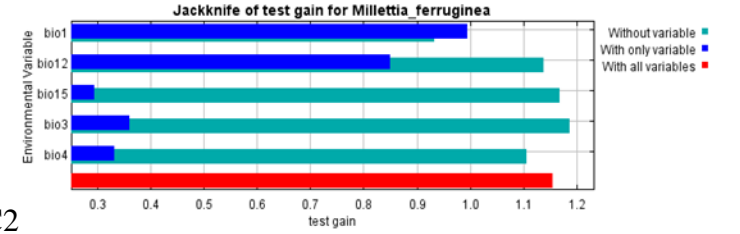


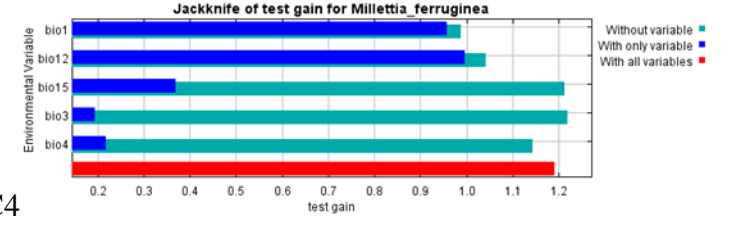
B4

C1

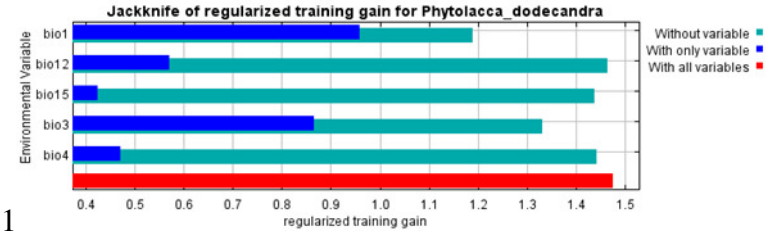


C2

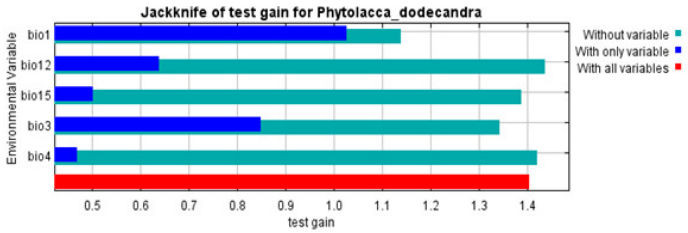
C3



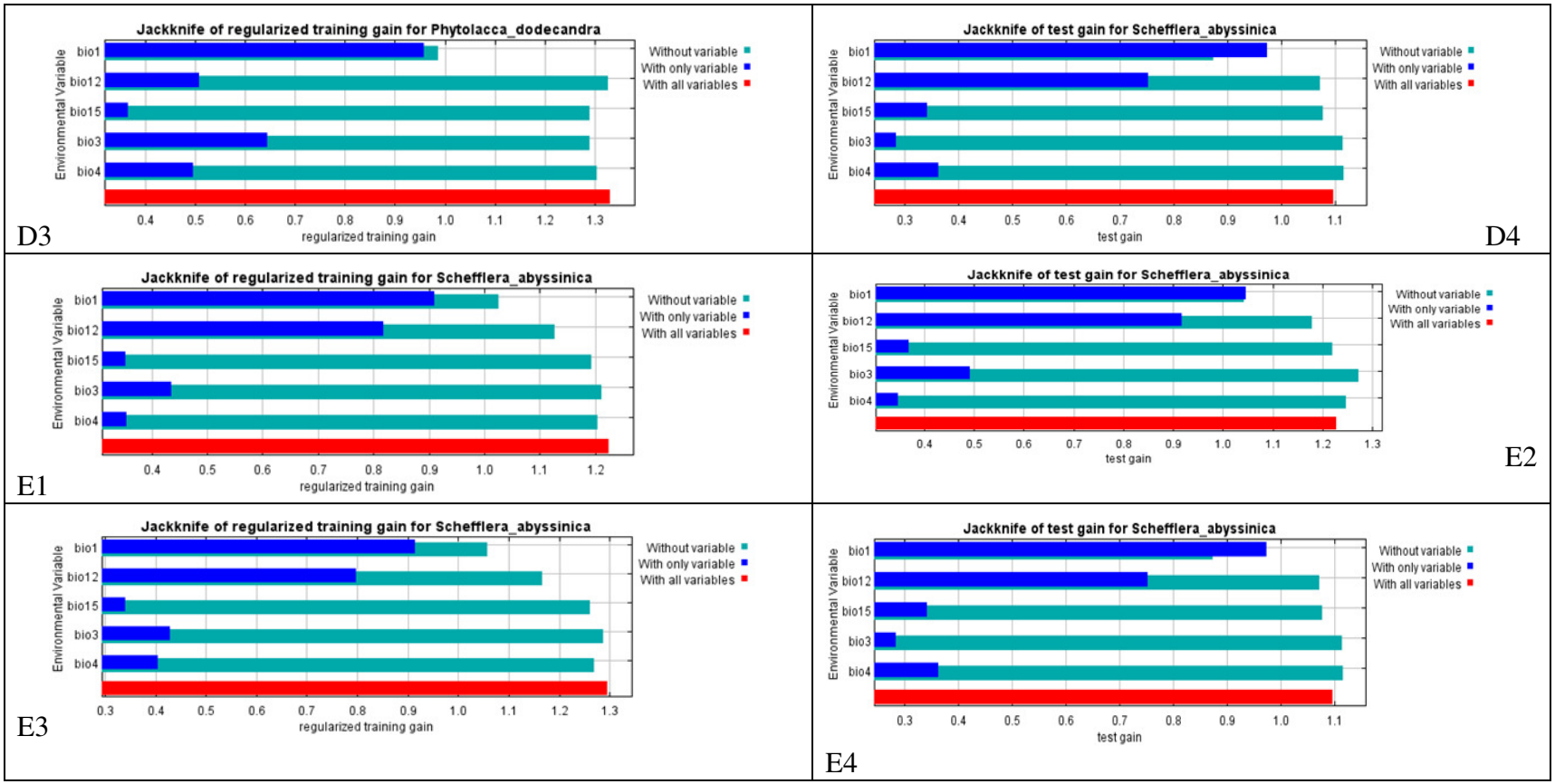
C4



D1



D2



A1-4 = *Acacia abyssinica*, B1-4 = *Cordia africana*, C1-4 = *Millettia ferruginea*, D1-4= *Phytolacca dodecandra*, E1-4= *Schefflera abyssinica*)

I, the undersigned, hereby declare that this thesis is my original work and that all sources of materials used for the thesis have been acknowledged.

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Signature: _____

Date of submission: May 06, 2016