DYNAMICS, SPATIAL CONFIGURATION, AND MODELLING OF YEGOF FOREST VEGETATION AND ITS SURROUNDING PATCHES, SOUTH WOLLO, ETHIOPIA

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Dynamics, Spatial Configuration, and Modelling of Yegof Forest Vegetation and its Surrounding Patches, South Wollo, Ethiopia

By

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A Thesis Presented to the Graduate Programmes of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Plant Biology & Biodiversity Management

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ABSTRACT

Dynamics, Spatial Configuration and Modelling of Yegof forest and its surrounding patches, South Wollo, Ethiopia

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This study comprised Land use and Land Cover (LULC), floristic composition and structural analyses, human forest interaction, and species distribution modelling of Yegof forest. This study is aimed to investigate the natural dynamics, spatial configuration and modelling of Yegof forest and its surrounding forest patches. The LULC maps of the landscape were produce from landsat MSS (1972-12-07), TM (1986-02-09), and ETM$^+$ (2015-03-10) images. The produced LULC maps were used to compare the magnitude of fragmentation using selected metrics. For floristic composition and structural analysis of Yegof forest and its surrounding forest patches, (Erkis, Harbu, Suki, Harego, Biraro, and Abuli) field data was collected on 164 sampling plots. The land use drivers and the status of the forest resources under different forest management regimes were identified and evaluated using structured household questionnaire survey. The current and the likely future distribution range of Hagenia abyssinica population, flagship species in the forest, were modelled. The data were analysed using suitable analytical software packages including, R, Biodiversity Pro, SPSS, MaxEnt, QGIS, DIVA-GIS, and FRAGSTATS. Significant differences between means and ranks were tested. The result of LULC analysis from 1986 to 2015 showed agriculture land and settlement area increased from 67.26% to 80.08% and from 1.63% to 1.93% in the landscape, respectively. In contrast, forestland and shrub land had decreased from 11.23% to 8.25% and from 17.83% to 3.35% in the landscape, respectively. The set of ten metrics has revealed that the forest of Yegof and the surrounding patch forests were experiencing a lesser fragmentation intensity in the year 1986 than that of 1972 and 2015. This study has recorded 292 species of vascular plants belonging to 219 genera representing 84 families. The vegetation of the Forests was classified into five, namely Juniperus procera, Olea europaea subsp. caspidata - Olinia rochetiana, Carissa spinarum - Euphorbia candelabrum, Nuxia congesta-Myrsine africana and Acacia bervispica-Dichrostachys cinerea -Acacia seyal community types. The community types were described with varying degree of species richness, evenness, and diversity. The elevation and slope qualifies as the best predictor for species composition, while heat load and landform do not mirror this pattern. Density of tree species in the forests decreases with increasing DBH and Height classes, which show that the forest is in the secondary state of development. Fuelwood harvesting is the major cause of deforestation in the area. Hagenia abyssinica population in the study area is found to be highly affected by climate change. So that, launching provenance trials in the area for the selection of highly adaptive individuals under the effects of climate change is indispensable.

Keywords: Forest cover change, Fragmentation, Floristic Composition, Yegof Forest.

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ANRS	Amhara National Regional State
AR	Arsi floristic region
Area Mean	Patch Area Distribution
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
AUC	Area under curve
BA	Basal Area
BAF	Bale floristic region
BC	Before the birth of Christ
bio1 to bio 19	indicates different bioclimatic variable
BMNP	Bale Mountains National Park
BP	Before Present
BSNP	Borena-Sayint National Park
CA	Class Area
CCA	Canonical Correspondence Analysis
CSA	Central Statistics Authority
DAF	Dry evergreen Afromontane forest and grassland complex
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
ED	Edge Density
EFAP	Ethiopian Forestry Action Program
EMA	Ethiopian Mapping Agency
ENN	Euclidean Nearest-Neighbor Distance
ETH	Ethiopian National Herbarium
ETM+	Enhanced Thermal Mapper Plus
FAO	Food and Agricultural Organization
FRAGSTATS	Spatial Pattern Analysis Software for Categorical Maps
GCPs	Ground Control Points
GD	Gondar floristic region
GJ	Gojam floristic region
GPS	Geographical Positioning System
Ha	Hectare
HAF	Hararge floristic region
IJI	Interspersion and Juxtaposition Index
IR	Infrared
IUCN	International Union of Conservation of Nature
IUFRO	International Union of Forestry Organization
IVI	Importance Value Index
KF	Kefa floristic region
LPI	Largest Patch Index

LULC	Land use/Land cover
masl	Meter above sea level
MaxEnt	Program for maximum entropy modelling of species' geographic distributions
MESS	Multivariate Environmental Similarity Surface
MIR	Mid Infrared
MODIS	Moderate Resolution Imaging Spectra diameter
MSS	Multispectral Scanner
Mt.	Mountain
NFPA	National Forest Priority Area
NIR	Near Infrared
NMA	Ethiopian National Meteorological Agency
NMSA	National Meteorological Services Agency
NP	Number of Patch
ONRS	Oromia National Reginal State
PCA	Principal Component Analysis
PLAND	Percentage of Landscape
QGIS	Quantum GIS
R^2	Coefficient of determination
rcp	Representative concentration pathways
SD	Sidam floristic region
SNNPRS	Southern nations Nationalities and Peoples National Regional State
SPSS	Statistical Package for the Social Sciences
SU	Shewa floristic region
SWIR	Short Wave Infrared
TCA	Total Core Area
TIR	Thermal infrared
TNRS	Tigray National Regional State
TU	Tigray floristic region
US	United Sates of America
USGS	United Sates Geological Service
UTM	Universal Transverse Mercator Projection
UV	Ultra Violet
VNIR	Visible and Near Infrared
WG	Welega floristic region
WorldClim	World Climate
WWNF	Wof Washa Natural Forest

CHAPTER ONE

1 INTRODUCTION

1.1 Background

In the distance past the highlands of northern Ethiopia was covered with Podocarpus-Juniperus forest. Study made around the highlands of northern Ethiopia evidenced that the vegetation has changed in response to human impact over the last 3000 years (Darbyshire et al., 2003). By then, the natural vegetation of the area was cleared and replaced by a secondary vegetation of Dodonaea scrub and grassland following the Semitic immigration to northern Ethiopia at about 500 BC (Darbyshire et al., 2003).

According to historical records, twenty percent of the land surface of Wello was covered with forest vegetation in the year 1939, the most important species being *Juniperus procera* and *Podocarpus falcatus* in Danqoro , Albukko, and Yegof forests (Baharu Zewude, 1998). The presence of a number of isolated forest trees, even on farmlands, forests around churchyards and religious burial grounds, indicate the occurrence of the vast expanse of forests earlier (Tamrat Bekele, 1993; Alemayehu Wassie et al., 2009).

The historical origin of Yegof Forest, the study area, is uncertain. But according to some historical literature, Yegof was found to be the enclosure of Emperor Lebna Dengel's palace during the sixteenth century (Baharu Zewude, 1998) and later, in mid nineteenth century , Queen Werqit of Wollo, an opponent of Emperor Tewodros, used the summit as her stronghold (Pankhurst, 2001).

The available record on the status of Yegof forest shows a continual reduction in its size of forest area. For example, in the year 1952 a total of 3200-3600 hectares of forest land was demarcated and declared as state forest (Baharu Zewude, 1998). Then, the forest had contracted to an area of 67 ha in the year 1971 (Young, 2012). Latter in 1985/1986, the forest was designated as a National Forest Priority Area (NFPA) in 1985/86 by the then State Forest Development and Conservation Department of the Ministry of Agriculture (EFAP, 1994). In the year 2011, the ownership of Yegof forest was transferred to the Amhara National Regional State Forestry Enterprise (Regulation No. 70/2009, ANRS, 2009), the total of 1462.5 hectares of Yegof forest vegetation has been managed by Amhara Forest Enterprise.

Evidence from the Soil Organic Carbon (SOC) isotope test was consistent with these historical documents suggesting the occurrence of long-lasting anthropogenic forest disturbances in the areas around Mt. Yegof since time immemorial (Zewdu Eshetu, 2002). Thus, it is possible to say that the Forest has experienced a long history of deforestation since 2450 before present (Hurni, 1988) and 500 BC (Darbyshire et al., 2003) indicating the existence of a long history of persistent anthropogenic impact experienced in the area.

So many factors contributed to the deforestation of Yegof forest. Some of which are unclear demarcation of the forest resulted from open access situation in which the forest faced severe disturbance from grazing animals, illegal cuttings of trees for construction, timber and fuelwood collection (Pankhurst, 2001). Consequently, the most valuable indigenous tree species, as well as wild animals, have been severely affected in the area. In the final year of the *Derge* and during the transition period, with the lack of restrictions, the sale of wood from state/community forests became a major survival strategy. This caused a massive destruction of the forest resource of the area. Though human factor is responsible for forest degradation in the country, population growth, poverty, unstable land-tenure system, property right over forests, lack of forest and land-use policies (Melaku Bekele, 2003), socio-political instability (Eshetu Yirdaw, 2002) and the setting up of sawmills by the Italians (1936 –1941) also resulted in accelerated deforestation being major driving factors often listed.

To tackle deforestation and safeguard the forests, various interventions were made since earlier times. For instance, armed guards, during the regime of Menilek were assigned to protect the forest and imposed fines as high as 50 Maria Theresa for unauthorized cuttings were some traces of sentry posts testifying the various historical attempts carried out to safeguard the forest resources of the area by previous governments (Baharu Zewude, 1998). Similarly, during the *Derge* regime, particularly, the 1985 famine that occurred in northern Ethiopia forced the government to carry out various environmental protection measures and concern for afforestation has been started on those droughts affected degraded and mountain area of the country (Dessalegn Rahmato, 1998).

In the year 2011, the management and utilization right of Yegof forest was transferred to the Amhara National Regional State Forestry Enterprise in accordance with the region's legal ground under the regulation No. 70/2009 (ANRS, 2009) and the enterprise started harvesting of plantation species since then.

Numerous studies globally have tried to explain the response of the species to climate change including:- either the species will drift to new locations that are similar to their current climatic condition, or they will change themselves to adapt the changing climate. Consequently, some species becoming less abundant or locally extinct and others thriving under the new conditions (Cusick et al., 2007). So that, this study is conducted to predict the potential distribution as well as the impact of climate change on *Hagenia abyssinica* tree species in Ethiopia. The extraction and documentation of this information help to implement appropriate conservation actions and can contribute to sustainable forest resource management of the area.

However, very few studies have been carried out so far dealing with the land use land cover changes of this area that initiated me doing further investigation on it. For example, LULC changes between 1958 and 1986 in Kalu District, Southern Wollo, was studied by Kebrom Tekle and Hedlund (2000). However, according to the same authors, "the computer-assisted photographic analyses of land cover changes from 1986 up to the present could not be undertaken because recent aerial photographs were not available and satellite images were not affordable". In addition, To date, very few studies have been carried out at landscape level, deals with the effect on fragmentation on species dynamics, except few studies deals with on Natural Resource Management in Post-conflict Situations by Punkhurst (2001), Deforestation in Wollo by Crummey (1988), Historical Perspective of Forest Management in Wollo by Bahru Zewde (1998) and also vegetation in South Wollo was studied by (Kebrom Tekle et al., 1997; Sebsebe Demissew, 1998; Tesfaye Bekele, 2000, 2005; Getachew Tadesse et al., 2008; Sultan Mohammed and Berhanu Abraha, 2013; Hussien Adal, 2014). However, studies like the contribution of forest patches on the conservation of vascular species composition and diversity are not yet quantified at local level. Generally, research works in the area have not so far been made in a full-fledged manner and hence little is known in ways on how to wisely use & manage the natural resources of the area.

The identification, demarcation, and preservation of the remaining natural forests and wildlife will be beneficial to present as well as future generations (Badege Bishaw, 2001). On one hand, the natural resources of the area have suffered due to recurrence of severe and prolonged droughts, and civil unrest (Maereg Tafere et al., 2013) and the remaining forests land of the area were converted to cropland, shrub land and grazing area (Estifanos Lemma, 2010; Hudad Barry, 2010). On the other hand, poverty and vulnerability are increasing in rural Wollo (Devereux and Sharp, 2006), deforestation and land degradation were increasingly observed, and therefore, there is an urgent need for the protection and management of the few remnant patches of natural forests and their biodiversity in the area.

The overall objective of this study is to explain the tempo-spatial changes so far observed in the study area, and so as to extract information for plant diversity conservation planning and sustainable development of South Wollo in Amhara National Regional State, Ethiopia.

The current study tries to fill the gap that was not addressed by the previous studies. This study has employed four aspects of forest cover change detection characteristics to be investigated include, (i) detecting the changes that have occurred, (ii) identifying the nature of the change, (iii) measuring the temporal, and (iv) areal extent of the change observed in the study area at present time. The study combines methods originating from different disciplines including GIS and remote sensing, taxonomy and plant ecology.

This study is also conducted to predict the potential as well as the future distribution of *Hagenia abyssinica* tree species in Ethiopia. The extraction and documentation of this information help to implement appropriate conservation actions and can contribute to sustainable forest resource management of the area. Moreover, the overall objective of this study is to explain the tempo-spatial changes so far observed in the study area and to extract information for plant diversity conservation planning and sustainable development of South Wollo in Amhara National Regional State, Ethiopia.

1.2 Research Objectives and Research Questions

1.2.1 Research objectives

1.2.1.1 General objective

The general objective of the study is to investigate the natural dynamics, spatial configuration and modelling of Yegof forest and its surrounding patches to extract information for plant diversity conservation planning and sustainable development of South Wollo in Amhara Regional State, Ethiopia.

1.2.1.2 Specific objectives

- To analyse the land use land cover change and dynamics;
- To quantify the magnitude of fragmentation in the area;
- To describe the floristic composition and structure;
- To characterize agents of deforestation and fragmentation in the forest;
- To determine the association between the characteristics of respondents with their preferred specific management option;
- To examine the distribution of *Hagenia abyssinica* under the effects of climate change.

1.2.2 Research questions

In light of the aforementioned research objectives, this study tried to answer the following key research questions:

- ✓ What are the trends and patterns of LULC cover change observed in the area?
- ✓ Does the magnitude of fragmentation in the area are similar along the studied period?
- ✓ What is the floristic composition and structure of the vegetation of Yegof and its surrounding patches?
- ✓ Who are the agents responsible for deforestation and fragmentation in the forest?
- ✓ Does the local community recognize a land use and land cover changes in the area?

- ✓ Which is the most acceptable forest management scheme for the area? Who and why they prefer?
- ✓ What are the current and likely future distribution range and suitable areas for of *Hagenia abyssinica*?

The results would help as a decision support system for policy makers, resource managers, and local communities

CHAPTER TWO

2 REVIEW OF RELATED LITERATURE

2.1 Plant Diversity and Vegetation types of Ethiopia

Ethiopia possesses one of the richest assemblages of plants in the African Continent (Vivero et al., 2005). The diverse topography and climatic conditions of Ethiopia led to the creation of habitats that are suitable for evolution. These have resulted in a rich mosaic pattern of different habitats, which promote species richness and diversity and micro-climatic differences, too contributing to the biodiversity (Puff and Sileshi Nemomissa, 2005). As a result, The inventory of the flora of Ethiopia has recorded 6027 species (including subspecies) of higher plants with 10% endemism (Ensermu Kelbessa and Sebsebe Demissew, 2014).

Information on the distribution and abundance of threatened plant species is of primary importance in the planning and implementation of biodiversity conservation activities (Vivero et al., 2005). However, species on the mountainous area are still insufficiently known (White, 1983), so information on the distribution of selected populations of plant species is vital (Secretariat of the Convention on Biological Diversity, 2006).

Few plant conservation activities are presently undertaken in Ethiopia despite the richness and threat status of the biodiversity in the country (Vivero et al., 2005). Habitat distraction and fragmentation resulted in the loss of biodiversity and species extinction (Gibson and Gibson, 2006), hastened by the extremely narrow distribution and limited ecological tolerance of some species in this region (Secretariat of the Convention on Biological Diversity, 2010). To counter these multiple biodiversity threats, Institute of Biodiversity Conservation (IBC) in partnership with farming communities has been working on biodiversity conservation (Chala Dechassa, 2015). Yet, no specific measures are being implemented in Ethiopia for the conservation of critically endangered plant species (Vivero et al., 2005)

Vegetation classification has been carried out over nearly the entire country. Different principles and the method of classification were employed. The first vegetation map covering the Horn of Africa (comprising the present states of Eritrea, Ethiopia, Djibouti and Somalia) was published by Negri (1940) at a scale of 1:7,000,000. The two detailed vegetation maps of Ethiopia, by Pichi Sermolli in 1957 and by White in 1983, were produced at the scale of 1:5,000,000 (Friis et al., 2010). White (1983) used the Yangambi classification, and represented an improvement over Schimper (Friis et al., 2010), especially in its treatment of forest, woodland and thicket, but it was also criticized for the use of the terms 'savanna' and 'steppe' and their definition. Moreover, part of vegetation map covering the whole of Africa (White, 1983), showed considerable differences with regard to the vegetation types and their extent (Friis et al., 2010).

Recently, Friis et al. (2010) have published a detailed vegetation map for Ethiopia with a scale of 1:2,000,000. The recent vegetation atlas, for example, has been produced using a digital elevation model with a resolution of 90 x 90 meters in connection with GIS technology. In this map, 12 vegetation types with 15 mapping units are recognized. The name of the twelve vegetation types are: (1) Desert and semi-desert scrubland; (2) *Acacia-Commiphora* woodland and bushland; (3) Wooded grassland of the Western Gambela Region; (4) *Combretum-Terminalia* woodland and wooded grassland; (5) Dry evergreen Afro-montane forest and grassland complex, (6) Moist evergreen Afro-montane forest; (7) Transitional rain forest; (8) Ericaceous belt; (9) Afroalpine vegetation; (10) Riverine vegetation; (11) Freshwater lakes, lakeshores, marshes, swamps and floodplains vegetation; and (12) Salt-water lakes, lake shores, salt marshes and pan vegetation.

The following points were discussed below on dry evergreen Afro-montane forest and grassland complex where the current study was carried out.

DAF is distributed throughout the highlands above 1800 meters and below 3000 meters from the border with Eritrea to scattered areas with high ground in the south excluding an area that received higher rainfall in the western and southeastern parts of the highland of Ethiopia. This vegetation type represents a complex system of successions involving extensive grasslands rich in legumes on heavy black clay soils and periodically swamped areas, shrubs and small to large-sized trees to closed forest with a canopy of several strata (Friis et al., 2010).

Farming was probably established thousands of years ago inside areas covered by this vegetation complex, and particularly the northern part of the Dry evergreen Afromontane forest and grassland complex (DAF) has been intensely utilized by man ever since, with the result that the forests have reduced in size and in most area it is replaced by bushland (Sebsebe Demissew, 2010).

A total of four hundred sixty species, subspecies, and varieties of woody plants have been documented to occur in DAF. Out of this, one hundred twenty-eight have only been recorded from this vegetation type. One hundred two have been common in both DAF and Riverine vegetation types. This vegetation type and *Acacia- Commiphora woodland and bushland* have one hundred two common species. Eighty-nine similar species, subspecies, and varieties of woody plants were recorded to occur in both DAF and *Moist evergreen Afromontane forest*. Seventy-four were shared between DAF and *Combretum-Terminalia woodland* and *wooded grassland* vegetation type. Fifty-six were shared between DAF and *Ericaceous belt vegetation* type; twenty were shared between DAF and *Afro alpine belt*; and fifty were shared between DAF and *Transitional rain forest vegetation* type (Friis et al., 2010).

2.2 Classification and Ordination

For centuries, ecologists have collected either quantitative observations to determine the resemblance between the objects under study (sites) or the variables describing them (species or other descriptors) (Legendre and Legendre, 1998). Measuring the association between objects or descriptors is the first, and sometimes the only step in the numerical analysis of ecological data.

Clustering and or ordination techniques are common in the measures of resemblance in the field of ecology (Wildi, 2010). Measures of resemblance between objects or descriptors will be used to cluster the objects or descriptors to produce scattered diagrams in spaces of reduced dimensionality (Legendre and Legendre, 1998).

Wildi (2010) uses the term 'ordination' to refer to a graphical representation of the similarity of sampling units and/or attributes in resemblance space. Ordination in reduced space is an operation by which the objects (or descriptors) are positioned in a space that contains fewer dimensions that in the original data set; the positions of the objects or descriptors with respect to one another may also be used to cluster them.

Choosing and using statistics for the biological study

Ecologists have used quantitative approaches since the publication by Jaccard in the year 1900, the first association coefficient. Floristic was developed from this seed, and the method was eventually applied to all fields of ecology, often achieving high levels of complexity (Legendre and Legendre, 1998). Psychometricians and social scientists developed non-parametric statistical methods and factor analysis and, later, non-metric multi-dimensional scaling (Legendre and Legendre, 1998).

Association coefficients are so many, diverse in numerical ecology, (Legendre and Legendre, 1998) documented coefficients suitable to the ecological phenomena. Some of them are of wide applicability; whereas, others have been created for specific needs (Dufrene and Legendre, 1997).

Kenkel and Orloci (1986) compared the Metric (eigenanalysis) and Nonmetric Multi-dimensional Scaling strategies for ecological ordination: Non-metric multi-dimensional scaling based on Euclidean distance following standardization proved to be the best strategy for recovering simulated coenoplane data. Of the metric strategies compared, correspondence analysis and the detrended form were most successful.

János (2006) recommended ordinal measures of resemblance and ordination and clustering algorithms.

Analysis of variance is particularly powerful for the analysis of univariate data. The traditional multi-variate analogues; however, are too stringent in their assumptions for most ecological multi-variate data sets; rather Non-parametric methods, based on permutation tests, are preferable (Anderson, 2001). Several coefficients have been rediscovered by successive authors and may be known under various names (Legendre and Legendre, 1998).

2.3 Measurement of Species Diversity, Richness and Evenness

The terms biodiversity has become very popular. Traditionally, diversity is composed of two distinct components: species richness (the total number of species) and evenness (how abundant each species is relative to other species) (van der Maarel, 2005). Species richness: the total number of species in a population of interest is the most fundamental and easily interpretable measure of diversity. It is most meaningful when the sample units are equivalent in terms of sample area as well as time spent searching (Magurran, 2005).

Assumptions of biodiversity measurement was first demonstrated by peet during 1970th (Magurran, 2005). These are that all species are equal, that all individuals are equal, and that abundance has been measured in appropriate and comparable units.

All species are equal. This means that no species will obtain special weighting. Richness measures make no distinctions treatment for both abundant and rare species.

As special case, an investigator may decide to focus on endemic species and compare the diversity of these at different localities (Magurran, 2005).

The relative abundance of a species in an assemblage is the only factor that determines its importance in a diversity measure. Richness measures make no distinctions amongst species at all and treat the species that are exceptionally abundant in the same manner as those that are extremely rare (Magurran, 2005). The same author has also offered an explanatory notion for the third assumption that species abundance has been recorded using appropriate and comparable units. Abundance must be in the form of number of individuals when the log series model is used. It is clearly unwise to include different types of abundance measure, such as a number of individuals and biomass, in the same investigation. Delineating the unit of study is an important part of biodiversity measurement. Species diversity can be measured from different approaches in terms of alpha, beta and gamma diversity.

Alpha diversity

When the diversity is needed to be examined at the smallest scale, micro-habitat or sample taken from within a homogeneous habitat is termed alpha diversity (Magurran, 2005). Two different approaches for the determination of species diversity are distinguished: (1) indices are derived from models about the distribution of plant units, with α the parameter of the log series distribution being the best known index; and (2) makes use of the distribution of species quantities over the species without assuming any particular distribution model. Indices of this type, the Shannon index (van der Maarel, 2005).

Beta diversity or differentiation diversity

The term β diversity is essentially a measure of how different (or similar) a range of habitats or samples are in terms of the variety (and sometimes the abundances) of species found in them (Magurran, 2005). Beta diversity is a measure of species heterogeneity across a population, and an index of the number of distinct communities present in the sample (Schulz et al., 2009), Beta diversity vegetation data with no specific gradient; Whittaker was used an appropriate measure of beta diversity (Schulz et al., 2009).

The higher β diversity values resulted from more species differences between samples and can be interpreted as lower similarity, whereas, the lower β diversity values resulted from few species differences between samples and can be understood as higher similarity (Magurran, 2005).

Gamma diversity

Gamma diversity is the total number of unique species recorded in the population of interest. Gamma (γ), is reported with the total area sampled, the diversity of a larger unit such as an island or landscape. As gamma diversity is defined to be the overall diversity of a group of areas of alpha diversity so epsilon or regional diversity (Magurran, 2005).

Regarding the choice of the index, different indices measure different aspects of the partition of abundance between species. For example, three commonly used measures of diversity. Simpson`s index, Shannon`s entropy and the total number of species, provide estimates of an effective number of species present, and differ only in their tendency to include or to ignore the relatively rarer species in the enumeration (Hill, 1973).

Simpson's index, for example, is sensitive to the abundance only of the more plentiful species in a sample and can therefore be regarded as a measure of "dominance concentration" (Whittaker, 1965). As dominance (D) increases, diversity decreases. Simpson's index is therefore usually expressed as 1 - D or 1/D. Simpsons's index is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness (Magurran, 2005).

Berger-Parker index, is simple dominance measure and the index can express the proportional importance of the most abundant species (Berger and Parker, 1975), whereas, Jack-knifing uses a technique to determine bias in statistics by recalculating using a subset of the data, a series of jack-knife estimates and pseudo-values which are produced with no assumptions about the underlying distribution. These pseudo-values are normally distributed and their mean forms the best estimate of the statistic (Dytham, 2011).

Magurran (2005), suggests the following index selection procedure : (1) a wide range of diversity measures should be attempt, (2) repeated sampling is also the key to species richness estimation and this means that jackknifing and bootstrapping are feasible, (3) consider whether a "heterogeneity" measure is justified, (4) consider either α or Simpson's index for larger sample size (N> 1,000) and small sample size, respectively, and (5) use the Berger-Parker index, provides a simple and easily interpretable measure of dominance, and (6) use the Simpson evenness measure, particularly if taxonomic distinctness measures are informative and easily interpretable.

2.4 Concepts of Forest Fragmentation

Huggett (1998) uses the term 'Fragmentation' to refer to the breaking up of large habitats or areas into smaller parcels. According to Tejaswi (2007), forest fragmentation refers to any process that results in the conversion of formerly continuous forest into patches of forest separated by non-forested lands. Habitat fragmentation is one of the greatest threats to biodiversity and one of the primary causes of species extinctions worldwide (Wilcox and Murphy, 1985).

Regarding the principle of landscape ecology, Forman (1995) has organized the general principles of landscape into four categories: landscape and regions; patches and corridors; mosaics; and applications. Forman's theory about the general and the spatial landscape ecological principles moves on the landscape structure research from the static position to the dynamic development. This gives the methodical implementation to study the landscape functions and processes (Ružička and Mišovičova, 2009).

Clark (2010) has summarized the most important terminologies in the study landscape ecology. The term includes a patch, matrix, composition, configuration, scale, and extent. According to the same author, (1) the term patch refers to an area of habitat differing from its surroundings, often the smallest ecologically distinct landscape feature in a landscape mapping and classification system; (2) matrix is refers to the majority of the surrounding landscape. In this case, the matrix primarily consists of fields of agricultural crops; (3) composition refers to the relative proportion of habitat types in the landscape, regardless of spatial distribution and (4) configuration refers to almost limitless aspects of landscape heterogeneity, especially the physical and spatial distribution of landscape elements.

Moreover, scale and extent are also important to understand the landscapes. For example, Extent is the extended range of study or the area included within the landscape boundary, such as a national park or state (Clark, 2010). The term scale embodies a multitude of concepts, which refers to the smallest area that can be resolved into a single type on the landscape.

Fragmentation is caused by five processes namely: perforation, dissection, fragmentation, shrinkage, and attrition (Forman, 1995). Forests, for example, are being perforated by clearings, dissected by roads, broken into discrete patches by felling, and the newly created patches are shrinking and some of them disappearing through attrition (Huggett, 1998).

Fragmentation can be induced through natural and human activity. Hence, landscape patterns result from complex relationships among multiple factors such as (1) The abiotic template includes climate, physical relief and soil development; (2) biotic interactions; (3) disturbance and succession, and (4) the ways in which humans use the land are key drivers of landscape pattern (Turner, 2005).

The natural or anthropogenous disturbance processes influenced and formed the landscape elements, determined the redistribution of nutrients and supported the landscape streams. The regulation of species circulation supported the environmental diversity. The energy, material and species flow is in the direct coherence with the landscape diversity and heterogeneity (Ružička and Mišovičova, 2009).

Forest fragmentation occurs due to human activities such as logging or conversion of forests into agricultural areas and urbanization (Forman, 1995), does not affect all species in the same way. Some species may be very vulnerable to microclimatic variability. However, for some species, impacts of habitat fragmentation are mainly due to changes in the spatial arrangement of suitable habitat across the landscape and more frequent interaction with an altered microclimate and other factors associated with human land use at the periphery of fragmented patches (Turner, 2001). Hence, the numbers of generalist species, species that can live in more than one habitat, edge species, and exotic species will raise (Huggett, 1998).

2.4.1 Using and choosing landscape metrics in forest management

Landscape metrics are quantitative indices used to quantify landscape pattern and their relationships. A wide array of metrics for landscape composition (what and how much is present, such as the number and amount of different habitat types) and configuration (how those classes are arranged spatially) were developed for categorical data. Excellent software packages such as FRAGSTATS is widely used to study landscape composition and configuration (Turner, 2005).

FRAGSTATS computes several statistics for each patch and class in the landscape and for the landscape as a whole. At the class and landscape level, some of the metrics quantify landscape composition, while others quantify landscape configuration (Mcgarigal, 2012). However, the statistical properties and behaviour of many pattern metrics remain poorly understood. This is due to the fact that the distributions of landscape metrics are not known, expected values and variances are not available for statistical comparisons to be made among multiple observations of a particular metric (Turner, 2005). Hence, care has to be made before choosing and using the landscape metrics.

The quantitative analysis of landscape patterns is fraught with numerous challenges including: (1) defining a relevant landscape for the phenomenon or question under consideration, (2) gaining a proper theoretical and empirical understanding of metric behaviour to aid in the interpretation of each metric, (3) understanding the theoretical and empirical redundancies among metrics to ensure their parsimonious use, and (4) developing a proper reference framework for ecologically interpreting the computed value of each metric. It is incumbent upon the investigator or manager to be aware of these limitations and interpret and present the results of their analyses within these limits (Mcgarigal and Ene, 2013). Despite their limitations, landscape metrics remain widely used and useful (Turner, 2005).

Several studies have demonstrated that these metrics are highly correlated and it provides redundant information (Forman, 1995), for example when comparing landscapes of identical size, total edge and edge density are completely redundant (Mcgarigal and Ene, 2013). So that, much research has been directed towards choosing of a small set of metrics to characterize landscape structure globally (Garcia-Gigorro and Saura, 2005; Garrison, 2005; Biodiversity Indicators Partnership, 2010; Midha and Mathur, 2010). In the same way, thus far, studies in Ethiopia, for instance, Desalegn Desissa (2012) has selected eight landscape metrics based on their popularity of the metrics in landscape analysis and their relevancy with the objective of his study. Thus, the selected metrics: (1) size metrics (class area, mean patch size, core area and number of patches); (2) shape metrics (area weighted mean shape index and area weighted mean fractal dimension), patch size (coefficient of variation) and (3) edge metrics (edge density). Moreover, recently, Leul Kidane (2015) has used five patch level metrics, nine class level metrics and nine landscape level metrics to quantify and examine landscape composition and configuration of the forest.

Forest area, shape, and isolation accounted for sharply decreasing proportions of variability in tree species diversity. Large forest fragments contained the greatest numbers of tree species and the highest proportions of rare tree species; irregular fragments had high proportions of regenerating, light-demanding pioneers and mature, animal-dispersed species and isolated fragments were floristically similar to less isolated fragments (Aerts et al., 2006). Genetic diversity (based on allelic richness) was significantly greater in large and less-isolated forest patches (Haile Yineger et al., 2014).

Forest area is the most important consideration when planning tropical forest reserves Hill et al. (2005). Most of the Ethiopian scholars also suggested that an urgent management interventions are needed for sustainable management of biodiversity

(Abate Ayalew et al., 2006; Desalegn Tadele et al., 2013; Abreham Assefa et al., 2013).

Clearly, conserving biodiversity is a hard task for land managers, due to the complexity and dynamism. However, Conservation strategies can be activated using target species, populations and communities at the patch, landscape and regional scales (Farina, 1998). Protecting a range of patches including small and isolated ones are needed to conserve the extant genetic resources of the valuable forests (Haile Yineger et al., 2014).

In recent years, a few authors have begun to assess the impact of fragmentation on plant species composition of Ethiopian forests (Desalegn Desissa, 2012; Leul Kidane, 2015). Shrub, vine, and geophytic angiosperm herb species composition were not similar in forest edge and interior habitats. Species richness of vascular epiphytes was higher in the interior than edge habitat (Desalegn Desissa, 2012). However, in the same study, no association was found between tree density, basal area and any fragmentation variables (patch size, shape, or edge density). The same author has concluded that, vascular epiphyte and Geophytic fern were severely affected due to the reduction of forest interior core. Similarly, the study in Hugumburda-Gratkhassu National Forest has also recorded that the forest edge habitats were found to possess lower species richness, diversity, tree density and basal area compared to the inner habitats (Leul Kidane, 2015).

2.5 The Use of Remote Sensing Techniques in Ethiopia

Forests in Ethiopia are distributed over in an extensive geographical range, but nowhere form large continuous areas (Miles et al., 2006). This exacerbates the vegetation assessment operations in terms of cost and time. Ethiopia did not monitor its forest cover on a regular basis (Austin et al., 2012). Forest cover change is a dynamic, widespread, and accelerating process, mainly driven by natural phenomena and anthropogenic activities, which in turn affect the natural ecosystem. Understanding forest patterns, changes and interactions between human activities and natural phenomenon are essential for implementing proper forest management interventions (Abyot Yismaw et al., 2014).

Though remote sensing has wider application in ecological studies at global level, applications mostly utilized in Ethiopia geared merely on remote sensing which is believed to be useful for detecting land use land cover change (Kebrom Tekle and Hedlund, 2000; Belay Tegene, 2002; Abate Shiferaw, 2011; Abdi Boru and Kositsakulchai, 2012; Temesgen Gashaw et al., 2014), as a tool to studies related with for forest fire and selection of charcoal production sites (Molinario et al., 2013; Rembolda et al., 2013), as a tool to study forest change in an area (Gessesse Dessie and Kleman, 2007; Berhan Gessesse, 2010; Abyot Yismaw et al., 2014), and carbon sequestration (Mesfin Sahle, 2011).

Regarding the software's utilized, ArcGIS Software's, ERDAS Imagine Software and ENVI software were most widely used in Ethiopia. In the articles reviewed, more than one type of software's was employed. The commonly used analysis Software was

ArcGIS. Besides these mentioned software's, it was possible to use open-source software solutions, such as R and QGIS, which are believed to have a widespread application for satellite monitoring in ecology (Cornelio, 2014; Pettorelli et al., 2014).

2.5.1 Frequently used satellite image products in Ethiopia

Remote sensing can provide consistent data at all scales (Wang et al., 2010). In addition, many satellite products are freely available (Pettorelli et al., 2014). Whereas, very few satellite image products were used in Ethiopia and the majority of Ethiopia scholars were using Landsat images including; (Belay Tegene, 2002; Eyayu Molla et al., 2010; Dagnachew Melaku and Abate Shiferaw, 2014; Gebrekidan Worku et al., 2014). This might be due to its easy accessibility as open source and other data collected by active sensors has been often not affordable and/or not easily accessible (Pettorelli et al., 2014). However, some researches had utilized other image products. For instance, ASTER imagery (Aynekulu et al., 2008), PALSAR radar (Tadesse and Falconer, 2014), MODIS image, SPOT 2006 images (Misrak Alemu et al., 2012), 2012), Aerial Photographs (Kebrom Tekle and Hedlund, 2000; Girmay Kassa, 2003), had been recommended to use their applications in forestry.

Each kind of imagery has its own benefits and drawbacks. For example, MODIS imagery has a significant advantage in temporal resolution but is very poor in spatial resolution; whereas, Landsat TM imagery performed very well in spatial resolution (Wang et al., 2010). Therefore, a model was developed called Spatial-Temporal Adaptive Algorithm for Mapping Reflectance Change (STAARCH) to fuse high spatial- (Landsat) and temporal-resolution (MODIS) for mapping of forest disturbance (Wang et al., 2010).

2.6 Effects of Climate Change on Biodiversity

Numerous studies have attempted to explain the response of Biodiversity to climate change using one of the two known ways. This include either the species will drift to a new locations that are similar to their current climatic condition, or they will change, adapting to the changing climate, with some species becoming less abundant or locally extinct and others thriving under the new conditions (Cusick et al., 2007).

Many ecologists have conferred that global warming trends are modifying the species distribution (Elith et al., 2006; Phillips and Dudík, 2008). Recent evidence suggests that plant species respond to climate warming by increasing their leaf area index, net primary production, and carbon biomass. It is found that annual temperature range and precipitation seasonality influence the current distribution while in the future, mean temperature of the coldest quarter will shape the geographical distribution of *Abies spectabilis* (Joshi, 2015).

Climate change has affected African biodiversity as species struggle to adapt to the changing conditions (Lovett et al., 2005). So that, detailed knowledge of species' ecological and geographic distributions is fundamental for conservation planning (Elith and Leathwick, 2009). Species distribution models help us to determine the current and future distribution of the species. The availability of environmental data, and powerful computers has fuelled a rapid increase in predictive modelling of species environmental requirements, geographic distributions and contributes in biodiversity conservation planning and management (Phillips et al., 2006).

2.6.1 Modelling of species distributions

Species distribution modelling (SDMs) extrapolates species distribution data in space and time, usually based on a statistical model (Franklin, 2010). Developing a species distribution model begins with observations of species occurrences, and with environmental variables thought to influence habitat suitability and then species distribution. The model can be a quantitative or rule-based model and, if the fit is good in its prediction capability between the species distribution and the predictors examined, it can provide insight into species environmental tolerances or habitat preferences (Franklin, 2010). SDM is now widely applied to determine the potential distributions of species in relation to environmental covariates (Wilson, 2011).

Though modelling can never provide a complete substitute for the detailed and ongoing collection of field data (Elith et al., 2006), an explosion of interest in species distribution using modelling is observed widely in recent decades (Franklin, 2010; Wilson, 2011). SDMs are now widely used across terrestrial, freshwater, and marine realms (Elith and Leathwick, 2009). The advancement in computer programing, Geographical Information System (GIS), and statistics software favour innovation and development of modelling methods. These may hasten model utilization in biogeography and climate change studies globally.

Varieties of statistical methods are available for estimating the occurrence of probabilities from presence-only data (Elith et al., 2006). Today, many modelling tools are available and large sets of maps can be produced easily (Wilson, 2011). In light of an increasing number of modelling methods, selection and utilization of a model is indispensable to obtain an acceptable result (Phillips and Dudík, 2008). In view of this, Elith et al. (2006), has compared 16 modelling methods over 226 species from 6 regions of the world, creating the most comprehensive set of model comparisons to the date. However, results were not similar depending on data types and the kinds of a model used. In the end, they contended that further development of efficient user interfaces for the more successful methods, and greater integration among modellers and end-users. Similarly, Elith and Leathwick (2009) have argued that appropriate model selection and evaluation; accounting for biotic interactions; and assessing model uncertainty are some challenges among the others. Authors including Saupe et al. (2012) suggests that model development will be powerful only when set in an appropriate and explicit biogeographic and population ecological context.

Recently, in a statistical explanation of MaxEnt for ecologists, the study has shown that MaxEnt is an appropriate option for ecological studies. This method has gained great interest by those working in comparisons as it has shown higher predictive accuracy than many other methods when applied to “presence-only” data (Franklin, 2010). MaxEnt is regularly updated, hence found to be suitable for its wider applications for users.

2.6.2 Utilization Species Distribution Model in Ethiopia

In the available literature surveyed so far, the trend of the utilization of species distribution model in Ethiopia is very few. Hence, only a few related works related with species distribution model practiced in the country are listed as follows.

Friis et al. (2010) have determined the potential distributions of four important species in Ethiopia using rainfall and temperature from WorldClim provided with DIVA - GIS. The species namely *Juniperus procera, Podocarpus falcatus, Pouteria adolfifriederici* and *Lobelia rhynchopetalum*were modelled using species observed from Dry evergreen Afromontane forest and grassland complex (DAF), Moist evergreen Afromontane forest (MAF) , and Afroalpine belt (AA). The distribution models were presented in the form of distribution map. The map uses the full colour code such as red for areas with high suitability; orange for areas with suitability; (yellow) suitable areas; (pale green) areas with moderate suitability; (dark green): areas with relatively low suitability; no colouring indicted areas were not suitable for the respected species.

Tewodros Wakie et al. (2014) have performed mapping of the current and potential distribution of non-native *Prosopis juliflora* in the Afar region of Ethiopia. During their modelling, one hundred forty three species-occurrence points were used. The model had indicated that the extent of *P. juliflora* invasion was estimated to cover 3,605 km^2 in the Afar region and 5,024 km^2 as the potential habitat for future invasions. The same authors have also demonstrated the possibility of using time series of MODIS vegetation indices, species occurrence points and climatic variables with MaxEnt modelling software to map the current and future distribution of species in Ethiopia (Tewodros Wakie et al., 2014).

Luizza et al. (2016) have attempted to integrate local pastoral knowledge, participatory mapping, and species distribution modelling for risk assessment of invasive rubber vine (*Cryptostegia grandiflora*) in Ethiopia's Afar region. The used inputs data were species occurrence points, MODIS-derived vegetation indices, topographic and anthropogenic variables processed with MaxEnt. The model revealed that the rubber vine poses a growing threat to Afar along with the future potential suitable habitat in the middle Awash River basin that extends downstream out of its current known location (Luizza et al., 2016). The same authors have also established the role of participating local communities for early detection of recently established invasive species while doing surveying in the area.

Meron Awoke (2017) has tried to model the distribution of wild and cultivated *Ensete ventricosum* in Ethiopia. The author has recommended that analysing the spatial distribution of species at spatial and temporal scale is indispensable for the planning of conservation and management activities implemented in the area (Meron Awoke, 2017).

2.6.3 Reasons for selecting a species to be model

Form the reviewed literature so far, the reason why a certain species was studied in its distribution using modelling was found to be various. The study species were selected depending the nature of the study.

Hagenia abyssinica is a wind-pollinated and wind-dispersed dioecious tree species that belongs to a monotypic genus in the Rosaceae family (Hedberg 1989). Flowering and seeding are observed all over the year with a break in the months with the coldest temperatures (Orwa et al., 2009). It is one of the endangered tree species in Ethiopia due to overexploitation and the Forestry Law prohibits the utilization of the species (FDRE, 1994).

Taye Bekele's chloroplast DNA haplotype diversity and postglacial recolonization of *Hagenia abyssinica* analysis showed that *Hagenia* recolonized Ethiopia from the south during the late Pleistocene and became abundant in the southern regions. Hence, the trends of postglacial recolonization of the species were first in the south and later expanded to north Ethiopia. Currently, the extant *Hagenia* populations are situated at higher altitudes, often in wetter depressions (Taye Bekele et al., 2009).

H. abyssinica is confined to Africa and its ecological range stretches from Ethiopia in the North to Zimbabwe (Orwa et al., 2009). It is native to Ethiopia and found between 2450-3250 masl, in the vegetation region of Ethiopia. The species is also native to Sudan, Uganda, Kenya, Tanzania, Central African Republic, Zimbabwe and Malawi (Hedberg, 1989), and exotic to India (Orwa et al., 2009). Its altitudinal range lies between 1800 and 3400m but it is normally absent from Afromontane rain forest and the taller types of undifferentiated montane forest (White, 1983).

According to Huggett (1998), five kinds of species appear to be most at risk under the effect of climate change; (1) peripheral species, a species range are vulnerable to extinction; (2) geographically localized species; (3) poor dispersers; (4) highly specialized species; and (5) climatically sensitive species, include wetlands, montane and alpine biomes, Arctic biomes, and coastal biomes.

Very little was found in the literature related to clarifying the question of what are the current and likely future distributions of *Hagenia abyssinica.* However, the evidence obtained from pollen records has suggested that the species has shifted its natural range during postglacial recolonization.

Following criteria of Huggett (1998), *Hagenia abyssinica* can be categorized as a species appear to be most at risk due to climate change. This is because the species is geographically localised, endangered and climatically sensitive species so that modelling the distribution of under climate change is indispensable.

2.7 Forest Development Efforts & Forest Management Schemes of the study forest

The forest of Yegof was the enclosure of Emperor Lebna Dengel's palace during sixteenth century (Baharu Zewude, 1998). and later in mid nineteenth century Queen Werqit of Wollo, an opponent of Emperor Tewodros, used the summit as her stronghold (Pankhurst, 2001). Armed guards those were posted there from the time of Menilek and of the imposition of fines as high as 50 Maria Theresa for unauthorized cuttings (Baharu Zewude, 1998).

The Forest has experienced a long history of deforestation starting about 2450 BP (Hurni, 1988), and 500 BC (Darbyshire et al., 2003) indicates a long history of anthropogenic impact. Correspondingly, the Soil Organic Carbon (SOC) isotope evidence was consistent with those historical documents, which suggest that long-lasting anthropogenic forest disturbances have occurred in the areas around Mt. Yegof (Zewdu Eshetu, 2002).

The natural pre-disturbance vegetation of the area is Podocarpus-Juniperus forest, which was cleared at about 500 BC, at about the time of immigration of Semitic peoples (Darbyshire et al., 2003), according to the compiled evidence of Chojnacki (1963), some travellers not only noted the fact of deforestation but also discovered the cause of it. For example, Du Bourg de Bozas, Chief of French expedition in 1901 argued that, “The Abyssinians are enthusiastic consumers of wood.” The traditional way of farming was a great enemy to vegetation in general and forests in particular (Chojnacki, 1963).

Open access situation aggravated the deforestation of vegetation in the area. During Italian period, a saw mill to exploit Yegof was installed (Baharu Zewude, 1998). with a pulley system to bring logs down from the top of the mountain (Pankhurst, 2001). Large tracts of slope land were cleared off their forest cover and turned into farm land, place with the encouragement or tacit approval of the occupation authorities (Dessalegn Rahmato, 1991)

After the restoration , neither the central government nor the provincial administration was able to establish effective control over the forests in the province, and encroachments continued (Dessalegn Rahmato, 1991); recurrent droughts on one hand, for example in the year 1965-66 known as the Wag-Lasta famine, resulted thousands to hungry and these destitute people sought access to forest products as a survival measure (Dessalegn Rahmato, 1991) and fire hazards occurred, in the 1950s; 1960s; 1970s and 1984 were frequently cited as major factors contributing much for the attack and damage of the forest resources in the area (Dessalegn Rahmato, 1991).

Yegof was declared as a state forest in 1965 and some limited planting practiced prior to the 1974 revolution (Pankhurst, 2001), but the declaration of the forest to be a state property had shifted the responsibilities of managing the forest from the community to the government (Chala Dechassa, 2015). State forestry under the *Derge* posed a threat to peasant livelihoods; it encroached on farm land, evicted house-holds living in and near it, and took away land that was customarily used for grazing and the delimitation of the forest area had resulted in conflict of interests between the state forest and the local people (Pankhurst, 2001).

In 1972, US surplus food was made available to pay for tree planting activities in the area (Dessalegn Rahmato, 1991, 1998). The Ministry of Agriculture in Addis instructed its office in Wollo to re-plant “mountain areas” that were under state ownership in July 1967. Nearly three years before, Mammo Seyoum had launched his afforestation program (Dessalegn Rahmato, 1998). For instance, Harego forest was protected in 1968/69 and then, the afforestation program was followed soon after that. In 1973/74 alone, 143,382 labourers were said to have been employed on a food-for-work basis to plant an estimated number of 600,000 trees (Baharu Zewude, 1998).

The 1985 famine that occurred during *Derge's* regime is believed to raise awareness in the role of afforestation so as to reverse the situation and those afforestation operations imposed from officials without discussing with the local people caused conflict and mistrust between the government and the local community and the problem remained most salient (Dessalegn Rahmato, 1991). A number of factors were at work. The expansion of the town especially the textile factory from below, the delimitation of the forest from above in 1986, and the forced withdrawal of people living on the slopes to resettle in lowlands in accordance of the villagization program of the time were the most salient (Pankhurst, 2001).

Yegof forest was designated as a National Forest Priority Area (NFPA) in 1985/86 by the then State Forest Development and Conservation Department of the Ministry of Agriculture (EFAP, 1994). The available records on the size and date of establishment were very contradictory, for example: according to Tesfaye Bekele (2005), Yegof forest had an area of 18,000 ha and was protected in 1973 by the then Ministry of

Agriculture. The figure was disjointed with Young (2012), the forest had an area of 67 ha, comprises 6 compartments and it was established in a year 1971.

According to Young (2012), the compartments were referred as: Yegof (a) comprises an area of 10 ha of forest land, Yegof (b) having an area of 4 ha, Yegof (c) with an area of 38 ha, Yegof (d) holds an area of 1 ha of forest land, Yegof (e) with an area of 0.15 ha and Yegof (f) an area of 15 ha. Generally, the forest doesn't have a clear demarcation on the ground till the present date (Young, 2012).

Thus, unclear demarcation of the forest resulted from open access situation. In which, the forest faced severe disturbance from grazing animals, illegal cuttings of trees for construction, timber and fuelwood collection (Pankhurst, 2001). Consequently, the most valuable indigenous tree species as well as wild animals have been severely affected in the area.

Reforestation in general and co-implemented, erection of an industry in particular had reduced rural landholdings of the local communities. Those interventions had given rise to conflicted interest with local community. One peasant near Kombolcha town complained: "The forest from above and the town from below are pressing hard on us" (Baharu Zewude, 1998). With such prevalent situations, employing guards and establishing checkpoints were found to be ineffective in halting the severe deforestation practiced so far and this disturbance of Yegof forest is continued currently regardless of the 35 guards assigned to protect the forest (Pankhurst, 2001).

During final year of the *Derge* and the transition period, due to the lack of restrictive legal measures by then, sale of wood from state/community forests was found to be a major survival strategy for those engaged in illegal cutting of forest products. This is believed to cause a massive destruction of the forest resources of the area. Poor peasants encroached on forests and grazing areas, and returnees and returnees were participating in illegal cuttings of wood for sale to urban areas (Pankhurst, 2001). Extraction of wood for construction and fuelling purpose is still prevalent.

The policy shift that was made by the transitional government of Ethiopia soon after the fall of the military regime in 1991 encouraged the private sector to invest in the forest sector, but also significantly increased the free uncontrolled exploitation of forests in Yegof (Baharu Zewude, 1998; Chala Dechassa, 2015). The rate of deforestation in Yegof forest was further aggravated by the deployment of large number of *Derge's* army in the area and the soldiers were cutting trees without requesting permission from the concerned government authorities to use as source of fuelwood for their camps and selling forest products for urban dwellers (Baharu Zewude, 1998; Pankhurst, 2001). Moreover, the nearby peasants were involved in the deforestation process paralleled with the soldiers during this period (Dessalegn Rahmato, 1998).

The Amhara National Regional State Forestry Enterprise has obtained the managerial and use rights of Yegof forest under Regulation No. 70/2009 from the regional government. Pursuant with this regulation, the enterprise has the following duties and responsibilities: (1) to accelerate the economic and social development of the region by extensively developing and producing forest and forest products as well as by increasing value to same; (2) to reduce the level of unemployment and thereby ensure sustainable gains of the regional community by creating wider job opportunities; (3)

to narrow the ever growing gap between supply and demand in wood and wood product at regional as well as national levels; and (4) to enhance foreign exchange capacity by producing forest and forest products, with an increasing value, exporting same and substituting the imported ones (ANRS, 2009).

From the aforementioned objectives of its establishment, one can easily understand that generating economic return remains the top priority for the enterprise than maintaining the existing biodiversity. The essences of the establishment of the enterprise seems only for the attainment of financial profit with harvesting the already established forest products without giving due attention for conserving the biodiversity. With this trend, further degradation of the forest resources eventually is inevitable.

CHAPTER THREE

3 MATERIAL AND METHODS

This chapter presents description of the study area, sampling design, methods of data collection and analysis.

3.1 Description of the Study Area

3.1.1 Location and topography

This study was carried out in Yegof forest and forest patches in its surrounding in South Wollo. It is in the North East part of Ethiopia. The site is located between 110 01' to 110 03' North latitude and 390 4' to 390 44' East longitude with an elevation between 1500 and 3014 masl. The map of the study area is shown in Figure 3.1.

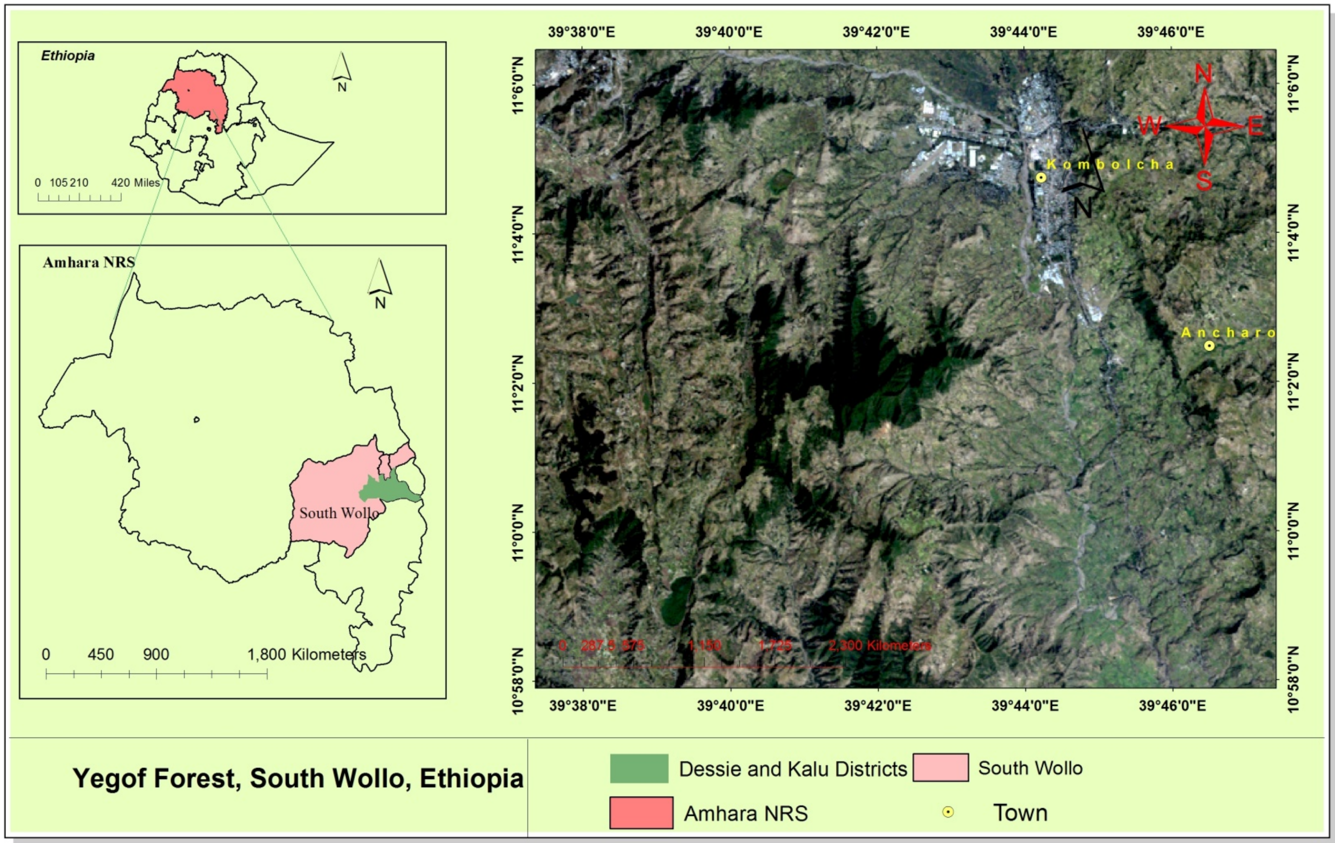


Figure 3.1 Map of the study area, Yegof forest and its surrounding patches, South Wollo, Ethiopia

3.1.2 Climate

The rainfall pattern of the area is influenced by two rain bearing wind systems: one conveying the westerly winds from the South Atlantic, and the other bringing the easterly winds from the Indian Ocean and from the Arabian Sea (Sebsebe Demissew, 2010).

In the study area, distinctly bimodal rainfall patterns are observed (Figure 3.2). The longer rainy season extends from June to September, which supports the major crop production. The shorter rainy season comes in March and April and allows minor crop production.

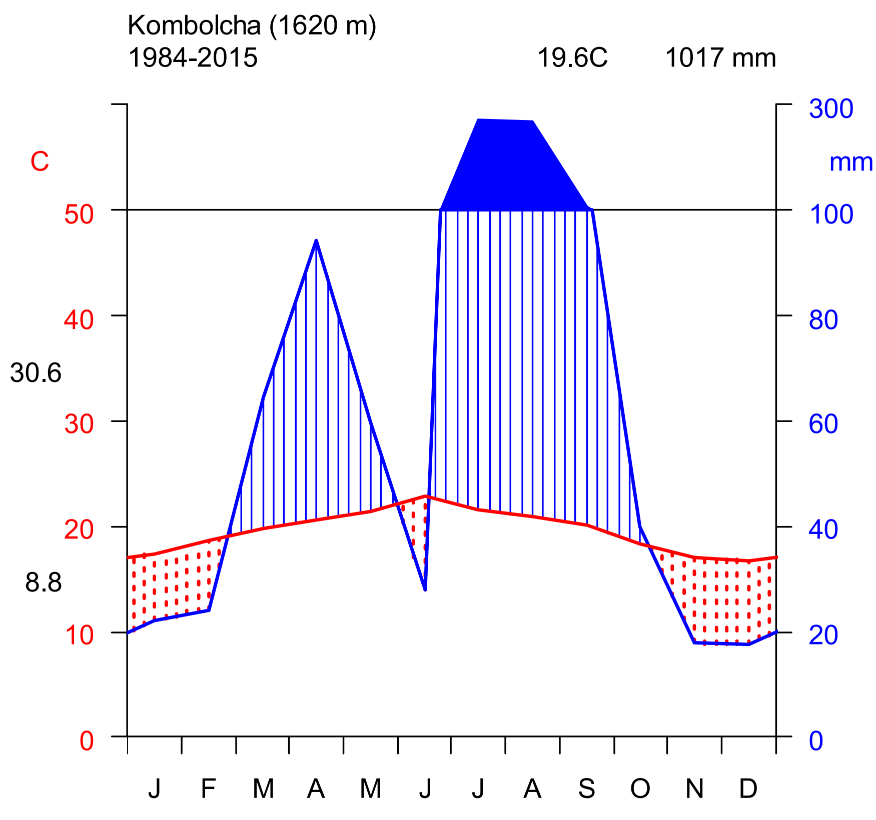


Figure 3.2 Climate diagram based on data from Komblcha Meteorological Station

Most of South Wollo highland farmers are *Belg* dependent, relying on the shorter *Belg* rains (March-April) for cultivation rather than the longer *Keremt* season due to fear of frost attack occurring recurrently in highland areas during this long rainy season(August- October), (Calow et al., 2000).

Mean annual temperature of 19.6 ^{0}C and annual rainfall of 1017 mm have been recorded over the years 1984-2015 at Kombolcha Meteorological Station, which is situated 2 km away from Yegof Forest. The annual minimum and maximum temperatures of the area are 8.8 ^{0}C and 30.6 ^{0}C, respectively (Figure 3.2).

3.1.3 Geology and soil

Relatively young volcanic rocks feature South Wollo. These were formed in three phases of activity during Palaeogene and Quaternary times, associated with the opening of the East African rift valley. These events gave rise to a thick, complex sequence of lava flows, sheet basalts, and pyroclastic rocks such as agglomerate and ash. Thick basalt lava flows are interbedded with ash layers and palaeosoils. The volcanic rocks are exposed in the highland areas. In the valleys and plains; however, the volcanic rocks are often overlain by unconsolidated sediments (Calow et al., 2000).

The region is characterized by high plateaus dissected by river basins of various sizes creating a rugged topography with bare rocks and boulders. An escarpment forms the edge of the highlands massif. The escarpment is dissected by deep valleys, which lead down to the lowland plains of the Awash valley (Calow et al., 2000). The largest perennial river around the study area is Borkena, flowing to the Awash River.

The soils, especially on steep slopes, are characterized by shallow depths with many boulders and rock outcrops (Kebrom Tekle et al., 1997). The dominant soil group of the area is Leptosols. The area is classified under the following soil units namely: Lithic Leptosols, Eutric Leptosols and Eutric Cambisols (Verelst and Wiberg, 2012). The major soil type in the study area is loam and sandy loam (Kebrom Tekle et al., 1997). The soil pH ranges from 6.0 to 7.26 and the texture varies from loam to clay loam with textural compositions of 19-28% (clay), 32-41% (silt), and 27-46% (sand) (Zewdu Eshetu, 2002).

3.1.4 Population and socio-economic activities

According to the Central Statistical Agency (2007), South Wollo has a total population of 2,518,862, with an increase of 18.60% over the 1994 census (CSA, 1998), of which 1,248,698 are men and 1,270,164 women. The largest ethnic group reported in South Wollo was the Amhara (99.33 %); all other ethnic groups made up 0.67% of the population. Amharic is spoken as a first language by 98.65%; the remaining ethnic group 1.35% spoke all other primary languages. With regards to religions, 70.89% were Muslims, and 28.8% of the population known to be followers of Ethiopian Orthodox Christianity (CSA, 2007).

Despite the very low resource and productivity levels, accompanied with high risks, crop production remains the largest single income source for rural households in South Wollo (Devereux and Sharp, 2006). Peasants have a good knowledge of seed varieties and kept as many different types in store as they can; this enabled them to quickly adjust their seeding plans in response to changes in the weather (Dessalegn Rahmato, 1991).

The commonly cultivated crops growing in the study area are- *Hordeum vulgare*, Triticum spp., *Vicia faba*, *Pisum sativum,Cicer arietinum*, *Lathyrus sativus*, *Zea mays*, *Eragrostis tef*, *Guizotia abyssinica*, *Carthamus tinctorius*, Brassica spp., *Linum usitatissimum,* and *Solanum tuberosum* (Dessalegn Rahmato, 1991; Sebsebe Demissew, 1998).

3.1.5 Patterns of land use

The total land area in South Wollo is 1,773,681 hectares. The cultivated land area accounts for 39%, of the total area of South Wollo (CSA, 2007). Farms contain several types of fields: the home fields, which are plots close to the homestead, and the outfields, located 3 to 5 kilometres from the house (Shimeles Hailu, 2013).

Agricultural activities have been carried out on steep mountain slopes of Wollo since the inception of agriculture 2,000 -5,000 years ago until the present day. This resulted in extreme degradation of the area due to soil erosion (Hurni, 1988). Historical records in between 1937 and 1997 had testified the occurrence of a significant loss of bushes in the study area (Crummey, 1998).

3.1.6 Natural vegetation

The vegetation type is dry evergreen Afromontane forest and grassland. The floristic composition of part of Wollo as studied by Sebsebe Demissew (1998) includes the native tree species such *as Croton macrostachyus, Ekebergia capensis, Juniperus* *procera*, *Olea europaea* subsp. *cuspidata, and Olinia rochetiana*. In addition, shrubby species such as *Calpurnea aurea, Carissa edulis, Dodonaea angustiolia, Euclea schimperi,* and *Euphorbia candelabrum* are present in the vegetation. Grasses, mainly species of *Hyparrhenia* and *Pennisetum* are, common in the area.

3.2 Methods of Data Collection

3.2.1 Remote-sensing data types and sources

Remote-sensing data was collected at different spatial and temporal scales. For this study, satellite imageries were acquired from AAU FTP server, and downloaded from the United States Geological Survey (USGS) and Earth Resources Observation Systems (EROS) data centre under the Landsat archive.

Landsat MSS (1972-12-07), TM (1986-02-09), and ETM+ (2015-03-10) were used in this study (Table 3.1). The dates of all images were chosen to be as closely as possible in the same season.

Table 3.1 Characteristics of Landsat satellite imagery

Instrument	MSS	TM	ETM+
Landsat	Landsat 1	Landsat 5	Landsat 8
Acquisition date	1972-12-07	1986-02-09	2015-03-10
Path/raw	180/052	168/052	168/052
Spectral bands no.	2VS, 2NIR	2 VS, 2 NIR, MIR	(3VS, 1NIR, 2MIR), (2 SWIR), (2TIR), (1 Cirrus (OLI) (Panchromatic)
Ground resolution	57*57 m	30m*30 m	(30*30) ,(60),(15) m

Universal Transverse Mercator (UTM) geographic projection was used together with digitally converted and rectified topographical maps. Digital Elevation Model (DEM) of the study area, with 30 meter from the Shuttle Radar Topography Mission (SRTM) of NASA was obtained. This data helps to observe the relationship between topography, mainly altitude and slope for forest cover change by using version of ArcGIS and QGIS softwares (QGIS Project team, 2016).

The table below shows the general description of LULC (Table 3.2). The identification and classification of the LULC were monitored and the six LULC categories were identified

Table 3.2 General description of land cover

Land cover	General description
Forest	Areas covered by trees forming closed or nearly closed canopies; predominant species are *Juniperus procera, Olea europaea* subsp. *cuspidata* and plantation spp.
Shrub land	Land covered by small trees, bushes, and shrubs. Less dense than forests
Grassland	The land is basically covered by grass and herbaceous species.
Settlement	Land occupied by small and large buildings, roads, and factories.
Water body	Area covered by lake and streams
Agriculture land	Area that includes cultivated land, barren eroded land, open area near homesteads, and grazing areas.

3.2.2 Sampling design for the study of vascular plant diversity

Forest patch size (ha) was estimated using satellite image of 2010, ArcGIS - Version 10.3 (ESRI, 2015) and Google Maps Area Calculator software. Field data were collected from September to October, and April to May 2016. As one of the major objectives of this study was to compare species richness and diversity along gradients of altitude and different habitat types, a combination of stratified and systematic random sampling design was used to collect data on vegetation and environmental data.

Prior to the onset of formal vegetation data collection, sample size has been determined based on the results obtained from nested plots. Nested plots having an area of 10 m × 10 m, 10 m × 20 m, 20 m × 20 m, 20 m × 40 m, 40 m × 40 m, and 50 m × 50 m were tested, and cumulative species–area curve was constructed. Larger sized plots accumulated more species than smaller ones. Whereas, in ragged topographic areas, taking large sample size may be liable for sampling error. Therefore, vegetation data was collected within sample size of 20m*20m ($400m^2$).

In this study, combination of stratified and systematic random sampling design was employed to compare species richness and diversity along gradients of altitude and different habitat types. Sampling was conducted from a total of 28 transect and 164 quadrats. Out of this total, 55 sample plots were from Yegof, 20 from Erkis, 24 from Harbu, 20 from Suki, 45 from Harego, Biraro, and Abuli forests (Figure 3.3).

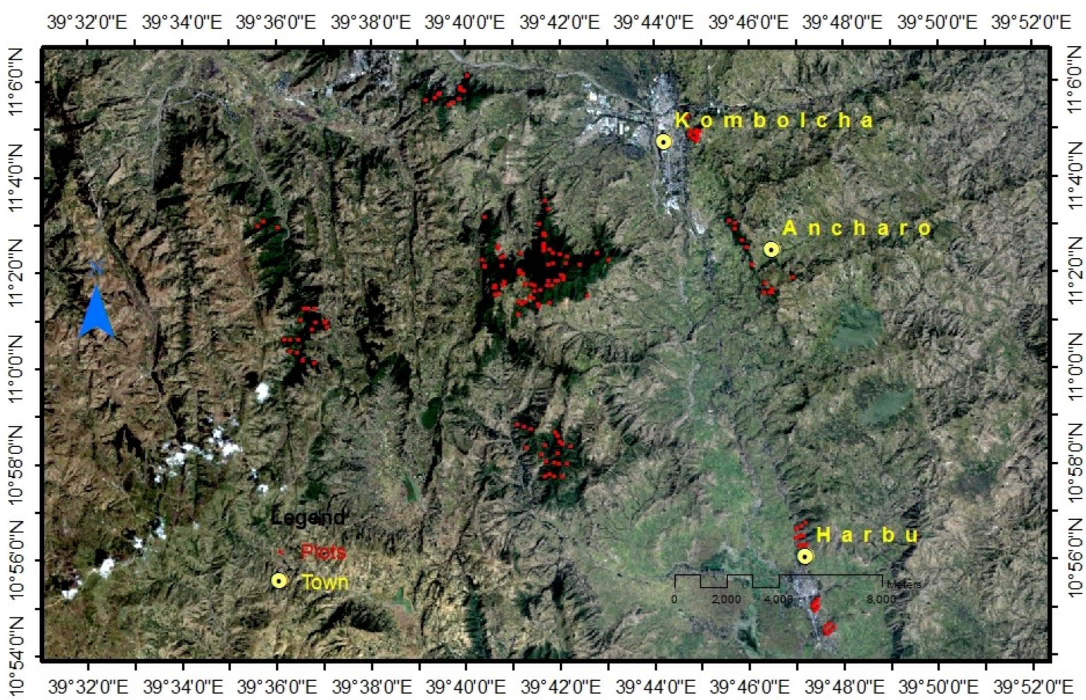


Figure 3.3 Spatial configuration of sampling plots in Yegof Forest and its surrounding patch forests. ● denote the positions of sample for vegetation sampling

The total sample area have an area of 6.56 ha, which out of the total forestland (314.7 ha) constituted a sampling intensity of one sample per approximately 49.17 hectares. Tree and shrub were enumerated in the sampled quadrats. Diameter was measured for all individual trees and shrubs having DBH (Diameter at Breast Height) greater than 2.5 cm. Individuals attaining 1m and above with DBH less than 2.5 cm were considered as saplings and these were counted. For seedling and sapling inventory, two sub quadrats of 2 m × 5 m at the beginning and at the end of the base line on opposite sides of the main quadrat was used. Herbaceous species were collected from five 1 m × 1 m sub-quadrats, four sub quadrats at the corner and one at the centre, within each 400m^2 quadrat. All individual plants were counted, and height and diameter at breast height (DBH) were recorded. The cover abundance of all vascular plants in each quadrat was visually estimated. Additional trees, shrubs, and herbaceous species outside sampling plots were collected and noted as present. Plants voucher specimens were collected, pressed, dried, identified and authenticated by reconfirming at the National Herbarium, Addis Ababa University and were deposited in the herbarium.

3.2.2.1 Environmental parameters for Vascular Plant Diversity

Many topographic factors influence the ecosystem. Among the influential factors Altitude, Aspect, Slope (Huggett, 1998), Landform, Topographic, Wetness Index (TWI), and 19 Bioclimatic and Windward and leeward of the are postulated to be tested.

Altitude was measured in metric unit and the slope in degrees. Aspect θ was transformed to a relative measure for heat load (HL, higher values indicate higher heat and water stress) using the equation $HL = [1-\cos(\theta)]/2$ (McCune and Keon, 2002). TRI of the study area was also calculated using Semi Automated Geoscientific Analyses (QGIS Project team, 2016).

Landform, (TPI) land classification helps the forester to identify the potential area for the establishments of forest resources in the area (Zawawi et al., 2014). Knowing landforms of an area helps to mapping of specific soil (Barka et al., 2011). Several digital elevation models can be used as input data for landform classification. In this study, ASTER GDEM (30 m resolution) projected and corrected, were used as input data. SAGA tools were used to compute topographic position index maps so as to produce landforms. There were nine classes of landform produced from elevation data. TPI map was produced having the values: 0 = Streams; 1 = Mid slope Drainages; 2= Upland Drainages; 3 = Valleys; 4 = Plains; 5 = Open slope; 6, Upper Slopes; 7= Local Ridges; 8= Mid slope Ridges; and 9 = High Ridges). TPI map was imported into ArcGIS. This tool helped to extract TPI value.

3.2.3 Data collection methods for socioeconomic survey

The data was collected using household interviews, key informant interviews, and group discussions.

Household interviews

Semi-structured questionnaires was prepared and then pre-tested before it was used to improve its clarity and checked for its accuracy enabling to collect the required data. It was translated into 'Amharic', the local language of the area in which the interview was conducted. Enumerators were recruited from the study area, and they were trained well before deployment.

Key informant interviews

A small group of respondents (usually 6-10 respondents) were interviewed together in a common location (Bhattacherjee, 2012). The key informants were older people and ritual leaders, who could remember and respond to past events regarding the forest status and land use change. The event calendar was established as a benchmark for comparison of conversion of the landscape over time.

Group discussions

Group discussion is an important technique to verify and refine the data that was acquired by structured interviews of household and key informants. Participants were farmer, Kebele officials, development agents, experts, and officials in the area. The discussion was carried out using checklists.

3.2.3.1 Sampling strategy for Human-forest interactions study

For this study, stratified sampling strategy was used; a representative sample was selected from the target population. The target populations were individuals residing in or adjacent to the forest patches. To cover locals' difference due to distance from Yegof forest, satellite images from Goggle earth pro was used to identify rural houses. In the image, buffer maps were applied to stratify the faire classification of the target population into three strata. Hence, individuals close to forest edges (1 km), mid distance (1–2 km), and far from forest edges (2–3 km) were delineated.

From each stratum, residents were selected using simple random sampling method. To avoid misplacement of an individual with respect to distance categories, GPS was used as a tool to validate the presence of an individual belonging to the respected strata. The sample respondents were then taken at certain uniform intervals from the prepared alphabetical list of the whole household heads living in each stratum.

3.2.3.2 Sample size determination for Human-forest interactions study

The data used for this study was collected both from primary and secondary sources. The primary data was obtained from the sample household's habituated in or adjacent to forest patches. Target populations were established on the bases of distance of their village from the forest boundary. At the end of the preliminary survey, 1046 households were identified as total population. The sample size was then determined using the following formula (Kothari, 2004).

$$n = \frac{z^2 * p * q * N}{e^2 (N-1) + Z^2 * p * q} \quad \text{.......................................Equation 1}$$

Where, n= sample size; N=size of population (1046) and e= desired significance level (0.05).

Two hundred eighty one households were taken as sample household. The number of households from each stratum was allotted using proportionate allocation procedures. Thus, using proportional allocation, the sample sizes for the different strata were 80,124 and 77, respectively, proportional to the sizes of the strata via, 298:461:287 (Table 3.3).

Table 3.3 Characteristics of the sample villages in and around Yegof Forest

Study village	Position in the Forest	Total No. of households	Sample Size
Yegof, Albati and Aba-Abdi Ager	Near to the forest (>1 km)	298	80
Mentera and Bekimos	Medium (1-2 km)	461	124
Ararot genda and Titmeda	Far from the forest (2-3 km)	287	77
		1046	281

3.2.4 Data sources for modelling of *Hagenia abyssinica*

3.2.4.1 Occurrence data

Hagenia abyssinica occurrence data was obtained from the standardized ecological sample surveys in Yegof and its surrounding patch forests and national herbarium records. Additional data was also obtained from Taye Bekele et al., (2009) entitled with Chloroplast DNA haplotype diversity and postglacial recolonization of *Hagenia abyssinica* (Bruce) J.F. Gmel. in Ethiopia (with permission).

3.2.4.2 Environmental variables

The environmental variables used for this species distribution modelling are bioclimatic, including-, soil, elevation, and land cover map of Ethiopia. Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables (Phillips, 2010), that are more directly related to the physiologic aspects of plant growth, but do not consider the timing when a particular state occurs (Scheldeman and Zonneveld, 2010). These variables represent the annual trends (mean annual temperature, annual precipitation) seasonality (annual range in temperature and precipitation) and extreme or limiting environmental factors (temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year).

Current climatic data was obtained from WorldClim 1.4 database at 1 km spatial resolution. This database consists of a set of minimum temperature (^{o}c * 10), maximum temperature (^{o}c * 10); and average temperature (^{o}c * 10). The unit used for the precipitation data is mm (milli meter). The 19 global climatic layers were generated by the interpolation of global climatic data such as average and seasonal temperature and precipitation records from 1960 to 2000. The projection, grid cell size and alignment and spatial extent were consistent across all layers (Elith et al., 2006). The bioclimatic variables and their descriptions are given in Table 3.4.

Table 3.4 Bioclimatic variables code and their description

Code	Description of Bioclimatic Variables
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Soil and land cover

There are ample published studies describing the effect of chemical and physical nature of the soil on the distribution of species. Soil has a direct effect on species distribution (Franklin, 2010). Soil data was obtained from the global soil database using the following port: http://www.grid.unep.ch/data/data.

The soil from this database has been commonly used for species distribution modelling (Pearson, 2010). Four soil data sets from the database were found zipped together along with the complete version of the soil units with 106 soil classes; the dominant soil slopes with seven slope categories and the dominant soil textures with eight texture categories, and the dominant soil phases with 18 phase categories. The raster image files are stored in binary format to be directly be read or imported into image analysis software.

3.2.4.3 Future climate data

The assessment of the impact of climate change on the species distributions usually involves detecting changes in species distribution by comparing the potential distribution areas in the current climate conditions with the future potential distribution areas based on a species' current climate preferences and future climatic conditions (Scheldeman and Zonneveld, 2010).

For this study, the future climate data was obtained from IPPC5 (CMIP5) at 30 seconds (1km) spatial resolution (WorldClim .org. /cmip5_30s). The climate data was projected from GCMs, downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current climate'. rcp45 green gas scenarios. Then, the future climatic condition, 2070 (averaged for 2061-2080), was used for modelling the impact of climate change on species' distribution.

3.3 Data Analysis

3.3.1 Image processes

3.3.1.1 Pre-Image processes

Before the actual image classification process, pre-processing was performed using QGIS image analysis software (Congedo, 2016). Pre-processing helps to improve images for a particular application. It was commonly comprises a series of sequential operations, including atmospheric correction or normalization, image registration, geometric correction, and masking (Haines-Young et al., 1993). Therefore, for this study, calibration and atmospheric correction was performed.

Calibration of images adjusts the images by converting raw radiance values of each pixel to top-of-atmosphere absolute reflectance values. Land sat images from DN (i.e. Digital Numbers) to the physical measure of Top of Atmosphere reflectance (TOA), or the application of a simple atmospheric correction using the DOS method (Dark Object Subtraction), which is an image-based technique, was performed. Image calibration of the Landsat (MSS, TM, and ETM^+) was accomplished through Semi-Automatic Classification Plugin within the QGIS interface (Congedo, 2016; Thiede et al., 2016).

Atmospheric correction then adjusts these values to ground reflectance at each pixel based on sun-ground-sensor geometry and atmospheric composition using semi-automatic classification plug in QGIS (Congedo, 2016; QGIS Project team, 2016).

Layer stacking, band set, image registration was performed in QGIS, before the actual image classification process. All four bands of MSS and six bands of TM and ETM^+, excluding the thermal band, were included during image pre-processing.

3.3.1.2 Image classification

Image classification is the process of sorting pixels into a finite number of individual classes, or categories of data based on their data file values. If a pixel satisfies a certain set of criteria, then the pixel was assigned to the class that corresponds to those criteria (Haines-Young et al., 1993). The two major types of classification function applied to remotely sensed data, namely unsupervised, and supervised.

A Semi-Automatic Classification (also supervised classification) was used in this study. This helped for the identification of object in an image, according to their spectral signatures (Congedo, 2016).

During the preliminary field visit, the various land cover classes were taken by systematic sampling using GARMIN 76 GPS devise. These samples were used as representative signatures for the various land cover types.

The ETM 2015 satellite image was classified by using maximum likelihood supervised classification schemes. Pixels are assigned to the class in which they have the highest probability of being a member. The sample-training signature was prepared from the ground control points (GCPs) collected for the ETM 2015 image.

For Landsat TM 1972 and ETM 1986 images, visual observation of the False Colour Composition (FCC) and , True Colour composite (TCC) of Landsat image and the spectral information of the known land cover categories were observed from classified image of the year 2015. Supervised classifications require the user to select one or more Regions of Interest (ROIs, also Training Areas) for each land cover class identified in the image. ROIs are polygons drawn over homogeneous areas of the image that overlay pixels belonging to the same land cover class.

In this study, training area creation was made using the Region Growing Algorithm in SCP (Semi-Automatic Classification Plugin). It used to select pixels similar to a seed one, considering the spectral similarity (i.e. spectral distance) of adjacent pixels.

3.3.1.3 Classification accuracy assessment

An analysis of the literature reviewed indicates that different methods of change detection produce different maps of cover change. An accuracy assessment was performed for any classified images using (Singh, 1989). Error matrix is the most common way to present the accuracy of the classification results (Congalton, 1991). Moreover, overall accuracy, user's accuracy, producer's accuracy, and Kappa statistic were used and derived in SAP (Congedo, 2016). Kappa is a measure of categorical agreement that describes the difference between the observed agreement and chance agreement (Franklin, 2010). Therefore, in this study, accuracy assessment methods were used to estimate the accuracy of supervised LULC image classification of the study area.

3.3.1.4 Change detection

In his review of digital change detection techniques using remotely sensed data, Singh (2010) indicates that different methods of change detection produce different maps of cover change. The majority of digital change detection techniques depend critically upon the accuracy of geometric registration of two images. In the case of mis-registration, a number of false alarms, especially in the region of rapid intensity change such as edges, occur. Precise geometric registration of images is often difficult to achieve due to lack of accurate ground control points.

In order to derive LULC change analysis effectively, new approaches namely MLUSCE refers to Modules for Land Use Change Evaluation was used. The plugin was designed to analyse, model and simulate land use changes. MOLUSCE incorporates well-known algorithms, which can be used in LULC change analysis, urban analysis as well as forestry applications risk of deforestation; and simulate future land use/cover and forest cover changes (Gismondi et al., 2014). Therefore, the LULC change information (the initial and final LULC maps) and the spatial variables: slope and elevation were loaded in MOLUSCE plugin for QGIS 2.18.0. LULC area changes and transition probabilities were computed. LULC change map were produced. The land LULC area unit was expressed in square kilometres and hectares (ha).

3.3.2 Analysis of forest fragmentation

The output of sub-project- I, classified images was used as input for present study which deals with the forest fragmentation of the area. FRAGSTAT V.4.2 was used for spatial pattern analysis (Mcgarigal and Ene, 2013). In line with the procedures of FRAGSTAT, the classified LULC map were converted into grid form and data further configured in a way appropriate to be imported to FRAGSTAT V.4.2

An eight-neighbourhood criterion for the definition of patches was used. FRAGSTATS allows the user to define a specific edge depth - a distance from the surrounding matrix into the forest interior beyond which is the core area. Therefore, 30-meter edge influence was chosen (Mcgarigal and Ene, 2013).

The set of ten metrics: Class Area, Number of Patch, Percentage of Landscape, Largest Patch Index, Edge Density, Area Mean, Total Core Area, Euclidean Nearest-Neighbor Distance, and Interspersion and Juxtaposition Index were used.

3.3.3 Vegetation data analysis

3.3.3.1 Software Packages

Depending on the nature of the data, for this study, different software package were employed. Data entry and simple arithmetic calculations were conducted using Excel 2010, XLSTAT Version 2014.5.03(Addinsoft team, 2014), Biodiversity Professional statistics analysis software (McAleece et al., 1997) and R statistical software version 3.4.2 (R Core Team, 2017) was used for diversity analysis. R statistical software was used for cluster analysis, for computation of coefficient of correlation and analysis of variance (ANOVA). For hypothesis testing, lower probability (P-value) at 0 .05, the common in biology, was used (Dytham, 2011).

The relation between plant species diversity and environmental conditions was also evaluated based on multivariate analysis using R software (R Core Team, 2017). The appropriate analysis technique was designated based on the nature of the input data following Legendre and Legendre (1998).

3.3.3.2 Plant Community Analysis

One of the most basic steps in vegetation analysis is classification of community types. It is the process of grouping similar entities together into classes based on selected shared characteristics (Schulz et al., 2009).

The choice of the method was made with precaution since it might influence the results drastically. The similarity between groups is generally greater in complete-linkage than in single-linkage, and intermediate in average-linkage (Wildi, 2010). Hence, some linkage functions are sensitive to outliers, absolute abundance, and distributions of the species.

Plant communities were identified through multivariate hierarchical clustering using R- software (version 3.4.2). To determine the optimal number of groups in the cluster analysis, different classification methods were used. Then, plant communities were identified using Hierarchical clustering method using similarlty ratio, ward-clustering algorithms. Ward produces nicely compact community (Zerihun Woldu, 2017).

Validation of the community was preformed using the package called “clv” in R software. The intra-cluster and inter-community distances was performed. This function helps to deduce about the cohesiveness or dispersion as well the relative proximity of community to each other.

3.3.3.3 Investigating Environmental

The relation between plant species diversity and environmental variables was evaluated based on multivariate analysis using R - software. The multivariate analysis included 164 sampling plots, species, and environmental variables. The appropriate analysis method was selected based on the nature of the input data (Legendre and Legendre, 1998) and also using rule to decide whether to use unimodal or linear method based on the length of the first DCA axis (Lepš and Šmilauer, 1999).

In this study, the association between the environmental data and the species composition were first tested using unconstrained ordination and then, regression of ordination axes were calculated on the measured environmental variables. Unconstrained ordination should only be used as a priori constraints because significant tests can lead to misleading choices (Zerihun Woldu, 2017).

Direct gradient analysis and indirect gradient analysis were performed using R - Software. These investigations help us to determine the relationship between floristic composition and environmental variables.

The variables were fitted into ordination scatter plots to explore the relationship among environmental variables and the vegetation data. The use of function envfit in vegan (R software) was used to calculate multiple regression of environmental variable with ordination axes (environmental variable used as dependent and selected ordination axes as independent variables (Legendre and Legendre, 1998).

3.3.3.4 Diversity Analysis

In this study, Simpson's index (D), Shannon, and Wiener Diversity Index, and Wilson and Shmida's β diversity index were used.

Shannon and Wiener Diversity indices are the most widely used measures of diversity indices. The index was calculated using from the equation-4

$$H' = -\sum P_i \; ln \; P_i \text{..} \text{ Equation 2}$$

Where "H" is the Shannon and Wiener diversity index, "Pi" is the ratio of a species average to the total species average, "ln" the natural logarism to base e (loge) (Magurran, 2005).

Beta diversity is a measure of species heterogeneity across a population, and an index of the number of distinct communities present in the sample (Schulz et al., 2009). Vegetation data with no specific gradient, Whittaker was used an appropriate measure of beta diversity as

$$\boldsymbol{\beta_w = \left(\frac{S}{S_c}\right) - 1} \text{..} \text{ Equation 3}$$

Where, Sc is the average number of species in the composite sample (the number of species in the whole data set), and S is the average species richness in the sample units.

While this measure does not have any formal units, values of $\beta_w < 1$ are rather low and $\beta_w > 5$ can be considered as high.

Wilson and Shmida's β diversity index (βT);

$$\boldsymbol{\beta_T} = \left(\frac{b+c}{2a+b+c}\right) \text{...Equation 4}$$

Where, β_T is Wilson and Shmida's beta diversity, a is total number of species that occur in both communities, "b" is the total number of species in the second community but not in the focal one, and "c" is the number of species in the local community but not in the second one.

Equation 5 was used to evaluate the similarity of plant communities between different vegetation categories, and equation 6 was used to evaluate the species diversity and species richness due to gradient change in altitude.

Simpson's index (D): gave the probability of any two individuals drawn at random from an infinitely large community belonging to different species as:

$$\mathbf{D} = \sum P_i^{\,2} \text{...................................... Equation 5}$$

Where, Pi = the proportion of individuals in the i^{th} species.

As D increases, diversity decreases and Simpson's index is therefore usually expressed as l-D or l/D. Simpson's index is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness (Magurran, 2005).

3.3.3.5 *Structural Data Analysis*

The data obtained from diameter at breast height and height of the plant was used for horizontal and vertical structure analysis. The horizontal structure is expressed in terms of species frequency, density, dominance, and IVI values.

Basal area of tree species with >10 cm DBH was calculated as follows (Kent and Coker, 1992)

$$\boldsymbol{Basalarea = \sum \frac{\pi d^2}{4}}$$ …………………………………………… Equation 6

Relative density, relative frequency, and relative dominance were also computed using the following formula:

Relative density (RD) of a species = (Number of individuals of a species/ Number of individuals of all species)*100;

Relative frequency (RF) of species = (Number of plots in which a species occurred/ Total number of occurring species)*100

Relative dominance (RDO) = (Total basal area of a species/ Total basal area of all species)*100

The importance value index (IVI) was calculated after (Kent and Coker, 1992) as follows

$$\boldsymbol{IVI = RD + RF + RD}$$ ……………………………..........................Equation 7

3.3.4 Data management and analysis of Human-forest interactions study

The quantitative data obtained from the formal survey was analysed using Statistical Package for Social Sciences (SPSS) version -20. Descriptive statistics were used to summarize key variables, and inferential statistics to analyse the relationships among these variables. In addition, the Multinomial Logit (MNL) model was employed to explain the preferences of forest management options among the households. It focused on the probability to choose one of the J categories knowing some explanatory variables. In this research, the dependent variable, forest management, was a nominal variable with three different options (forest harvesting employing clear-cutting, conservation and afforestation prior to harvesting).

The analytical expression of the model is shown as follows:

$$\log\left(\frac{p(y=j/x_i)}{p(y=1/x_i)}\right) = \alpha_i + \beta_j X_I \qquad \text{.. Equation 8}$$

Where, the category 1 is called the reference or control category, clear-cutting was used the reference in this study. All obtained parameters have to be interpreted relative to this reference category.

The two options (conservation and afforestation prior to harvesting) were compared against the reference category, which was used by forest enterprise in the area. Likewise, the reference category was specified for the two categorical dependent variables. By describing the different attributes of the respondents, the model helps to choice the determinant of farmer's decision on forest management option.

3.3.5 Species distribution model

3.3.5.1 Model Building

For this study, the MaxEnt V 3.2.0 (Phillips et al., 2017) was used to run species distribution model. Model was built in accordance with the procedure used by Phillips (2017). Species occurrence and environmental variable files were prepared in a way to be imported and processed into MaxEnt software. A file containing presence localities, a directory containing environmental variables, and an output directory were supplied to perform the model run (Phillips, 2017).

75% of the occurrence localities selected randomly was used as training data and the remaining 25% reserved for testing the validity of the models. This training data was prepared by adapting the procedure used by (Phillips et al., 2006). This enabled the user to assess the average behaviour of the algorithms and allowed statistical testing of the observed differences in performance. Duplicate presence points in one raster cell were removed from the analysis to reduce sampling bias (Scheldeman and van Zonneveld, 2010).

3.3.5.2 Model Evaluation

In order to test the predictive performance of a model, it is necessary to have data against which the model predictions can be compared. This can be done simply by testing the ability of the model to predict the calibration data (Merow et al., 2013). However, this approach makes it difficult to identify models that have over-fit with the calibration data (Pearson, 2010).

According to Elith et al. (2011), using the same data to calibrate and evaluate SDMs tends results in over-estimation of the predictive performance of the model. Pearson (2010) has also advised to use test data which are different from the calibration data. Collecting new data is found to be non-feasible and, in such circumstances, partition of the data into portion to calibrate the model is recommended by Franklin (2010). Similarly, MaxEnt provides a number of options for cross-validation, where presence locations are usually split into training data which is used to fit the model, and test data is used to evaluate model predictions (Merow et al., 2013).

Pearson (2010) has summarized the methods of setting thresholds value for presence-only species data type using; fixed value. Thresholds were determined (an arbitrary fixed value for example taking 0.5 thresholds probability; lowest predicted value (the lowest predicted value corresponding with an observed occurrence record), fixed sensitivity (the threshold at which an arbitrary fixed sensitivity is reached (for example, 0.95, meaning that 95% of observed localities will be included in the prediction), and average probability/suitability. The choice of an appropriate decision threshold is reliant on data type and the nature of study (Pearson, 2010). For example, 10 percentile training presence, helps to generate binary presence (1) and absence (0) raster formats and then, the layers of potential species' distribution with future projections can be compared and combined (Scheldeman and van Zonneveld, 2010).

3.3.5.3 Threshold-independent evaluation

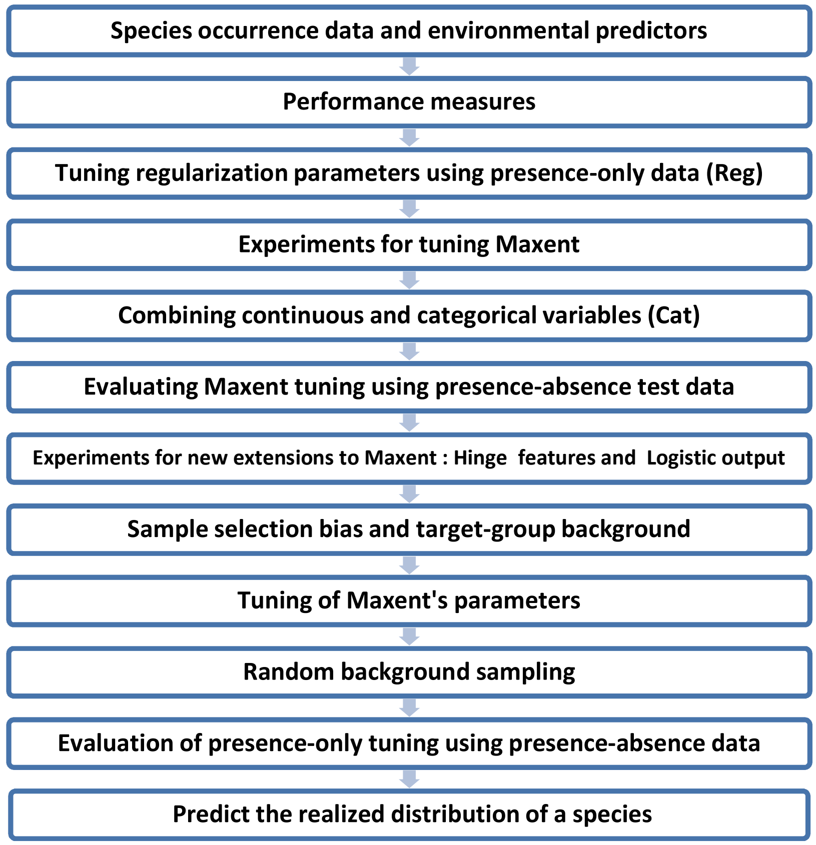
When model output is continuous, threshold-dependent evaluation will be sensitive to the method used to select a threshold for creating a binary prediction. So, threshold-independent evaluation is often useful to derive a test statistic that provides a single measure of predictive performance across the full range of possible thresholds using a statistic known as AUC (Pearson, 2010).

AUC is interpreted as the probability that a randomly chosen presence location is ranked higher than a randomly chosen background point (Merow et al., 2013). This statistic is usually abbreviated AUC but is sometimes referred to as ROC (Franklin, 2010). Compared model performance using receiver operating characteristic (ROC) curves was common (Merow et al., 2013).

Regarding the interpretation of AUC value, Franklin, (2010) detailed that the AUC is calculated by summing the area under the ROC curve. The AUC ranges from 0.5 for models that are no better than random to 1.0 for models with perfect predictive ability. Thus, a high AUC score reflects that the model can discriminate accurately between locations at which the species is present or absent (Pearson, 2010).

In conclusion, workflow on modelling of species distribution with MaxEnt was outlined (Figure 3.4) by adapting procedure from Elith et al. (2006), Phillips et al. (2006); Phillips and Dudík (2008) and Franklin (2010).

Figure 3.4 Flow chart to undertake species distribution modelling in MaxEnt



CHAPTER FOUR

4 RESULTS

4.1 Land Use/Land Cover Change

4.1.1 Land use/Land cover classification and accuracy

The overall accuracies for the three reference years ranged from 99.22% to 99.42% with the Kappa statistic was ranging from 0.822 to 0.924 (Table 4.1). The Kappa results show a high level of agreement for each of the three classified images. Producer and user accuracies of the Landsat classified image in 1972, 1986, and 2015 for all land uses were above 90% (user's accuracy).

As indicated in Table 4.1, confusions in water body classes were low in all study years. Misclassifications were observed in forest, grass, and shrub classes. For instance, in the second column of Table 4.1(a), out of the total 60 randomly generated reference samples for forest, 60 were correctly classified as forest. Similarly, in the first row of Table 4.1(b), four samples of shrub and one sample of grass were found to be misclassified as forest.

The user's accuracies in the case of forest classes were 96.37, 98.23, and 98.38 for classified images of 1972, 1986 and 2015, respectively. Lower producer's accuracy (83.3) was attained in classified images of 1975 in the grass class.

Table 4.1 Error matrix of classification accuracies for (a) 1972, (b) 1986, (c) and 2015

Reference data (a)									
Classification	1	2	3	4	5	6	Total	UA %	PA%
Forest (1)	**60**	0	0	0	0	0	60	100	100
Shrub (2)	0	**30**	0	0	0	2	32	83.33	100
Grass (3)	0	0	**24**	0	0	0	24	100	100
Settlement (4)	0	0	0	**18**	0	1	19	90.0	100
Water (5)	0	0	0	0	**29**	0	29	100	100
Agriculture(6)	0	0	0	0	0	**191**	193	99.48	100
Total	60	30	24	18	29	194	355		

Overall accuracy [%] = 99.22; Kappa hat classification = 0.96

Reference data (b)									
Classification	1	2	3	4	5	6	Total	UA%	PA%
Forest (1)	**558**	4	1	0	0	0	563	98.23	99.11
Shrub (2)	4	**209**	0	0	1	1	215	97.66	97.2
Grass (3)	6	1	**273**	0	0	0	280	99.63	97.5
Settlement (4)	0	0	0	**170**	0	0	170	100	100
Water (5)	0	0	0	0	**223**	0	223	99.55	100
Agriculture (6)	0	0	0	0	0	**1613**	1613	99.93	100
Total	568	214	274	170	224	1614	3064		

Overall accuracy [%] = 99.41; Kappa hat classification = 0.99

			Reference data (c)						
Classification	1	2	3	4	5	6	Total	UA%	PA%
Forest (1)	**456**	0	0	0	0	0	456	99.56	100
Shrub (2)	2	**122**	0	0	0	0	124	100	98.38
Grass (3)	0	0	**60**	1	0	6	67	100	89.55
Settlement (4)	0	0	0	**161**	0	1	162	99.38	99.38
Water (5)	0	0	0	0	**201**	0	201	100	97.10
Agriculture (6)	0	0	0	0	0	**1261**	1261	98.72	100
Total	458	122	60	162	201	1268	2271		

Overall accuracy = 99.42%; Kappa hat classification = 0.99, Where UA = user's accuracy and PA = producer's accuracy.

The columns represent actual location of samples on the ground, while rows display classified data showing location of samples in the classified images. Diagonal numbers showed in bold are the correct classifications (Table 4.1). The off-diagonal numbers in rows and columns are misclassifications or errors.

Table 4.1(c) indicated that, agriculture land has the lowest producer accuracy (98.72) because of some co-fusion with grass and settlement pixels. Settlement also has the lowest user accuracy due to the addition of agriculture land pixels.

The classification accuracies of water pixels have 100% producer and user accuracy. This shows that there is no confusion with other cover units in all study years.

4.1.2 Land use/ land cover classification

Supervised classification using the maximum likelihood algorithm in QGIS was used to generate six main land use/land cover classes for all images: (1) Forest, (2) Shrub, (3) Grassland (4) Settlement (5) Water bodies and (6) Agriculture land. These land use/land cover classes for the area were derived from images of the year 1972, 1986, and 2015.

4.1.3 Land use/Land cover distribution

For this study, agriculture land, grassland, shrub land, and forestland were identified to be the major LULC types in the year 1972, 1986, and 2015. The greatest share of LULC from all classes is agriculture land (Figure 4.1). Agriculture land covers an area of 33,629.8 ha, 33,199.56 ha and 39,541.9 ha contributing 67.27%, 68.32%, and 80.08% of the total area in the year 1972, 1986, and 2015, respectively.

As indicated in Figure 4.1, shrub land are the second largest land cover next to agriculture land , which cover an aerial size of 9,670.28 ha (17.83%) in the year 1972.

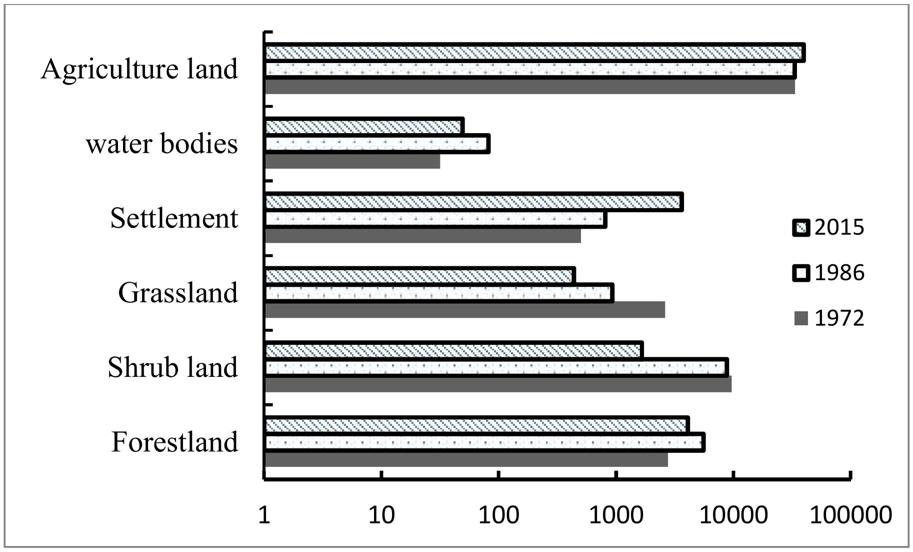


Figure 4.1 LULC types of the year 1972, 1986, and 2015, x-axis shows the hectare of each land uses in logarithmic scale to the base 10.

Grassland is the third largest land use/land cover next to shrub land. It covers an aerial size of 2613.52 ha of land, which is 5.31% of the total area in the year 1972. On the other hand, the least aerial coverage are settlements and water bodies, which accounts for 501.84 ha (1.02%) and 31.68 ha (0.06%) of the study area, respectively in the year 1972.

Shrub land was the second largest land use types next to agriculture land in the year 1986. It covers an aerial size of 8,800.74 ha, which is 17.83% of the total land area. On the other hand, grass, settlements and water bodies accounted for 927.54 ha (1.88%), 806.49 ha (1.68%) and 81.72 ha (0.17%) of the total study area, respectively.

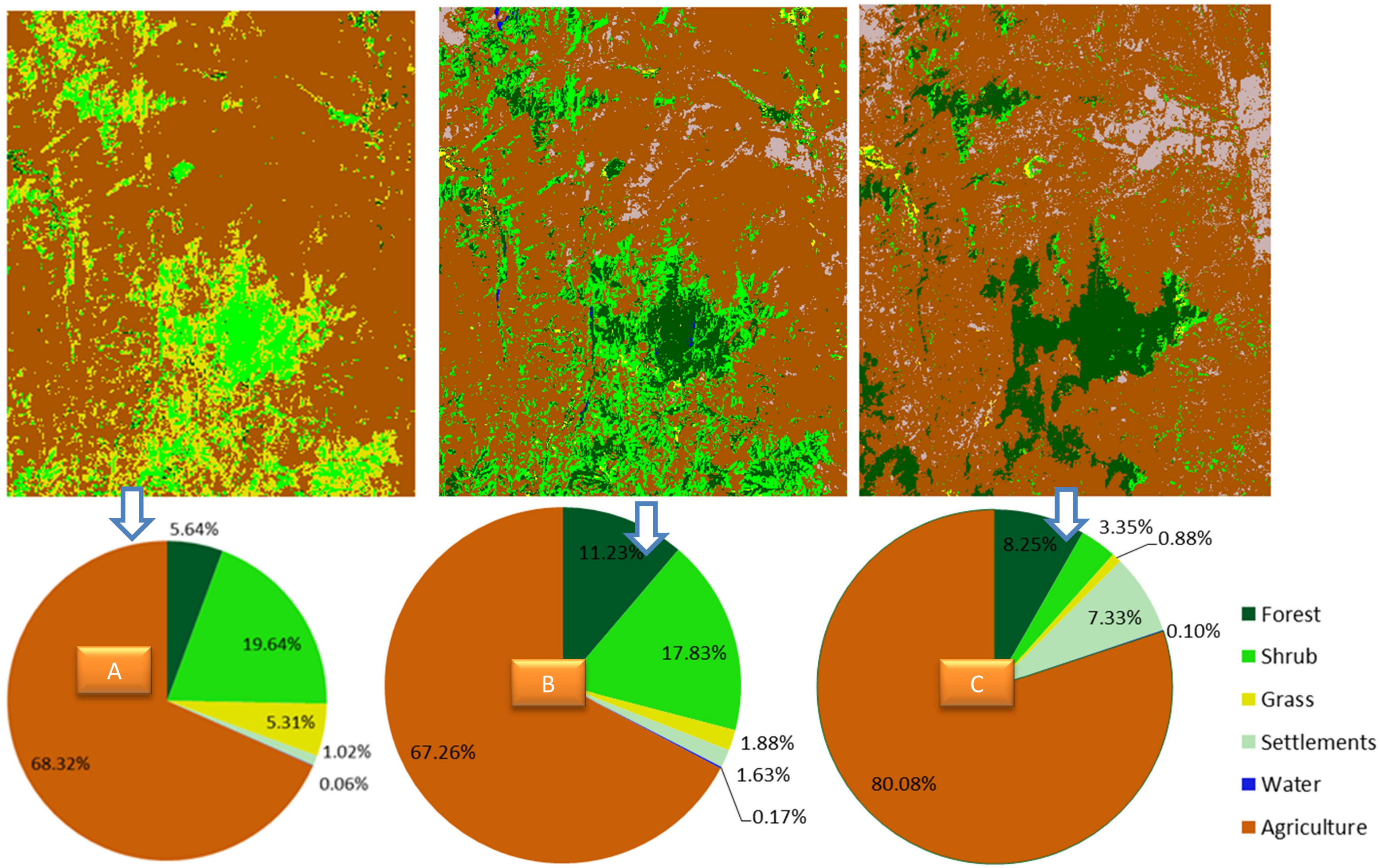


Figure 4.2 Land use/land cover distribution in the years A, 1972; B, 1986 and C, 2015

With respect to LULC of 2015, agriculture land was the largest land use/land cover type and it covers an area of 39,541.86 hectares (ha) of land, which contributes about 80.08% of the total land area. Next to agriculture, forestland is the second largest class covering an aerial size of 4,072.77 ha (7.33%).

The third largest LULC next to forest is settlement. Settlement covers an aerial size of 3619.17 ha, which is 1.93% of the total land area in the year 2015. Shrub, grass, and water bodies accounted for 1,655.28 ha (3.35%), 436.77 ha (0.88%) and 49.14 ha (0.01%) of study area, respectively.

4.1.4 Land use/land cover changes

The LULC changes from the year 1972 to 1986 are summarized in Table 4.2. Accordingly, agriculture land comprises an area of 33,629.81 ha (68.32%) and 33,199.56 ha (67.26%) of land in the year 1972 and 1986, respectively. Hence, the size of agricultural lands was reduced by 430.25 ha (1.06%) from the year 1972 to 1986.

Table 4.2 Land use/ land cover change from 1972 to 1986

	1972	1986	Δ	Δ (ha/yr)	1972%	1986%	Δ %
Forest	2778.4	5542.1	2781.08	212.59	5.64	11.23	5.58
Shrub	9670.28	8800.74	-869.54	-66.89	19.64	17.83	-1.81
Grass	2763.52	927.54	-1835.98	-129.69	5.31	1.88	-3.43
Settlement	501.84	806.49	304.65	23.43	1.02	1.63	0.61
Water	31.68	81.72	50.04	3.85	0.06	0.17	0.10
Agriculture	33629.8	33199.56	-430.25	-33.10	68.32	67.26	-1.06

Shrubs hold an area of 9670.28 ha (19.64%) and 8,800.74 (17.83%) in the year 1972 and 1986, respectively. They were the second largest LULC types next to agriculture.

However, the size of the shrub land class was reduced in 869.54 ha (1.81%) from the year 1972 to 1986

Regarding to the forestland, it was the third dominant LULC class next to shrub. Forestland increased by 5.64 % from 2,778.4 ha in 1972 to 5542 ha in 1986. The rate of change was estimated to be 212.59 ha per year. What is interesting in this data is that area of forest and settlement showed an incremental pattern, while shrub and grasslands were showing decrement since 1972.

Table 4.3 Land use/ land cover change from 1986 to 2015

	1986	2015	Δ	Δ(ha/yr)	1986%	2015%	Δ %
Forest	5542.1	4072.77	-1469.33	-50.67	11.23	8.25	-2.98
Shrub	8800.74	1655.28	-7145.46	-246.40	17.83	3.35	-14.48
Grass	927.54	436.77	-490.77	-16.92	1.88	0.88	-0.99
Settlement	806.49	3619.71	2813.22	97.01	1.63	1.93	0.29
Water	81.72	49.14	-32.58	-1.12	0.17	0.01	-0.15
Agriculture	33199.6	39541.9	6342.3	218.70	67.26	80.08	12.82

Regard to the LULC in 1986 and 2015 (Table 4.3), agriculture land has increased by 12.82% from 33,199.6 ha in 1986 to 39,541.9 ha in 2015. The rate of change was estimated to be 218.70 ha per year.

Shrub land was the second largest LULC types next to agriculture. It was reduced from 8,800.74 ha in 1972 to 1,655.28 ha in 1986, which is a reduction of 7,147.46 ha at the rate of -246.40 ha of land per year. Similarly, in relation with the forestland, it was decreased from 5542.1 ha in 1986 to 4,072.77 ha in 2015. The rate of change was estimated to be 212.59 ha per year. Hence, the size of the forest area was reduced in 1469.33 ha at the rate of (-50) ha per year.

In summary, the change of the results of LULC from 1986 to 2015 showed that 6,342.3 ha and 2,813.31 ha of land which was converted into agricultural and settlement land, respectively. On the other hand, the coverage of forest, shrub, grassland and water bodies decreased by 1,469.3 ha, 7145.46 ha, 490.77 ha and 32.58 ha, respectively.

As far as the LULC changes from 1972 to 2015 was concerned (Table 4.4), agriculture land increased by 11.97% from 33,629.81 ha in 1972 to 39,541.86 to 2015. Hence, 5,912.05 ha of land were converted to agricultural land. The rate of change was estimated to be 140.76 ha per year.

Table 4.4 Land use/ land cover change for 1972 to 2015

	1972 (ha)	2015 (ha)	Δ	Δ(ha/y)	1972%	2015%	Δ %
Forest	2778.4	4072.77	1294.37	30.82	5.63	8.25	2.62
Shrub	9670.28	1655.28	-8015	-190.83	19.59	3.35	-16.24
Grass	2763.52	436.77	-2176.75	-51.83	5.6	0.88	-4.72
Settlement	501.84	3619.71	3117.87	74.24	1.02	1.93	0.91
Water body	31.68	49.14	17.46	0.42	0.06	0.01	-0.05
Agriculture	33629.81	39541.86	5912.05	140.76	68.11	80.08	11.97

Shrub land covers an area of 9,670.28 ha (19.59%) and 1,655.28 ha (3.35%) in the year 1972 and 2015, respectively. It was the second largest LULC types next to agriculture land in the year 1972. However, the size area reduced by 8015 ha at the rate of 190.83 ha per year.

Forest cover an area of 2,778.4 ha (5.63%) and 4,072.77 ha (8.25%) of land in the year 1972 and 2015, respectively. Hence, forest coverage in the study area increased by 1,294.37 ha of land at the rate of 30.82 ha per year. It was fond to be the third largest land use types next to agriculture and shrub land.

Overall, results of LULC change from 1972 to 2015 indicated that 5,912.05 ha and 1,294.37 ha of land were converted into agriculture and forestland, respectively, while, shrub land and grassland decreased in their area coverage by 16.24% and 4.72%, respectively.

4.1.5 The transition of land use/ land cover

The transition matrix shows that the proportions of pixels changed from one land use/land cover to another types of LULC. Pixel value is converted into hectare. It helps us to determine what is actually changing to what category of land use and land cover type. This information can play a vital role in land resource management.

Table 4.5 Transition matrix of LULC (ha) between the year 1972 to 1986

Transition Matrix		LULC of 1986						
		Forest	Shrub	Grass	Settlements	water	Agriculture	Total
LULC of 1972	Forest	**2223**	306	28	0	0	222	2778
	Shrub	675	**6941**	96	96	0	1832	9640
	Grass	1299	193	**111**	28	52	1105	2788
	Settlements	0	15	20	**346**	0	110	492
	Water	0	1	1	0	**28**	0	30
	Agriculture	1345	1345	673	336	0	**29931**	33630
	Class Total	5542	8801	929	807	80	33200	

Table 4.5 provides data for the LULC dynamics in hectare for the study area. For example, values shown diagonally in bold text implies an area of land, which was not

changed to other land uses during the given periods. Hence, 2223 ha of forestland was not altered between 1972 and 1986 in the study area. Similarly, shrub (6941 ha), grass (111 ha) and agriculture land (29931 ha) were not converted to other LULC types.

Likewise, the proportion of unconverted land from respective class value ranges from 3% (grass) to 92% (water).

Regarding the transition of agriculture land from the year 1972 to 1886, the size of agriculture land was reduced by 430.25 ha (1.06%). This area was converted to all other land uses except water body. The area of 869.54 ha of shrub land in 1972 was converted to other land uses, mainly to forestland.

Table 4.6 Transition matrix of LULC (ha) between the year 1986 and 2015

		LULC of 2015						
		Forest	Shrub	Grass	Settlement	Water	Agriculture	Class Total
LULC of 1986	Forest	**1829**	554	111	55	0	2993	5542
	Shrub	1445	**88**	88	1520	0	5689	8830
	Grassland	28	9	**195**	176	0	519	927
	Settlement	81	8	42	**208**	0	452	790
	Water	26	0	0	0	**49**	7	82
	Agriculture	664	996	0	1660	0	**29884**	33204
	Class Total	4073	1656	436	3619	49	39543	

The proportions of pixels changing changed from one land use/land cover to another (Table 4.6). The transition matrix shown in Table 4.6 diagonally in bold text indicated an area of land, which was not changed into other LULC during the given period. For example, 1829 ha, 88 ha, 195 ha, 200 ha and 29884 ha of forest, shrub, grassland and agriculture, respectively, have not been changed.

Table 4.7 Transition matrix of LULC (ha) between the year 1972 and 2015

		LULC of 2015						
		Forest	Shrub	Grass	Settlement	Water	Agriculture	Class Total
LULC of 1972	Forest	**1167**	139	0	222	0	1250	2778
	Shrub	1644	**967**	290	97	0	6672	9670
	Grass	912	193	**138**	249	28	1244	2764
	Settlement	10	20	5	356	0	110	502
	Water	3	0	1	5	**22**	0	32
	Agriculture	336	336	0	2690	0	**30267**	33630
	Class Total	4072	1655	434	3619	50	39543	

The transition matrix shown in Table 4.7 diagonally in bold text indicated an area of land, which was not changed into other LULC during the given period. For example, 1167 ha, 967 ha, 138 ha, and 30, 267 ha of forest, shrub, grasslands and agriculture, respectively, have not been changed.

As shown (in Figure 4.3) between the year 1972 to 2015, there was an expansion of there was an expansion of agricultural land and settlements. agriculture land, forestland, and settlement were increased by 11.97%, 2.62%, and 0.91% through the year 1972 to 2015, respectively, whereas, out of the total area, the size of shrub land and grassland has decreased by 16.94% and 4.72%, respectively.

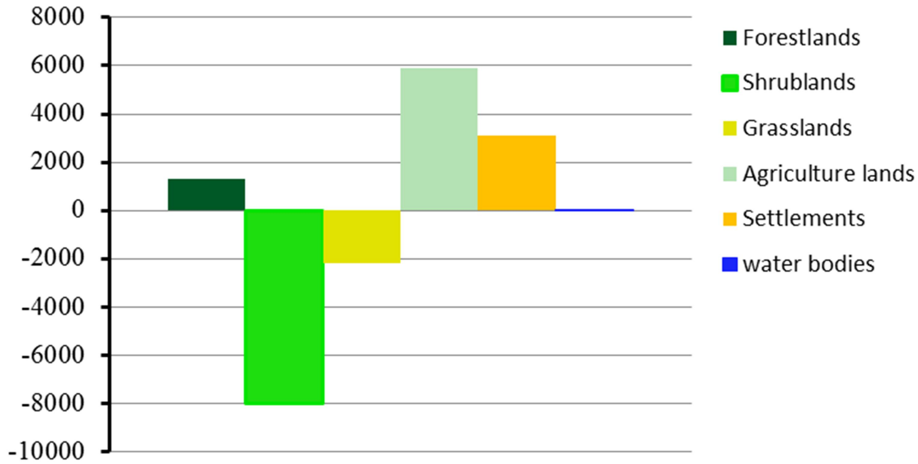


Figure 4.3 LULC changes from the year 1972 to 2015. “Y”-axis shows the net change of each LULC type in hectares

4.2 Spatial Composition and Configuration

The first set of analyses examined composition and configuration of the landscape for the year 1972, 1986, and 2015. During these study periods, the areal extent and spatial configuration of patches within a landscape were quantified as follows:

4.2.1 Agriculture land

Euclidean nearest-neighbor distance (ENN), the simplest measure of patch context, has been used extensively to quantify patch isolation (Mcgarigal and Ene, 2013). The values of ENN in this study were found to be 76.32, 79.2, and 74.83 meters for the year 1972, 1986 and 2015, respectively. Whereas, the value of the isolation for the year 1972 is higher than the results observed in 1986 by 2.88 meter, that of 2015 has further reduced by 4.37 meter when compared to the value of 1986.

Interspersion and Juxtaposition Index (IJI) values of agriculture land for the year 1972 1986, and 2015 were 63.2%, 54.7%, and 70.3%, respectively. The highest IJI value was attained in the year 2015.

The number of agriculture land occurred in the area for the year 1972, 1986, and 2015 were 1548, 1682 and 1747, respectively. The number of the patch in the landscape during the study period was found to be reduced, but the size of the minimum area of the patches existing during these periods were considered as a bench mark for the study, i.e., 1972, 1986 and 2015, was 44.7, 19.7 and 43.9 ha of land, respectively.

Largest patch index (LPI) quantifies the percentage of total landscape area comprised of the largest patch (Table 4.8). LPI value of agriculture land in the landscape was 57.7, 50.1, and 62.7 of the landscape in the year 1972, 1986 and 2015, respectively.

Table 4.8 Representation of spatial pattern at class level for six LULC types during the three periods (1972, 1986 and 2015), based on the landscape metrics for Yegof and its surrounding forest patches.

PLAND = Percentage of Landscape; LPI = Largest Patch Index; AREA_MN = Patch Area Distribution; ED = Edge Density; NP = Number of Patches; ENN_MN = Euclidean Nearest Neighbor Distance Distribution; IJI = Interspersion & Juxtaposition Index, PAFRAC = Perimeter-Area Fractal Dimension

LULC/ Year	NP	PLAND	LPI	ED	AREA_MN	PAFRAC	ENN_MN	IJI (%)
1972								
Agriculture	1548	58.4	57.7	58.3	44.7	1.4	76.3	63.2
Shrub	6015	14.1	1.7	74.3	1.2	1.5	52.3	72.9
Forest	1583	3.8	1.4	17.2	1.1	1.5	178.4	45.6
Grassland	1305	1	0.1	7.5	0.3	1.5	145.1	56
Settlement	1204	1.2	0	10	0.3	1.5	176.5	7.5
Water	12	0.1	0.1	0.1	4.8	1.2	297	45.3
1986								
Agriculture	1682	57	50.1	63.8	19.7	1.4	79.2	54.7
Shrub	7453	9.3	0.4	45.2	1	1.5	80.7	52.9
Forest	1329	8.8	1.5	28.2	1.8	1.4	99	55.4
Grassland	1287	1.5	0.1	8.3	0.7	1.5	162.3	60.2
Settlement	1495	1.3	0.1	7.6	0.5	1.4	159.6	9.9
Water	72	0.1	0.1	0.4	1.1	1.3	614.9	53.4
2015								
Agriculture	900	63.1	62.7	68.5	43.9	1.5	74.8	70.3
Shrub	4324	2.6	0.1	20.2	0.4	1.5	114.6	41.7
Forest	1747	6.5	2	17.4	2.3	1.4	126.3	35.7
Grassland	818	0.7	0.1	4	0.5	1.5	216.3	57.8
Settlement	7560	5.8	0.4	36.2	0.5	1.5	96	4
Water	1	0.1	0.1	0.1	49.1	N/A	N/A	33.9

4.2.2 Forestland

The number of patches is one of the most important fragmentation metric commonly used in quantifying forest fragmentation of a given area. In this study, the number of forest patches for the years 1972, 1986, and 2015 were found to be 1583, 1329 and 1747, respectively.

The mean area of the forest patch was found to be 1.1, 1.8, and 0.4 ha for the year 1972, 1986 and 2015, respectively. Hence, in the year 2015, the number of forest patch has increased with a concomitant reduction in the size of the mean value of the forest (Table 4.8).

The proportion of forest patch in the landscape has increased from 3.8% (1972) to 8.8% (1986) and then reduced to 6.5% in the year 2015. Similarly, the area of forest patches has increased from 2519.7 ha to 5481.8 ha during the year 1972 to 1986; but reduced to 4072.8 ha in the year 2015 (Figure 4.4).

The value of ENN computed in this study was 178.4, 99.0, and 126.3 meters for the year 1972, 1986 and 2015, respectively. The value isolation in the year 1972 was reduced by 79 m of the year 1986. ENN of 1986 was increased by 27 meter in the year 2015.

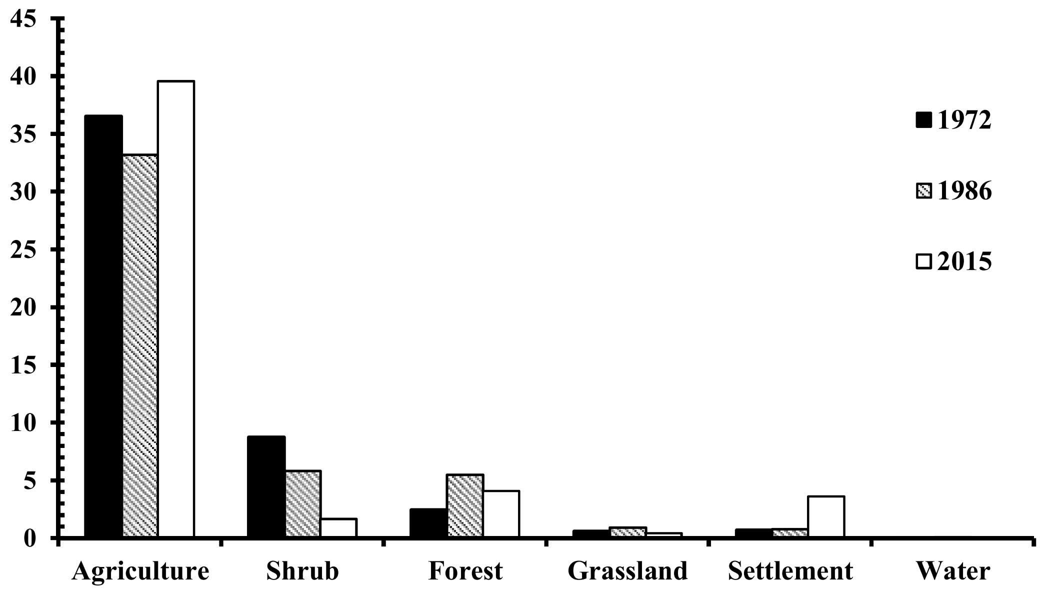


Figure 4.4 The size of class area during the study years, the vertical axis display the class area in thousand hectares

The value of IJI for forest patch of the year 1972, 1986, and 2015 was 45.6%, 55.4%, and 35.7%, respectively. It indicated that the forest patches have become further far apart over time and changed from 55.4 in 1986 to 35.7 in 2015. Observation of such a pattern of change in the landscape clearly indicated the level of forest fragmentation occurring in the study area.

LPI value of the forest patch in percentage was found to be 1.4, 1.5, and 2.0 from the total landscape for the year 1972, 1986 and 2015, respectively. Regarding Edge density (ED), forest patches contained a total of 17.2, 28.2, and 68.5 meters per hectare in the year 1972, 1986, and 2015, respectively. The largest ED was recorded in the year 2015.

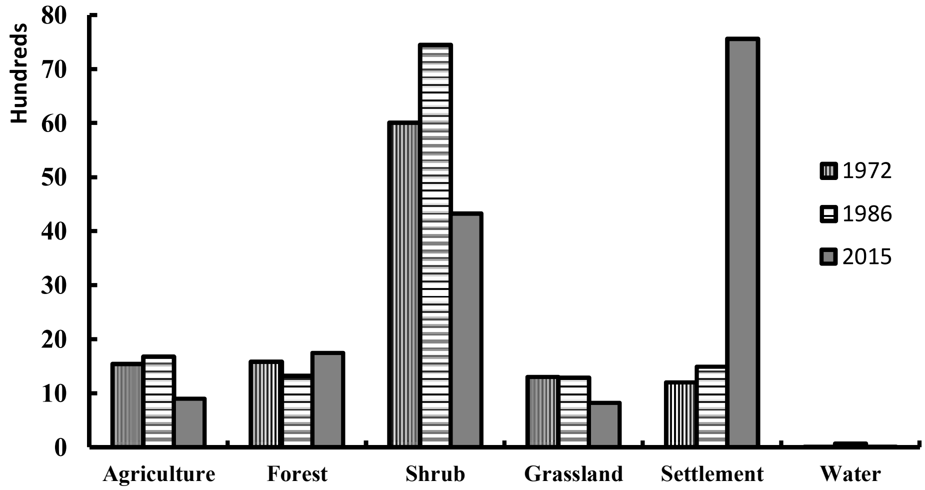


Figure 4.5 The number of patches during the study years

4.2.3 Shrub land

The proportion of shrub land was 14.1, 9.3, and 2.6 in the year 1972, 1986 and 2015, respectively. Hence, the proportion of shrub land in the landscape was reduced across the study years.

The number of shrub land patches were 6015.0, 7453 and 4324.0 for the year 1972, 1986 and 2015, respectively (Figure 4.5). The highest number of shrub patch was observed in the year 1986. The number of shrub patch in the landscape has increased from the year 1972 to 1986; but it has reduced from the year 1986 to 2015.

The mean area size of the shrub patch in hectare was 1.2, 1.0, and 0.4 in the year 1972, 1986 and 2015, respectively. With regard to largest patch index value in percent, 1.7, 0.4, and 0.1 of the landscape were quantified in the year 1972, 1986, and 2015, respectively.

Shrub land encompassed a total of 74.3, 45.2, and 20.2 meters per hectare in the year 1972, 1986, and 2015, respectively. The largest ED was recorded in the year 1972.

The values of ENN for shrub land were 52.30 meter, 80.7 meter, and 114.6 meter in the year 1972, 1986, and 2015, respectively. The value of the isolation in the year 1972 has increased by 28.4 meter over the year 1986. Similarly, ENN has increased by 62.3 meter from the year 1986 to 2015. Interspersion and Juxtaposition Index (IJI) of shrub land of the years 1972, 1986, and 2015 were 72.91%, 52.9%, and 41.7%, respectively.

4.3 Results from Vegetation analysis

4.3.1 Floristic composition

In terms of growth form, 152 (52.1%) were herbs, 77 (26.4%) shrubs, 52 (17.8%) trees, 11 (3.8%) lianas. The ten species-rich plant families contribute to 51.8% of the species in Yegof forest and its surrounding forest patches (Table 4.9).

Family Asteraceae has the highest number of genera (30), followed by Fabaceae (16) and Poaceae (15). Four families contain more than fourteen genera and their ratio to the Flora of Ethiopia and Eritrea. Seven families were containing six to three genera and 47 families were represented by a single genus (Table 4.9).

Table 4.9 Plant families in Yegof forest and its surrounding patches

Family Name	No. of genera in YP	No. of Species in YP	Percentage in YP	No. of species in Flora of Ethiopia & Eritrea	Percentage with the flora
Asteraceae	30	43	14.73	440	9.77
Fabaceae	16	26	8.90	607	4.28
Poaceae	15	19	6.51	580	3.28
Lamiaceae	14	14	4.79	221	6.33
Solanaceae	6	9	3.08	78	11.54
Apiaceae	9	9	3.08	57	15.79
Euphorbiaceae	6	9	3.08	209	4.31
Malvaceae	6	8	2.74	139	5.76
Acanthaceae	5	7	2.40	245	2.86
Rubiaceae	6	7	2.40	101	6.93

Remarks: YP = the forest of Yegof and its surrounding forest patches.

Among the recorded species in this study (Annex 2), twenty-one were endemic species. The largest number of endemic species (7) was recorded from the family Asteraceae, followed by Aloaceae (3), Fabaceae (3), and Poaceae (2). Further analysis showed that the vascular plants in the study area are flowering plants whereby dicots and monocots accounted for about 86% and 11.9%, respectively. Ferns were represented by four species (1.7%).

4.3.2 Vegetation structure

4.3.2.1 Diameter Class Distribution

Analysis of the DBH indicated that the average number of individuals decrease from the lowest size classes to the highest size class (Figure 4.6). The number of individuals decreased with increasing diameter classes, suggesting a more or less inverted J-shaped population structure: This general pattern indicates healthy regeneration status. However, species such as *Hagenia abyssinica* and *Prunus africana* lack individuals in the middle or smaller size classes.

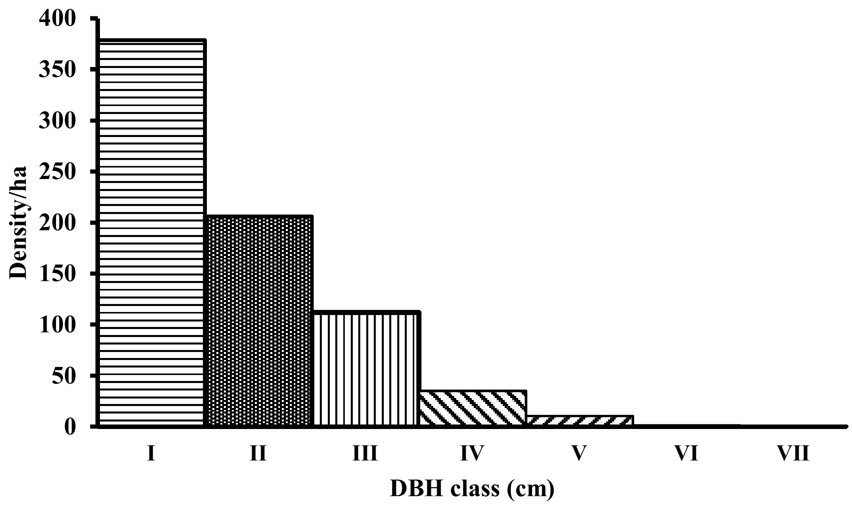


Figure 4.6 DBH classes versus the average number of individuals in Yegof Forest and the sounding patches (Key: I = < 10; II = 10.1–20; III = 20.1–50; IV = 50.1–70; V = 70.1–90; VI= 90.1–110; and VII= 110.1–130)

The forest at Yegof has the highest density of trees > 10 cm DBH, followed by the Erkis, Suki, Harego, Abuli, Harbu and Biraro. The highest and lowest density of tree (>10 cm DBH) per hectare was found in the forest of Yegof and Biraro, respectively (Table 4.10).

Table 4.10 Tree density per ha in the Yegof and its surrounding forest patches; a = for trees > l 0 cm DBH; b= for trees > 20 cm DBH; a/b = ratio between a and b.

Name of the forest or patch	a	b	a/b
Yegof	458.2	253.4	1.8
Erkis	350.7	176.6	2.0
Harbu	289.3	110.1	2.6
Harego	386.6	151.0	2.6
Suki	394.2	158.7	2.5
Biraro	325.1	120.3	2.7
Abuli	340.5	135.7	2.5

In the patch of Harego (2.6), Harbu (2.6), Biraro (2.7), and Abuli (2.5) forests, the highest proportions of small-sized (a/b ratio) was obtained, which indicates the dominance of small-sized individuals in the forest.

4.3.2.2 Density, Basal area and Importance Value Index (IVI)

The total density of woody species (DBH >10 cm) ranging from 294 to 460 was estimated in the study forests. Among the studied forests, Harego was found to be the denser and Harbu was a less dense forest patch (Table 4.11).

Table 4.11 Basal area in m^2/ha and density of individual per hectare) in the study forests.

Characteristic	Basal area, DBH > 10 cm	Density, DBH >10	Density, 10cm<DBH> 20 cm	Density, DBH> 20 cm	Density, DBH,< 2 cm
Yegof	25.0	294.4	204.8	253.4	752.6
Suki	18.1	448.2	174.1	176.6	798.7
Harbu	11.2	307.2	179.2	110.08	596.5
Harego	14.2	460.8	235.5	151.04	847.4
Erkis	15.5	358.4	231.5	158.72	752.6
Biraro	11.0	384.1	204.8	120.32	709.1
Abuli	12.2	396.8	207.36	135.7	737.3

The total basal area for the Yegof forest was 25 m^2ha^{-1}, while it was 18 m^2ha^{-1}, 15.5 m^2ha^{-1}, 14.2 m^2ha^{-1}, 12.2 m^2ha^{-1}, 11.2 m^2ha^{-1}, and 11 m^2ha^{-1} for the patch of Suki, Erkis, Harego, Abuli, Harbu, and Biraro, respectively (Table 4.11).

In the Yegof forest *Olea europaea* subsp. *cuspidata* of 48.04 individuals per ha (20%), *Olinia rochetiana* of 41.02 individuals (17.33%), *Carissa spinarum* 32.8 individuals (13.86%), *Calpurnia aurea* of 10.5 individuals per ha (4.46%), and *Dodonaea angustifolia* of 22.66 individuals (9.75%) species per hectare was obtained.

Relative Dominance (RDO), Relative Frequency (RF), Relative Density (RD), and Importance Value index (IVI) is calculated to each forest independently. The values of the five most importance species in the respected forestd are presented in Table 4.12.

Table 4.12 Density, basal area and IVI of the five species in the Yegof forest and its surrounding patches.

			BA/ha	Rdo	Density/ha	%	RF	IVI
Biraro								
	Acacia lahai		0.60	15.70	25.00	6.28	4.76	26.74
	Euphorbia candelabrum		0.50	13.18	22.92	5.76	5.95	24.89
	Acacia seyal		0.50	13.08	20.83	5.24	4.76	23.08
	Euclea racemosa		0.11	2.99	58.33	14.66	4.76	22.41
	Acacia etbaica		0.38	10.04	25.00	6.28	5.95	22.28
		Total	**2.11**	**54.99**	**152.08**	**38.22**	**26.19**	**119.40**
Yegof								
	Olea europaea subsp. *cuspidata*		1.12	21.81	48.05	20.30	15.91	58.02
	Olinia rochetiana		1.38	26.77	41.02	17.33	6.82	50.92
	Carissa spinarum		0.02	0.48	32.81	13.86	6.82	21.16

	Juniperus procera		0.51	9.98	5.86	2.48	8.52	20.98
	Dodonaea angusifolia		0.03	0.55	22.66	9.57	6.82	16.94
		Total	**3.07**	**59.60**	**150.39**	**63.53**	**44.89**	**168.01**
Suki								
	Olea europaea subsp. *cuspidata*		1.22	25.86	31.25	10.78	8.54	45.18
	Juniperus procera		0.60	12.66	35.00	12.07	7.32	32.05
	Olinia rochetiana		0.55	11.69	15.00	5.17	6.10	22.96
	Myrica salicifolia		0.57	12.10	18.75	6.47	2.44	21.00
	Pittosporum viridiflorum		0.10	2.06	21.25	7.33	4.88	14.27
		Total	**3.04**	**64.38**	**121.25**	**41.81**	**29.27**	**135.46**
Abuli								
	Juniperus procera		1.92	26.59	52.08	15.72	7.02	**58.11**
	Olinia rochetiana		1.29	17.80	25.00	7.55	15.79	**34.12**
	Myrica salicifolia		0.91	12.60	22.92	6.92	8.77	**30.05**
	Olea europaea subsp. *cuspidata*		0.45	6.28	20.83	6.29	10.53	23.10
	Dombeya torida		0.27	3.77	25.00	7.55	10.53	**18.34**
		Total	**4.85**	**67.04**	**145.83**	**44.03**	**52.63**	**163.70**
Harbu								
	Acacia brevispica		1.70	30.98	68.75	21.07	11.65	**63.70**
	Dichrostachys cinerea		0.87	15.89	58.75	18.01	12.62	**46.52**
	Acacia lahai		0.69	12.54	31.25	9.58	4.85	**26.97**
	Pterolobium stellatum		0.11	1.95	20.00	6.13	11.65	**19.73**
	Grewia villosa		0.10	1.79	17.50	5.36	6.80	**13.95**
		Total	3.47	63.14	196.25	60.15	47.57	170.87
Erkis								
	Podocarpus falcatus		3.07	33.94	10.00	2.43	2.67	**38.37**
	Maesa lanceolata		1.02	11.28	20.00	4.86	8.00	**24.14**

	Olinia rochetiana		0.91	10.08	17.50	4.26	6.67	**21.00**
	Olea europaea subsp. *cuspidata*		0.39	4.31	26.25	6.38	10.00	20.70
	Albizia schimperiana		0.65	7.16	20.00	4.56	5.33	17.36
		Total	**6.03**	**66.78**	**93.75**	**22.49**	**32.67**	**121.57**
Harego								
	Olea europaea subsp. *cuspidata*		1.14	29.84	68.75	15.14	9.62	54.59
	Myrsine africana		0.23	6.03	87.50	19.27	7.69	32.99
	Dodonaea angusifolia		0.09	2.25	89.58	19.72	7.69	29.67
	Carissa spinarum		0.07	1.77	37.50	8.26	15.38	25.41
	Euclea racemosa		0.08	2.01	31.25	6.88	7.69	16.58
		Total	**1.60**	**41.90**	**314.58**	**69.27**	**48.08**	**159.24**

Table 4.12 shows that, *Olea europaea* subsp. *cuspidata*, *Juniperus procera* and *Olinia rochetiana* are among of the five major species in Abuli, Suki, and Yegof forests; although, their level of dominance is found to be different in each forest. For example, *Juniperus procera* is contributing 26.6%, 12.6%, and 9.9% of the total basal area in Abuli, Suki, and Yegof forests, respectively. Similarly, 25%, 21.8% and 6.3% of the total basal area in Suki, Yegof, and Abuli was due to by *Olea europaea* subsp. *cuspidata*. Both species have occurred concomitantly in the forest of Yegof.

Acacia lahai, Euphorbia candelabrum, *Acacia seyal*, *Euclea racemosa* and *Acacia etbaica* are the five dominant species in the forest of Biraro. These five species accounted for 54.9% of the total basal area. The dominant species were *Olea europaea* subsp. *cuspidata*, *Myrsine africana*, *Dodonaea angusifolia*, *Carissa spinarum*, and *Euclea racemose* in Harego (Table 4.12). These species account for 41.9% of the total basal area.

Olea europaea subsp. *cuspidata* exhibited the highest IVI (58.02), followed by *Olinia rochetiana* (50.92*),* *Carissa spinarum*, (21.6) *Juniperus procera* (20.98) and *Dodonaea angusifolia* (16.94) are the five dominant species in Yegof forest. These five species contributed for 59.9% of the total IVI.

In this study, *Acacia brevispica* and *Dichrostachys cinerea* in the forest of Harbu and *Olea europaea* subsp. *cuspidata* in Yegof and Suki forest scored high IVI due to their relatively high frequency of occurrences, *Myrsine africana*, *Dodonaea angusifolia* and *Carissa spinarum* in the forest of Harego tallied high IVI due to their relatively high frequency of occurrences and density.

4.3.2.3 Height distribution

Vertical structure in the forests of the study area is depicted in Figure 4.7. Standardized height and vertical structure classification criteria varied considerably since ‘tall’ in boreal regions or in a desert may be quite different from ‘tall’ in the humid tropics (van der Maarel, 2005). Therefore, for this study, tree species were exhibited in seven height classes; I (<5 m), II (5-10 m), III (10-15 m), IV (15-20 m), V (20-25 m), VI (25-30 m) and VII (> 30 m). Individuals of height classes’ I-II covered 194.6 individual ha^{-1} (60%) while the upper height classes (VI and VII) covered only 46.08 trees ha^{-1} (7%).

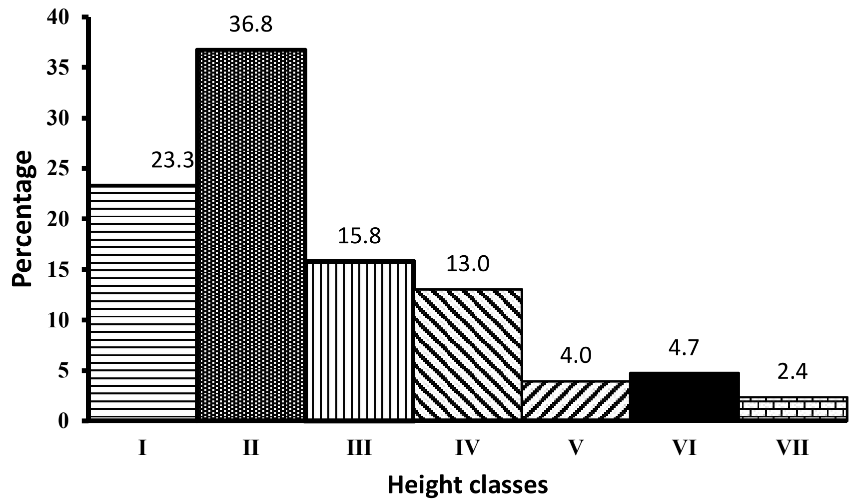


Figure 4.7 Height-class (m) distribution of trees in the study forests

The distribution of trees in different height classes is shown in figure 4.7. A considerable proportion (i.e. > 80%) of the individuals in the Biraro and Abuli forests belongs to the lowest height classes (i.e. >5 m and 5 to 10 m). For Suki and Yegof forests this figure are 66%, and 64%, respectively.

The highest height class tree species in the Yegof and its surrounding patches are *Podocarpus falcatus*, *Juniperus procera*, *Prunus africana*, *Ekebergia capensis*, and *Acacia abyssinica*.

Only few individuals attain heights of more than 20 m in the patches of Habu, Harego, Biraro, and Abuli. For Yegof and Suki forests, these figures are 4.23% and 2.7% of the individuals, respectively (Table 4.13). The tallest trees in the study are *Podocarpus falcatus, Juniperus procera, Prunus africana,, Ekebergia capensis*, and *Acacia abyssinica*.

Table 4.13 Height-class distribution in the Yegof forest & its surrounding patch.

Height Class (m)	Yegof	Suki	Erkis	Habu	Harego	Biraro	Abuli
<5	35.09	38.46	41.67	29.21	43.80	46.92	33.14
5-10	29.24	27.47	31.25	46.04	29.20	37.44	47.34
10-15	29.24	27.47	26.04	19.80	18.25	13.74	17.16
15-20	2.34	3.85	1.04	4.95	8.76	1.90	2.37
20-25	1.75	1.65					
25-30	1.17	1.10					
<30	1.17						

4.3.2.4 Population structure

The population structures of the 25 most-common tree species in the Forests were analysed and six general patterns were identified (Figure 4.8a-f)

The first pattern was formed by species with inverted J-shape. These species have the highest density in lower DBH classes with gradual decline in density towards the bigger classes (Figure 4.8a). This group is represented *Olea europaea* subsp. *cuspidata, Dombeya torrida, Galiniera saxifrage, Allophyllus abyssinicus* and *Bersama abyssinica*

The second pattern was formed for species having irregular distribution over diameter classes (Figure 4.8b). Some DBH classes had small number of individuals while other DBH classes had large number of individuals. This type of regeneration pattern was observed in *Myrica salicifolia, Acacia etbaica* and *Acacia sieberiana.*

The third type (Figure 4.8c) shows a J - shaped distribution pattern where the number of individuals decreases in the first and second DBH classes, but increases toward the higher classes. This type of regeneration pattern was observed in *Juniperus procera.*

The forth pattern was a U-shaped curve (Figure 4.8d) formed by species with few or no individuals in the middle DBH classes, and represented only by the lower and higher DBH classes. A species with this type of population structure was *Ekebergia capensis* and *Ziziphus mucronata*

The fifth pattern depicting “bell”- shaped (Figure 4.8e) formed with ample individuals in the middle DBH classes is characterized by few number of the lower and higher DBH classes. *Rhus retinorrhoea* and *Nuxia congesta* had bell-shaped structural pattern.

The sixth pattern representing “I”-shaped (Figure 4.8f) showed no reproduction and complete absence of individuals in regeneration and intermediate classes as exemplified by *Hagenia abyssinica*, *Erythrina brucei*, and *Podocarpus falcatus*.

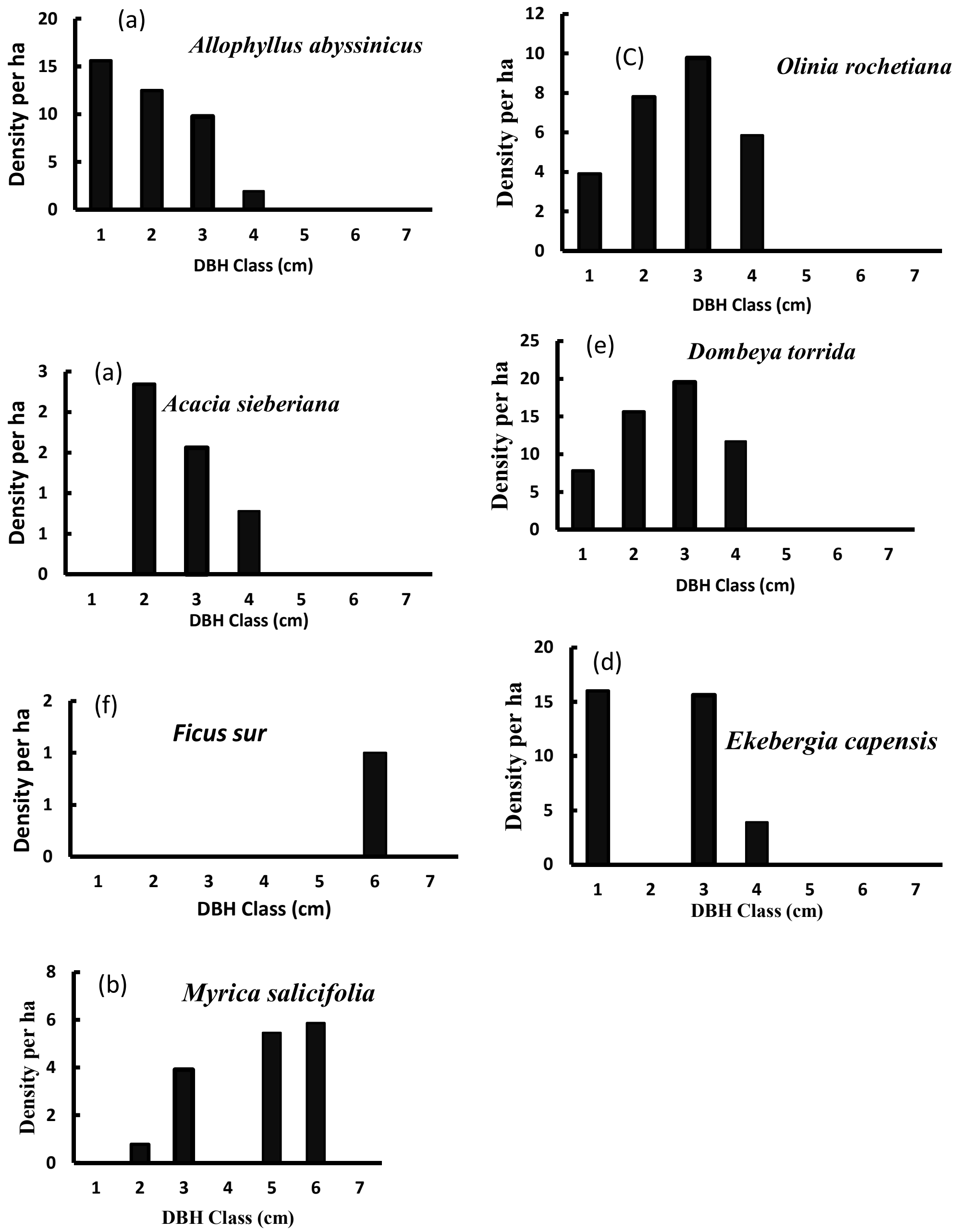


Figure 4.8 Representative patterns of species population structures in the study forests

4.3.3 Regeneration Status of Yegof Forest and its surrounding forest patches

The density of seedlings and saplings of tree species in the forests is presented in Figure 4.9, a total of 976.6 seedlings per ha, 742.2 saplings per ha, and 460.8 mature individuals per ha were recorded (Figure 4.9).

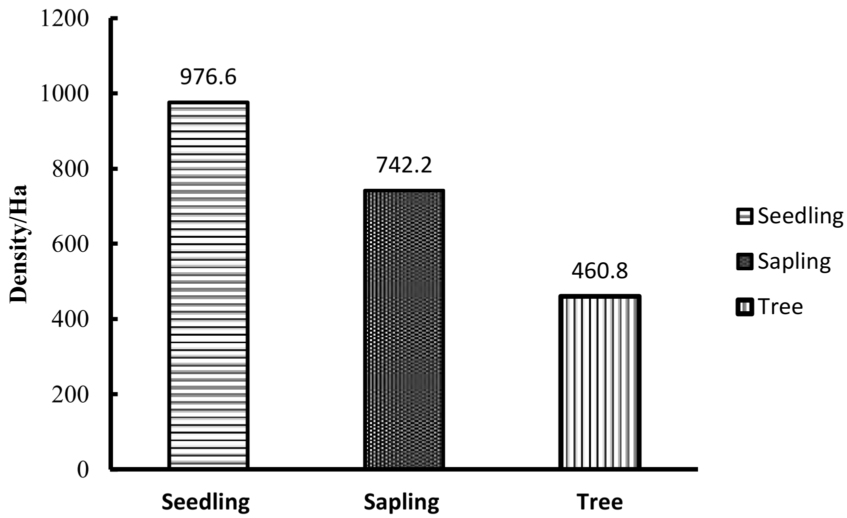


Figure 4.9 The density of seedlings and saplings of tree species in Yegof forest and its patches

The ratio of seedlings to adult individuals of tree species (DBH > 10 cm) in the forest was 2.12:1. The ratio of seedling to saplings was 1.32:1, and sapling to mature individuals was 1.61:1. The result shows the presence of more seedlings than saplings and saplings than mature trees, which indicates successful regeneration of forest species.

Of these saplings, *Myrsine africana* had 101.6 individual's ha^{-1} (13.7%), *Dodonaea angustifolia* 109.34 individual's ha^{-1} (14.7%), *Carissa spinarum* 54.7- individual's ha^{-}

[1] (7.4%), *Olea europaea* subsp. *cuspidata* 62.5 individual's ha^{-1} (8.4%) and *Euclea racemosa* 46.9 individual's ha^{-1} (6.3%) contributing to the leading proportion of individual seedling per hectare.

A total of 976.56 seedlings/ha wereas counted in the study forests. Of these, *Myrsine africana* had 281.3 individual's ha-1(22.40), *Osyris quadripartite* has 132.81 individual's ha-1(13.60) *Dodonaea angustifolia* 109.38 individual's ha^{-1} (11.20%), *Carissa spinarum* 93.75-1 (9.60%), and *Olea europaea* subsp. *cuspidata* 78.13(8%).

4.3.4 Community classification

Five plant community types were classified using of agglomerative hierarchical classification method using similarity ratio (Figure 4.10). Analysis of intera and inter community distances was also performed to evaluate the classification. Community type II and V has a lowest distance (0.86). The highest distance (0.96) was obtained between community types I and V, the highest value indicates that the communities are dissimilar (Table 4.14). The intra community distance was ranging from 0.33 to 0.43 in community III and V, respectively. The cophenetic correlation coefficient of 0.66 was obtained in this classification.

Table 4.14 Results of inter community distance

Community types	I	II	III	IV	V
Community I	0.00	0.91	0.94	0.93	0.96
Community II	0.91	0.00	0.89	0.87	0.92
Community III	0.94	0.89	0.00	0.87	0.90
Community IV	0.93	0.87	0.87	0.00	0.86
Community V	0.96	0.92	0.90	0.86	0.00

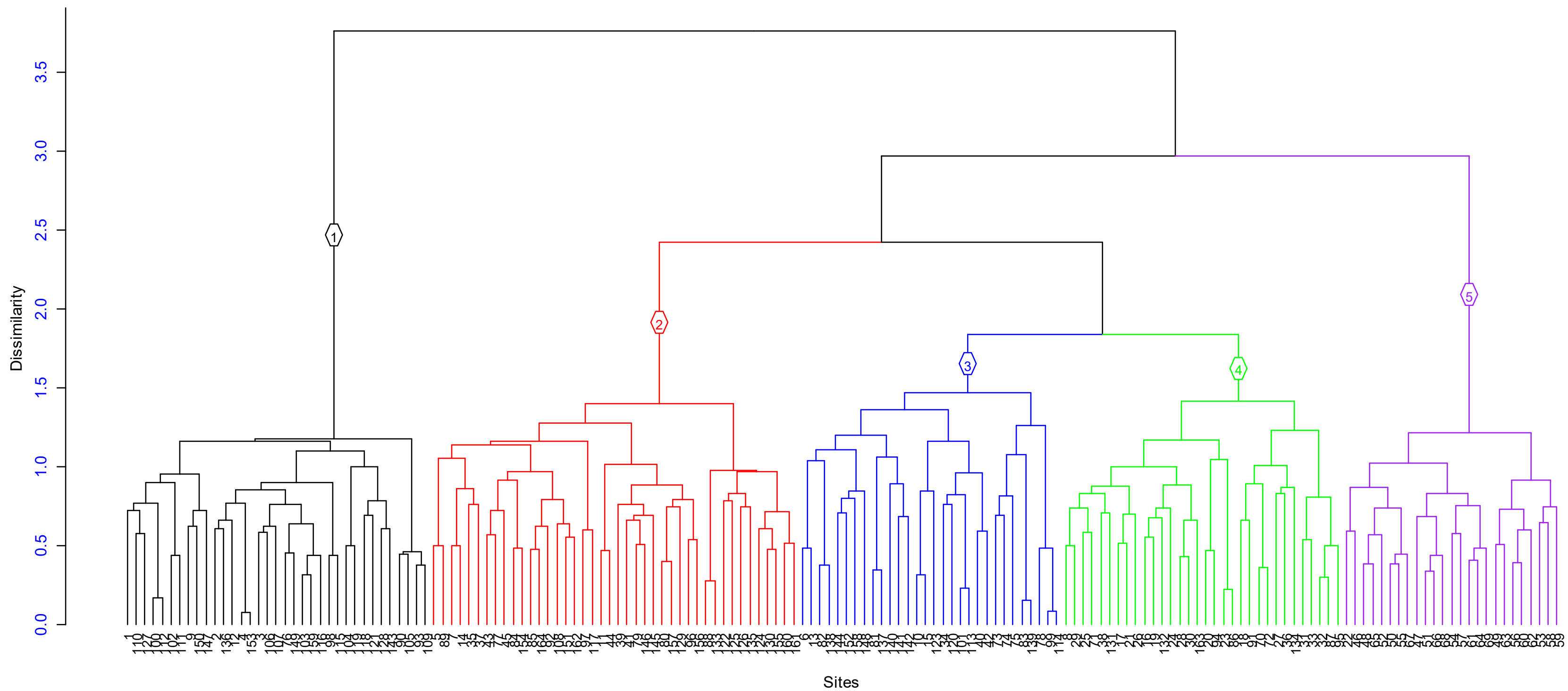


Figure 4.10 Community types as classified using Hierarchical clustering using Similarity Ratio

After performing cluster validation, two or three dominant species having the highest importance value index in the respected cluster was used as the name of the cluster (Annex 3). The established community types along with their characteristics are presented as follows:

***Juniperus procera* community (Type -1)**

This community is located between 1900 and 2800 masl with 35 plots and 161 species associated to it. *Juniperus procera, Olinia rochetiana, Bersama abyssinica, Galiniera saxifrage, Nuxia congesta* and *Myrica salicifolia* are the dominate trees. *Rosa abyssinica, Dodonaea angustifolia*, *Erica arborea* are the dominant shrubs. *Galiniera saxifrage, Alchemilla abyssinica, Laggera tomentosa* and *Hypoestes triflora* are found to be the dominant herb.

***Olea europapea* subsp. *caspidata - Olinia rochetiana* community *(*Type-II)**

This community is located between 1800 and 2900 masl with 42 plots and 182 species associated to it. *Dodonaea angustifolia, Olea europaea, Olinia rochetiana* and *Euphorbia candelabrum* are the dominate tree. *Erica arborea, Osyris quadripartite, Euclea racemosa, Jasminum grandiflorum, Jasminum abyssinicum, Lippia adoensis* and *Maytenus arbutifolia* are the dominate shrubs. *Geranium aculeolatum, Arthraxon prionodes,* are dominant herb are the dominant herb in this community type.

***Carissa spinarum - Euphorbia candelabrum* (Type III)**

This community type occurs at altitudinal ranges from 1800 to 2600 masl, which is a mid-altitude. The community is comprised of 32 plots and 154 species.

Carissa spinarum, Clutia abyssinica, Eucea racemose, Euphorbia candelabrum, Galiniera saxifraga, Myrica salicifolia Olinia rochetiana and *Ekebergia capensis are the dominant trees. Myrsine africana, Carissa spinarum, Dodonaea angustifolia, Capparis tomentosa, Maytenus arbutifolia,* and *Pterolobium stellatum* are the dominant shrubs. The dominant herbs are *Clutia abyssinica, Andropogon abyssinicus* and *Arthraxon prionodes.*

Nuxia congesta-Myrsine africana Community Type IV

The community is comprised of 32 plots and 135 species. It occurs at altitudinal ranges from 1900 to 2600 masl. *Nuxia congesta, Olea europaea, Myrica salicifolia, Galiniera saxifraga* are the dominant tree in this community.

*Erica arborea, Dodonaea angustifolia, Carissa spinarum, Myrsine africana, Buddleja polystachya, Euclea racemose,*and *Pterolobium stellatum* are the dominate shrub. *Andropogon abyssinicus* is the dominant herb.

***Acacia bervispica- Dichrostachys cinerea -Acacia seyal* community (Type V)**

This community type occurs at altitudinal ranges from 1500 to 1900 masl, which is a lower altitude. It is composed of 72 species from 25 sampled plots. In this community, *Acacia bervispica, Acacia seyal, Acacia nilotica* are the dominant tree species.

Grewia bicolor, Grewia ferruginea, Grewia trichocarpa, Cordia monoica and *Capparis tomentosa* are the dominant shrub. *Hypoestes forskaolii* and *Hyparrhenia hirta* are the dominant herb.

4.3.5 Community -environmental relationships

The multivariate analysis included 164 sampling plots, species, and environmental variables. The appropriate analysis method was selected based on the nature of the input data (Legendre and Legendre ,1998). CCA was used to display environmental factors fitted into the ordination scatter plot to depict the relationships with site and species.

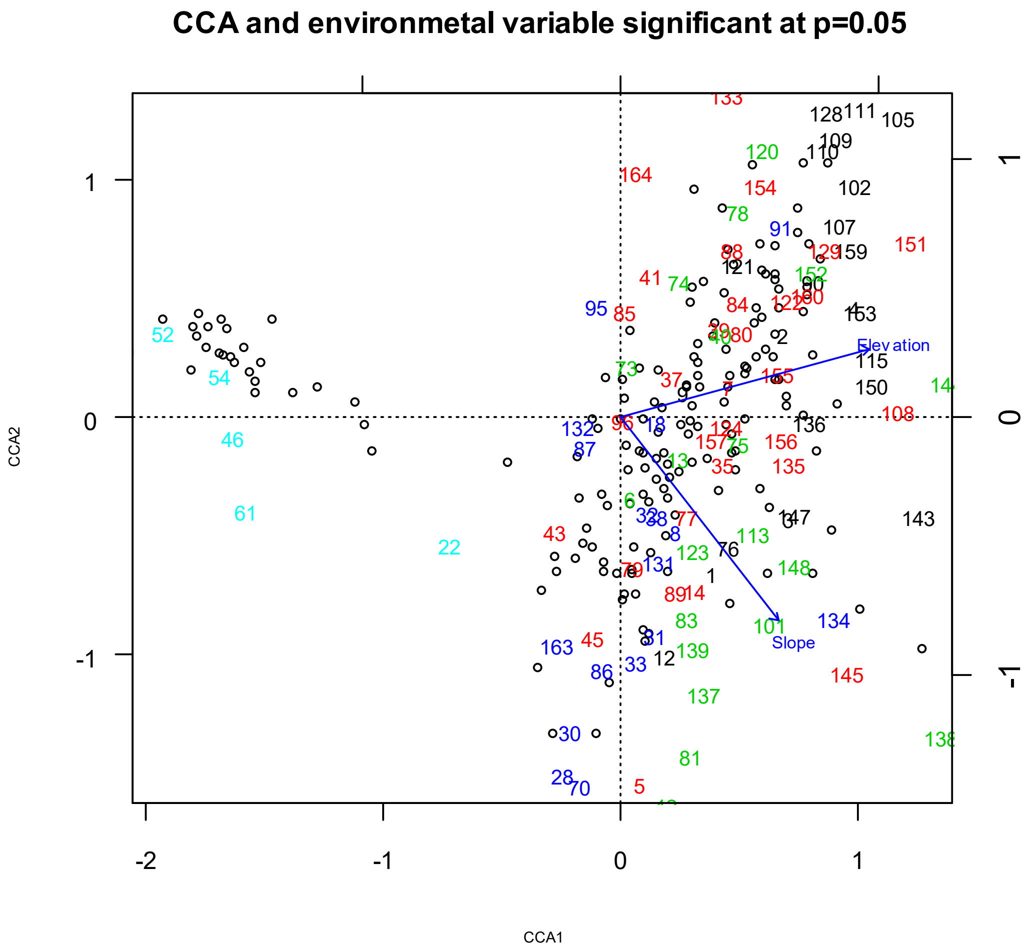


Figure 4.11 CCA1 (x -axis) and CCA2 (y -axis) to display sites and fitting environmental variables

In this study, elevation, aspect, slope, landform, and bioclimatic variables were used as environmental variables. Among this, elevation and slope have significantly difference on vegetation of the study sites.

Table 4.15 Environmental factors showing significant at p=0.05

	Df	Sums ofSqs	MeanSqs	F.Model	R2	Pr(>F)	
Elevation	1	3.871	3.8705	11.8202	0.06761	0.001	***
Aspect	1	0.393	0.3934	1.2015	0.00687	0.208	
Landform	1	0.297	0.297	0.9071	0.00519	0.596	
Slope	1	0.681	0.6809	2.0793	0.01189	0.006	**
Heatload	1	0.266	0.2664	0.8135	0.00465	0.719	
Residuals	158	51.737	0.3274	0.90378			
Total	163	57.245	1				

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The ANOVA results (Table 4.15) showed significant differences (P < 0 01) with respect to elevation and slope (P< 0.05). The elevation and slope qualifies as the best predictor for species composition as it reflects the group structure with a probability error of p = 0.05, while heat load, aspect and landform does not mirror this pattern. The majority of these tests assume that the sample is normally distributed. However, Shapiro -Wilk normality test for elevation, W=0.965, p> 0.00, alpha=0.05, as the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis (Ho), and accept the alternative hypothesis (Ha). Hence, the variable from which the sample was extracted does not follow a normal distribution and Kruskal -Wallis test was used.

Five community types identified in the Yegof and its surrounding forest patches data are significantly different in elevation and slope (Table 4.15). To identify which samples are responsible for rejecting Ho, multiple comparison procedures were used for further elaboration using Tukey's HSD (Honestly Significant Difference) test. The outputs were presented graphically using 95% family -wise confidence level (Figure 4.12).

Table 4.16 Tukey's HSD tests for the pairwise comparisons of mean differences between community, when the elevation is considered as a factor and fitted to the community.

Community types	diff	lwr	upr	p adj
II and I	-142.04	-301.47	17.39	0.11
III and I	-129.29	-302.60	44.03	0.24
IV and I	-307.47	-477.84	-137.09	0.00
V and I	-814.73	-997.14	-632.32	0.00
III and II	12.76	-153.76	179.27	1.00
IV and II	-165.42	-328.88	-1.97	0.05
V and II	-672.68	-848.65	-496.72	0.00
VI and III	-178.18	-355.21	-1.15	0.05
V and III	-685.44	-874.08	-496.80	0.00
V and IV	-507.26	-693.20	-321.32	0.00

Tukey's HSD tests for the pairwise comparisons of mean differences between community (Table 4.16) showed significant differences (p < 0 05) between the pairs of community with respect to elevation except community pairs of I-II, III-I and III-II.

Table 4.17 Tukey's HSD tests for the pairwise comparisons of mean differences between community, when it's fitted with slope as a factor.

Community types	diff	lwr	upr	p adj
II and I	-1.09	-7.19	5.02	0.99
III and I	3.09	-3.55	9.73	0.70
IV and I	3.77	-2.76	10.29	0.50
V and I	-16.01	-23.00	-9.02	0.00
III and II	4.18	-2.20	10.56	0.37
IV and II	4.85	-1.41	11.11	0.21
V and II	-14.92	-21.66	-8.18	0.00
VI and III	0.68	-6.10	7.46	1.00
V and III	-19.10	-26.33	-11.88	0.00
V and IV	-19.78	-26.90	-12.66	0.00

When slope was fitted as factor into community types , the results from the Tukey's HSD tests for the pairwise comparisons of mean differences between community has indicated (Table 4.17 and Figure 4.12) IV and I, IV and II , IV and III were significant at p >0.01, but no significant difference with respect to other commuity.

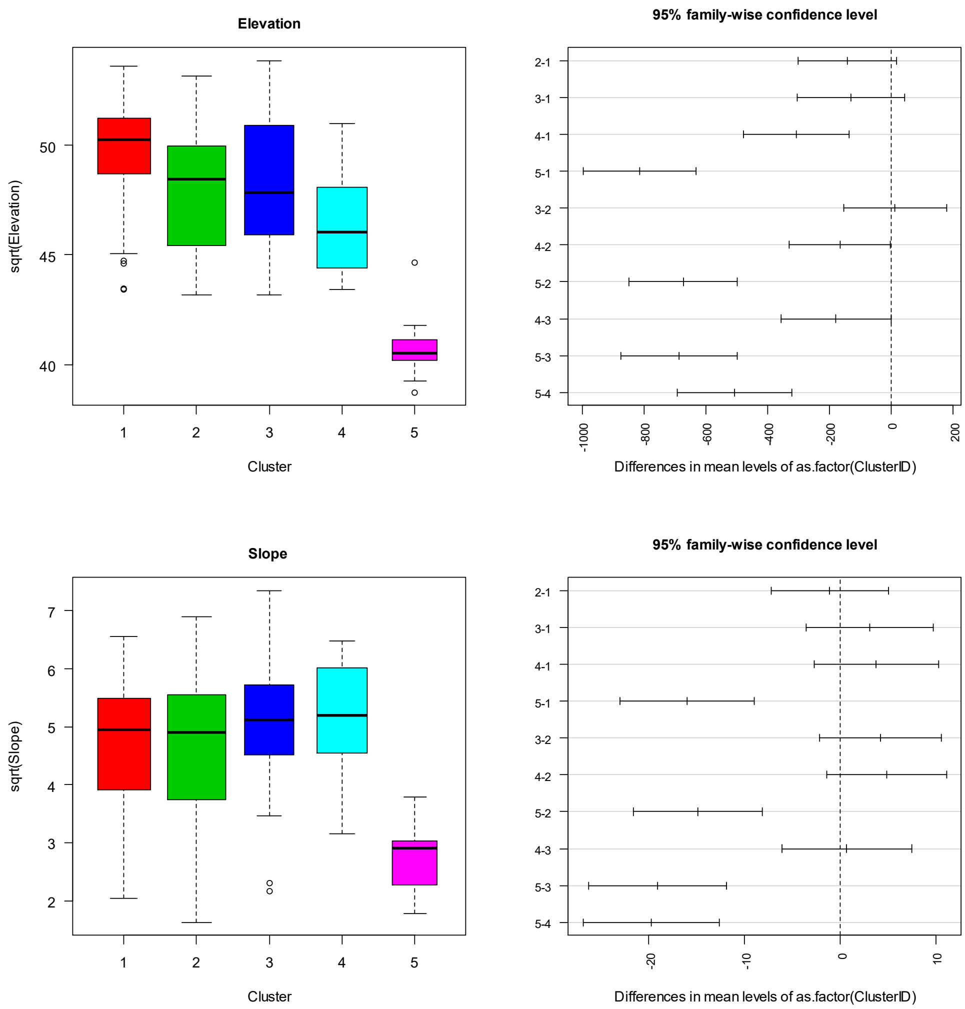


Figure 4.12 Comparison of differences among means boxplot

With regard to landform, the results of the Tukey's HSD tests has indicated that IV and I, IV and II, IV and III were found to be different. *Acacia bervispica-Dichrostachys cinerea - Acacia seyal* community was found at different landform configuration, whereas, the distribution of plant species in the study area was not influenced by aspect as a variable.

4.3.6 Plant diversity

4.3.6.1 Species area curve

Species area curve was used to estimate the expected number of new species that may be encountered for given additional sampling efforts. Figure 4.13 shows the number of species that are encountered in this study. Over 202 (77%) species were sampled only from the first 50 (30%) sampling plots. New species were not obtained on plot number 150 onwards, and then the accumulation curve was observed levelling off before the total number of sampling is reached

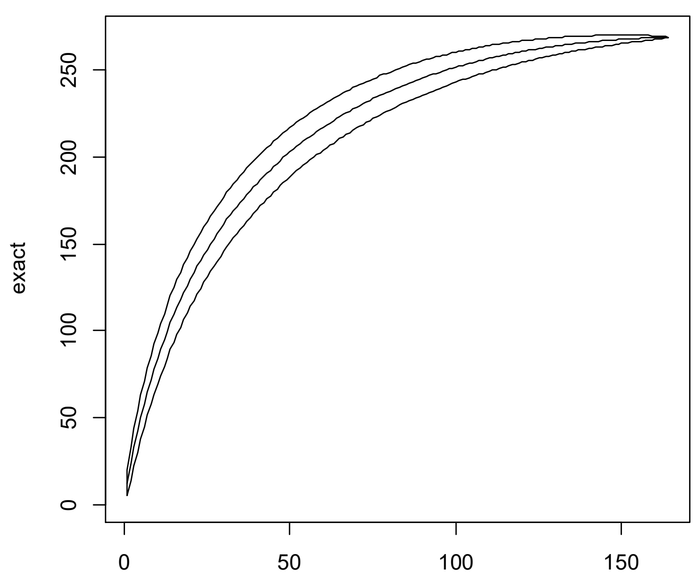


Figure 4.13 Species Accumulation Curve, the "X" and "Y" axis showed the number of sampled sites and the exact number of species that area found in the respected sites, respectively

4.3.6.2 Diversity analysis of community types

The diversity of the each community types was evaluated based on its species richness (the number of species), and evenness (the way species quantities are distributed).

Table 4.18 Diversity analysis of community types

	Richness	H	Simpson	Shannon Evenness	Simpson Evenness
Community I	161	4.23	22.80	0.83	0.14
Community II	182	4.35	29.69	0.84	0.16
Community III	154	4.56	48.88	0.90	0.32
Community IV	135	4.20	37.09	0.86	0.27
Community V	72	3.57	21.41	0.84	0.30

Table 4.18 shows an overview of the diversity analysis of the community types. Simpson diversity index of 48.88 and 21.41 were found to be the highest and lowest value in the case of community type III and community type IV, respectively.

4.3.6.3 Species richness, diversity and equitability in the Yegof forest and its patches

Comparison of the forests based on their species richness, diversity and equitability were made using wide range of diversity measures, only the selected indices for this study is presented in Table 4.19.

Table 4.19 The Estimates of diversity of Yegof forest and its surrounding patches, south Wollo, Ethiopia.

Forest	Richness	H	Simpson	Shannon Evenness	Simpson Evenness
Abuli	83	3.83	24.35	0.87	0.29
Biraro	79	3.97	38.35	0.91	0.49
Harego	90	4.14	42.21	0.92	0.47
Harbu	55	3.60	26.54	0.90	0.48
Erkis	110	4.33	49.79	0.92	0.45
Suki	115	4.29	39.40	0.90	0.34
Yegof	199	4.61	44.59	0.87	0.22

The total number of species in Abuli was 83, 79 in Biraro, 90 in Harego, 55 in Harbu, 110 in Erkis, 115 in Suki, and 199 in Yegof. Generally, Yegof would be considered to be more diverse since it has one hundred 199 species of vascular plants but Harbu has only fifty -five.

The value of Shannon diversity in Abuli was (3.83), Biraro (3.97), Harego (4.14), Harbu (3.60), Erkis (4.33), Suki (4.29) and 4.61 in Yegof. The highest value of Shannon diversity was found in Yegof and the lowest in Harbu (Table 4.19).

The value of Simpsons evenness in Abuli was (0.29), Biraro (0.49), Harego (0.47), Harbu (0.48), Erkis (0.45), Suki (0.34) and Yegof (0.22). The highest value of Simpsons evenness was found in Biraro (0.49) and lowest in Harbu (0.22).

The correlation coefficient is a measurement of the similarity of the variables: the more the variables are similar, the higher the correlation coefficient. The similarity coefficients using spearman correlation coefficient was calculated (Table 4.20). The correlation coefficient of 0.62 was obtained between Harego and Biraro forests, of 0.59 was between Suki and Harego and 0.59 between Harego and Abuli. Harbu forest is less correlated with Yegof, Suki, and Erkis with the values of 0.13, 0.31, and 0.35, respectively.

Table 4.20 Spearmans rank correlation among the forest Patches

	Abuli	Biraro	Harego	Harbu	Erkis	Suki	Yegof
Abuli	1.	*	*	*	*	*	*
Biraro	0.4832	1.	*	*	*	*	*
Harego	0.5913	0.6205	1.	*	*	*	*
Harbu	0.4001	0.4967	0.4373	1.	*	*	*
Erkis	0.5528	0.4699	0.5285	0.3526	1.	*	*
Suki	0.5239	0.4999	0.5948	0.3149	0.5205	1.	*
Yegof	0.5813	0.3223	0.459	0.1356	0.5069	0.5474	1.

Harego, Abuli, and Biraro forests were found to be relatively highly similar. The correlation coefficient was ranging from 0.59 to 0.62. Those forests areas were found to have more similar variables, whereas, Harbu contained different variable with other forests. Each of such an area will, therefore, contain species that are found there and nowhere in other forests.

4.3.6.4 Similarity of the Yegof forest with other vegetation of Ethiopian

A similarity analysis was carried out using Sorensen index to evaluate the similarity of the Yegof forest & its surrounding forest patches with other five forests of Ethiopia (Table 4.21).

Table 4.21 Floristic similarities between vegetation of Yegof & its surrounding patches and five other vegetation

Forest	Elevation	a	b	c	Sor.
Yegof forest & its surrounding patches	1500 - 2900				
Borena Sayint National Park[1]	2100 - 3700	173	234	121	0.59
Bale mountains National Park[2]		251	179	43	0.20
Zengena Forest[3]	2,470 -2,585	268	24	26	0.18
Hugumbirda-Gratkhassu NPFA[4]	1780 - 2700	248	56	46	0.30
Vegetaion of Central Plateau of Shewa[5]	2581- 2900	250	158	44	0.22

Key: Where C= Common species, species in Yegof & its patches; b= Species of the compared forests; Sor = Sorensen index; 1= Hussien Adal (20014); 2 = Haile Yineger et al. (3010–3410); 3= Desalegn Tadele et al. (2013); 4= Leul Kidane et al. (2010); and 5= Tamrat Bekele (1993).

The forests of Yegof and Borena Sayint National Park showed a higher (0.59) similarity to each other than to any other forest. The second higher similarity (0.30) was obtained between Yegof and Hugumbirda -Gratkhassu NPFA (Table 4.21).

4.4 Human-Forest Interactions

Human-forest interactions are a very wide concept while this study deals with the status of the forest, drivers of forest decline, agent of deforestation and preferred intervention to manage forest resources of the area.

4.4.1 Economic and demographic description of the households

The sample population was composed of 93% male and 7% female respondents. Among the respondents, 93% were married, 3% were single, and the remaining 4% were divorced. 83% of the respondents have lived in the area for the last three decades. Only 6% of the respondents attended secondary school, 11% attended elementary school, 34% can read and write; whereas, 41% of the respondents were illiterate.

On the basis of the economic class of the respondents, 11.7% of the respondents were rich, 71.5% medium; whereas, 16.7% of the respondents were poor. Regarding the occupation of the heads of the households, the majorities, i.e., 91% of the respondents were farmers, 5.3% of the respondents were civil servants, and the remaining were pity traders and daily labourers.

Table 4.22 Economic bases of the sample population

Wealth types	N	Minimum	Maximum	Mean	Std. Deviation
Land holding	281	0	2	.76	.335
Large-ruminant animals	239	1	6	2.64	1.083
Small-ruminant animals	162	1	11	3.60	2.075
Chickens	161	1	10	3.52	2.133
Pack animals	67	1	3	1.27	.510

Key where, large ruminant animals = cows and oxen; small ruminant animals = sheep and goat. *Source*: Own data, 2016, As indicated in Table 4.22, the average holdings at household level for live animals were 2.64 large ruminant animals, 3.60 small ruminant animals and 1.27 pack animals and the average land holding size for the majority of the respondents was found to be 0.76 ha, with an exception of two individuals who were considered landless.

4.4.2 The status of the forest resource

The Forest has experienced a long history of deforestation starting about 2450 BC (Hurni 1988). However, drawing such long period information in social studies was found very difficult. Therefore, in this study, the recent history of the forest dynamics was captured.

Table 4.23 Perception of the respondents on the status of forest

Perception of the Respondent			Year in period					Total
				> 10 years	10–20 years	20–30 years	Before 30 year	
Forest cover change	Increased	Count	0	40	63	12	1	116
		%	0.00%	34.50%	54.30%	10.30%	0.90%	100.00%
	Decreased	Count	0	10	4	72	3	89
		%	0.00%	11.20%	4.50%	80.90%	3.40%	100.00%
	Remained unchanged	Count	73	0	0	0	0	73
		%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	Indifferent	Count	3	0	0	0	0	3
		%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Total		Count	76	50	67	84	4	281
		%	27.00%	17.80%	23.80%	29.90%	1.40%	100.00%

Source: Own data, 2016; where, % = indicated the within forest cover change.

In terms of forest quality, nearly all respondents feel that Yegof forest has been deteriorating in its quality (Table 4.23). 41% of the respondents feel that the size of forest area has increased and the remaining 31.7% of the respondents indicated that the size forest area has been reduced from time to time.

Among those respondents, 80.9% have maintained that considerable area of forestland had gone from the year 1986 to 1996; while, some respondents (11.2%) feel that forest area was being reduced in size during the last ten years.

4.4.3 Agent of deforestation

Those respondents perceiving the size of the forest area has reduced were also asked to describe whom they suspected them as an agent for the deforestation and according to their response, youth along with landless farmers and Kebele administrative bodies, were suspected as primary agents for participating in the deforestation activities by 83.3% (n=75) and 7.8% (n=7), respectively.

Table 4.24 gives the perception of respondents the towards forest conversion, 62% of the them feel that forest was converted to shrub land.

Table 4.24 The number of the respondent on forest conversion

	Forest of the area was changed into	Frequency	Percent
1	Open and farm land	25	28.09%
2	Shrub land	56	62.92%
3	Grazing land	5	5.62%
4	Settlement	3	3.37%

Source: Own data, 2016

4.4.4 Major drivers of forest decline

The four major drivers of deforestation were identified by key informants and participants of focus group discussions were (i) low legal enforcement on penalizing the wrong doers, (ii) lower agricultural productivity and food insecurity which in turn impose additional pressure in harvesting products from forest to earn an income for their livelihoods, (iii) poor forest governance leads the forest to the open access situation, and (iv) high fuelwood energy demand.

The respondents has also identified and rated the as major causes for the decline of forest resources in the area (Table 4.25). The respondents were asked to list the drivers and then they tried to rank the driver according to the degree of severity. During ranking the causes, the respondents used the values ranging from 1 up to 7. The smaller value (1) was assigned for primary cause and the larger value (7) was allotted for the drivers that have a negligible impact on the ongoing deforestation process.

Table 4.25 The identified and rated causes of deforestation in and around Yegof Forest

Rank	Causes of deforestation	Mean	Std. Deviation
1	Fuelwood consumption	2.80	1.83
2	Construction and timber uses	2.98	1.82
3	Agriculture land expansion	4.13	1.90
4	Grazing activities	4.14	1.67
5	Urban expansion	4.15	2.36
6	Climate related change	4.55	2.12
7	Burning of Forest	4.85	1.24

Source: Own data, 2016

Table 4.25 presents the major LULC drivers of the study area as stated by the majority of the respondent. According to these respondents, fuelwood consumption was ranked first followed by demand for construction or timber use as second and expansion of land for agricultural purposes as the third ranked factors responsible for the deforestation occurred in the area.

4.4.4.1 Agriculture land expansion and settlement

The average size of land holding in the area was 0.76 ha. This study also revealed that about one-thirds of the interviewed households own land size of 0.5 ha per household. 76.2% of the respondents have believed that the size of the cultivated land in the area was remained unchanged for the last 30 years. However, 5.3% of respondents stated that open and farm land have increased at the expense of the forest and shrub land. On the other hand, 18.5% of the farmers living far away from the forest have pointed out that those previous areas allotted for farmland were converted into settlement.

4.4.4.2 Fuelwood

Fuelwood harvesting is the major cause of deforestation in the area. The majority (96%) of the households interviewed stated that the dominant source of household energy consumption in the area comes from fuelwood. Animal dung and crop residues were also used as an alternative source of household energy following fuelwood. Regarding fuel sources, of the total respondents, 50% (n=141), 28% (n=79), and 17% (n=50) used to collect fuelwood from Agricultural land, forest, and homestead, respectively. The remaining households were found dependent for their energy source from fuelwoods collected from the community woodlot and grazing land.

Table 4.26 Cross tabulation of sources of fuelwood of the households versus distance from Yegof forest

			Distance residents from forest			Total
			1	2	3	
Fuelwood sources	Agricultural land	Count	25	72	44	141
		%	31.20%	58.10%	57.10%	50.20%
	Forest	Count	41	27	11	79
		%	51.20%	21.80%	14.30%	28.10%
	Community woodlot	Count	0	0	2	2
		%	0.00%	0.00%	2.60%	0.70%
	Grazing land	Count	2	2	1	5
		%	2.50%	1.60%	1.30%	1.80%
	Homestead	Count	12	23	15	50
		%	15.00%	18.50%	19.50%	17.80%
	Market	Count	0	0	4	4
		%	0.00%	0.00%	5.20%	1.40%
Total		Count	80	124	77	281
		%	100.00%	100.00%	100.00%	100.00%

Source: own data, 2016

When we evaluate the respondents dependence rate on the forest in obtaining fuelwoods for their household consumption on the basis of using distance from the forest as a factor in the first distance category (0-1 km), the majority (51.20%) of the respondents are highly dependent on fuelwoods collected from the forest and the trend of dependency on fuelwoods collected from the forest has reduced as one moves from distance category one to category three (Table 4.26).

4.4.4.3 Livestock farming and grazing activities

Livestock grazing was ranked the fourth among the identified causes of deforestation in the study area (Table 4.29).

Table 4.27 Available feed s for their livestock cross tabulated with distance from the forest, Each subscript letter denotes a subset of distance from forest categories its column proportions do not differ significantly from each other at the 0.05 significance level.

Source of Feed			Distance of residents from the forest			Total
			1	2	3	
Available feed s for their livestock	Freely grazing on Agricultural land	Count	7a	26b	11a,b	44
		%	15.90%	59.10%	25.00%	100.00%
	Forestland (Freely grazing)	Count	48a	11b	5b	64
		%	75.00%	17.20%	7.80%	100.00%
	Grazing land (Freely grazing)	Count	2a	19b	9b	30
		%	6.70%	63.30%	30.00%	100.00%
	Cut and carry from the forestland	Count	8a	33b	7a	48
		%	16.70%	68.80%	14.60%	100.00%
	Factory products residues	Count	0a	0a	2a	2
		%	0.00%	0.00%	100.00%	100.00%
	Agricultural residues	Count	5a	20b	24c	49
		%	10.20%	40.80%	49.00%	100.00%
	None	Count	10a	15a	19b	44
		%	22.70%	34.10%	43.20%	100.00%
Total		Count	80	124	77	281
		%	28.50%	44.10%	27.40%	100.00%

Source: Own data, 2016

As shown in Table 4.27, the majority of the respondents used the forestland as major alternative feed source for their livestock. Those individuals residing near the forest were found entirely dependent on the forest as they practiced free grazing system for their large ruminat animals.

4.4.5 Preferred intervention to manage forest resources

Governments of Ethiopia, both in the past and at present have tried to implement different intervention measures with a major objective of safeguarding the remaining forest resources. For instance, after the year 2011, the managerial responsibilities and use rights of Yegof forest was transferred to the Amhara National Regional State Forestry Enterprise under the regions legal ground. The newly established enterprise has started harvesting of the plantation species with little involvement in the establishment of new plantation as seen so far. The majority (72.6%) of the respondents were not satisfied with the current situation practiced by the enterprise, but the remaining, 27.4% were found happy with the current forest management options implemented by the enterprise.

In this study, the participants in the focus group discussions have also revealed that the forest enterprise has started clearcutting method while harvesting the forest products from the plantations established at earlier times with great efforts. This harvesting method has clearly caused conflict with interest and aspiration of the community. The local community feared the inevitable degradation, desertification, loss of forest diversity, and loss of fuelwood sources as a consequence to occur due to the ongoing implementation of inappropriate forest harvesting using clearcutting method by the enterprise.

Conserving the remaining forest with halting the current ongoing harvesting operation was found to be an ideal forest management option by the 128 (45.6%) respondents. These respondents were describing the possible benefits to be earned if their preferred management option mentioned above has got acceptance from the government. According to these respondents, with the implementation of such management option, they enumerated the following possible benefits; (1) avoiding the depletion of water resources, (2) maintaining soil fertility, (3) conserving the forest diversity, (4) insuring the sustainability and (5) maintaining their ritual and religious ceremonies practiced in the forest so far.

Twenty seven percent of the respondents showed their interest that they prefer the enterprise should establish its own forest and harvest its own rather than exploiting the already established. They argued that this type of intervention is believed to increase the size of the forest area and facilitates the introduction of new technologies proven to be a panacea for the improvement of the survival of tree seedlings challenging them at present in the area.

These responses are very important in designing management options that have compatibility with their interest and acceptance by the community. This, in turn, requires identifying important characteristics of respondent households for predicting their preferred management options.

A robust multinomial logit regression model was used to determine the different characteristics of respondents with their preference for specific management option. The likelihood-ratio tests for independent variables also resulted in rejection of the null hypothesis for each of the independent variables that it is not different from zero (Table 4.28).

Probability (p) value was computed from the chi-square distribution to test the fit of the multinomial logistic regression model. The deviance goodness-of-fit test significance is higher than 0.05 (that is, is non-significant); we fail to reject the null hypothesis that there is no difference between observed and model-predicted values, implying that the model's estimates fit the data at an acceptable level. The model fit pseudo-r^2 value of 0.726 and 0.816 for the case of cox and snell and Nagelkerk, respectively. It reflects a good relationship of the predictor variables to the dependent variable.

Table 4.28 Likelihood Ratio Test

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Attended elementary school (yes = 1)	234.577	17.187	2	.000
Attended secondary school (yes = 1)	221.617	4.227	2	.121
Reads and writes (yes = 1)	233.547	16.157	2	.000
Distance	226.443	9.053	2	.011
Wealth class	227.946	10.556	2	.005
Livestock owners	218.173	.783	2	.676
Family size	224.711	7.321	2	.026
Farm size	218.950	1.560	2	.458
Sex	235.434	18.044	2	.000
Occupation	217.616	.226	2	.893
Current intervention was not satisfactory	368.449	151.059	2	.000
The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.				

Source: own data, 2016

Among the listed sets of parameter estimates, farm size, being an owner of livestock and occupation were not significant in determining any of the forest management options (Table 4.28). All of the other variables have small (less than 0.05) significance values, so you can consider them as factors.

Table 4.29 Determinants of preferences of local community in the forest utilization

Forest Management Option a*		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								LB	UB
Conservation only	Attended elementary school (yes = 1)	3.97	2.96	1.80	1	0.18	53.17	0.16	17679.48
	Attended secondary school (yes = 1)	3.26	3.91	0.70	1	0.40	26.14	0.01	55689.09
	Reads and writes (yes = 1)	1.46	1.22	1.42	1	0.23	4.31	0.39	47.49
	Distance	-2.06	0.86	5.73	1	0.02	0.13	0.02	0.69
	Wealth class	0.49	0.95	0.26	1	0.61	1.63	0.25	10.57
	Livestock owners	-0.01	0.43	0.00	1	0.98	0.99	0.42	2.32
	Family size	0.70	0.30	5.37	1	0.02	2.01	1.11	3.63
	Farm size	-0.27	1.39	0.04	1	0.85	0.76	0.05	11.65
	Sex (male = 1)	3.43	1.97	3.03	1	0.08	30.98	0.65	1479.2
	Occupation	0.11	0.66	0.03	1	0.87	1.11	0.31	4.03
	current intervention was not satisfactory	-8.26	1.60	26.56	1	0.00	0.00	0.00	0.01
Re afforestation and harvesting	Attended elementary school (yes = 1)	1.87	3.01	0.39	1	0.53	6.49	0.02	2351.24
	Attended secondary school (yes = 1)	2.02	3.92	0.27	1	0.61	7.55	0.00	16421.44
	Reads and writes (yes = 1)	-0.03	1.24	0.00	1	0.98	0.98	0.09	10.96
	Distance	-1.62	0.86	3.52	1	0.06	0.20	0.04	1.08
	Wealth class	-0.48	0.96	0.25	1	0.62	0.62	0.10	4.04
	Livestock owners	0.13	0.44	0.09	1	0.76	1.14	0.48	2.71
	Family size	0.59	0.30	3.78	1	0.05	1.80	1.00	3.26
	Farm size	-0.92	1.41	0.43	1	0.51	0.40	0.03	6.31
	Sex (male = 1)	5.53	1.96	7.96	1	0.01	251.77	5.41	11715.20
	Occupation	0.18	0.67	0.07	1	0.79	1.20	0.32	4.48
	current intervention was not satisfactory	-8.56	1.67	26.33	1	0.00	0.00	0.00	0.01

Where a= the reference category is clear-cutting; UB=Upper Bound; LB= lower Bound; *B* = coefficient; Std. Error =standard error of *B*; Wald =Wald statistic,; exp(*B*)= log-likelihood if term removed from model. (*Source*: Own data, 2016.)

Different factors influence the choice of preferred options for managing the forest in the area (Table 4.29). Among the factors, sex, literacy level, distance from the forest, wealth class, number of livestock owned and current intervention had positive significant effects on the choice of a specific management option. Distances away from the forest are negatively correlated with only conservation option. Respondent supporting conservation was preferred by those who were situated near to the forest rather than far distant increased by a factor of 0.13 of the odds favouring conservation rather than opposing. Similarly, respondents situated far away from the forest were negatively correlated with re-afforestation and harvesting option. Near to the forest rather than far away from the forest increases by a factor of 0.20 the odds of favouring afforestation and harvesting rather than opposing. Respondents whose literacy level are reading and writing only tend to favour the conservation only option. However, respondents with education level of less than reading and writing (0) than reading and writing increases by a factor of 4.31 the odds of favouring conservation rather than opposing.

Table 4.30 Observed and predicted functions

Observed	Predicted			
	Conservation only	reforestation and harvesting	Clearcutting	Percent Correct
Conservation only	93	15	2	84.5%
Reforestation and harvesting	29	35	2	53.0%
Clearcutting	0	2	61	96.8%
Overall Percentage	51.0%	21.8%	27.2%	79.1%

(Source: Own data, 2016)

In Table 4.30, the number of errors where the predicted value of the dependent variable (51.05%, and 21.8% and 79.1%) was lower than the observed value (84.4%, 53.0% and 96.8%) as a percent of all cases on or below the diagonal, are termed as false negative rate. Therefore, overall percentage of the model, which showed 79.1%, is the best. Hence, most respondents favoured conserving the remaining forest as the predicted, corrected value of 84.5%.

4.5 Modelling the Distribution of *Hagenia Abyssinica*

This section uses *Hagenia abyssinica* as a case study to understand the impacts of changing climate. This study found in the forest of the study area.

4.5.1 Omission and prediction

The omission rate is a statistic indicating a model performance (Scheldeman and Zonneveld, 2010). For this study, the statistical analysis was performed using 25% of the sample records that were randomly set aside for validity testing (Phillips, 2017). As shown in Figure 4.14, the omission on the test sample was fitted with predicted omission.

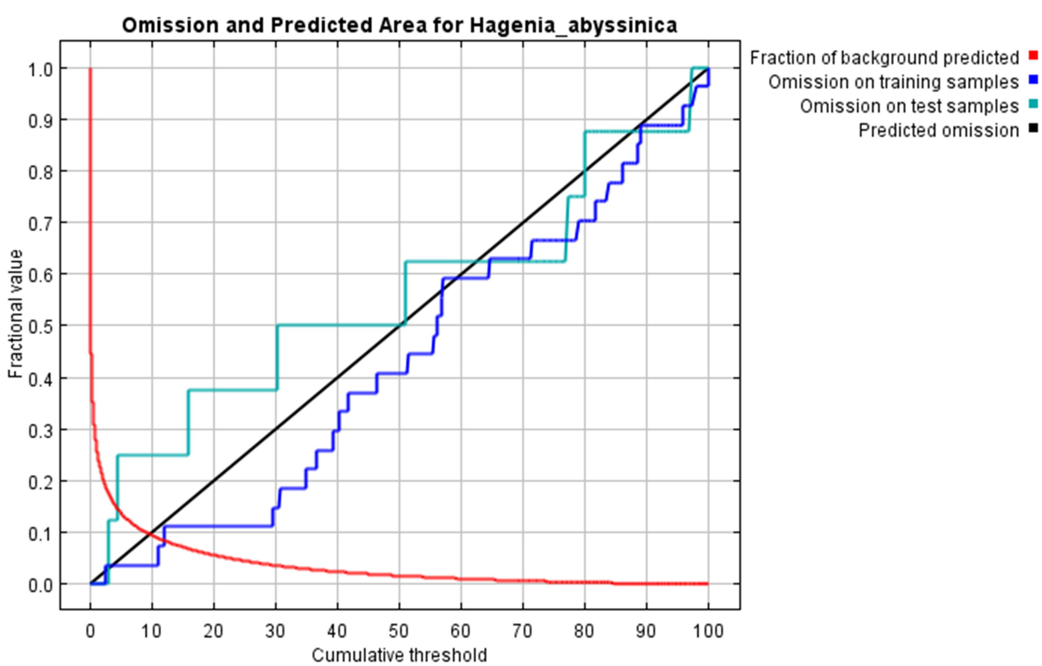


Figure 4.14 Omission and predicted area for *Hagenia abyssinica*

The parameters used for evaluating the predictive ability of the models generated by MaxEnt, the Area Under Curve (AUC) is presented in Figure 4.15 indicating the red (training) line to show a higher AUC than the blue (testing) line.

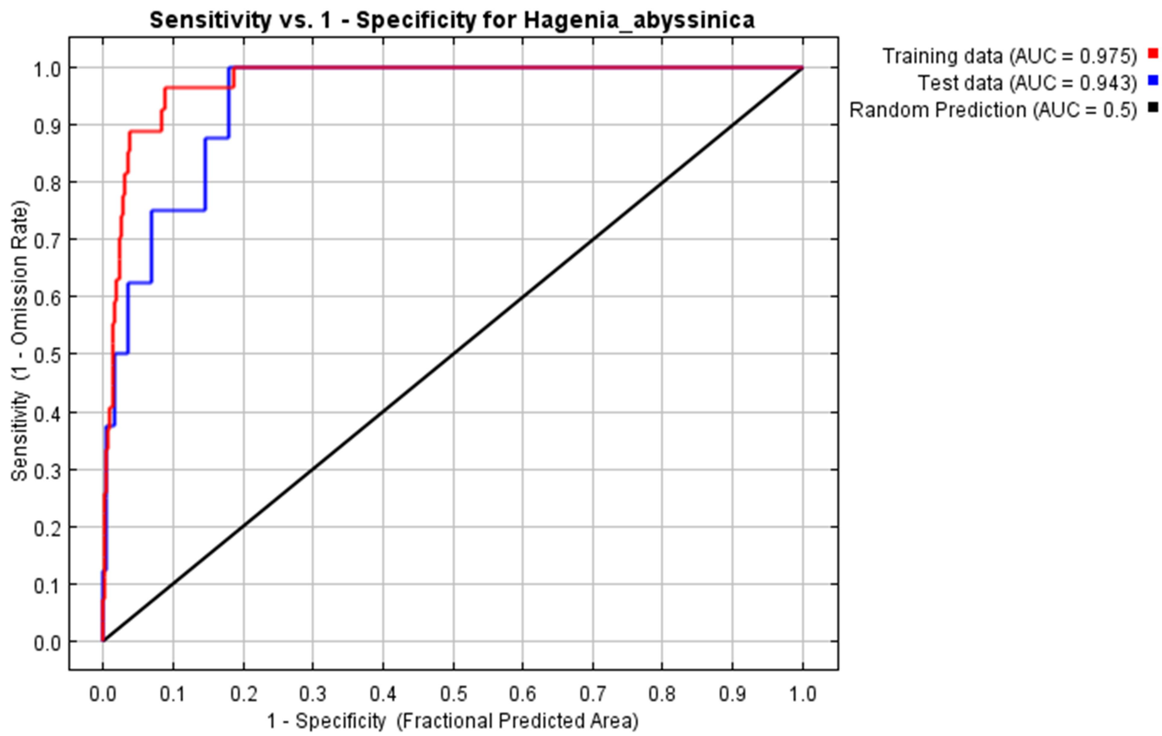


Figure 4.15 Sensitivity Vs specificity for *Hagenia abyssinica* species

Hence, the red line showing the "fit" of the model to the training data is the real test of the model's predictive power. Moreover, the blue line does not falls below the turquoise line indicating that the model performs better than a random model. Moreover, the AUC for training and test data was found to be more than 0.943. This indicated that the model is excellent in its predictability.

4.5.2 Analysis of the Realized Niche of *Hagenia abyssinica*

The realized niche of *Hagenia abyssinica* was identified based on the current specie's presence points and the corresponding climate data. Following the procedure outlined by (Scheldeman and Zonneveld, 2010), a two-dimensional climatic niche based on bio1 and bio12 climate parameters as presented in Figure 4.16; the annual mean temperature and annual precipitation for *Hagenia Abyssinica* ranges from 9 °c to 19 °c and 940 to 1985 mm per year, respectively.

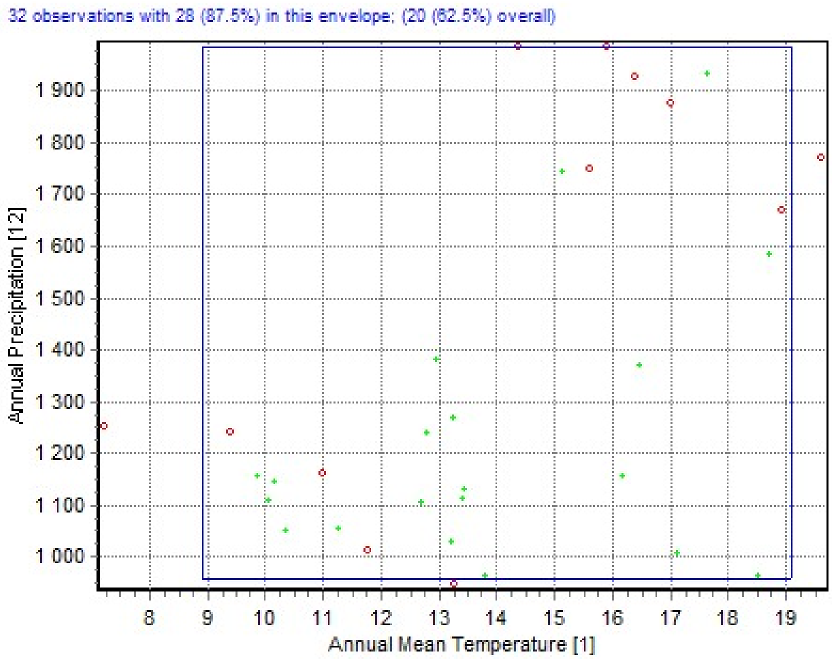


Figure 4.16 Two dimensional climate niche based on the annual mean temperature and annual precipitation

Hagenia abyssinica was found well adapted in those areas receiving the precipitation during warmest quarter ranging from 220 to 570 mm per quarter and the maximum temperature in the warmest month ranging from 10 to 20 °c (Figure 4.17)

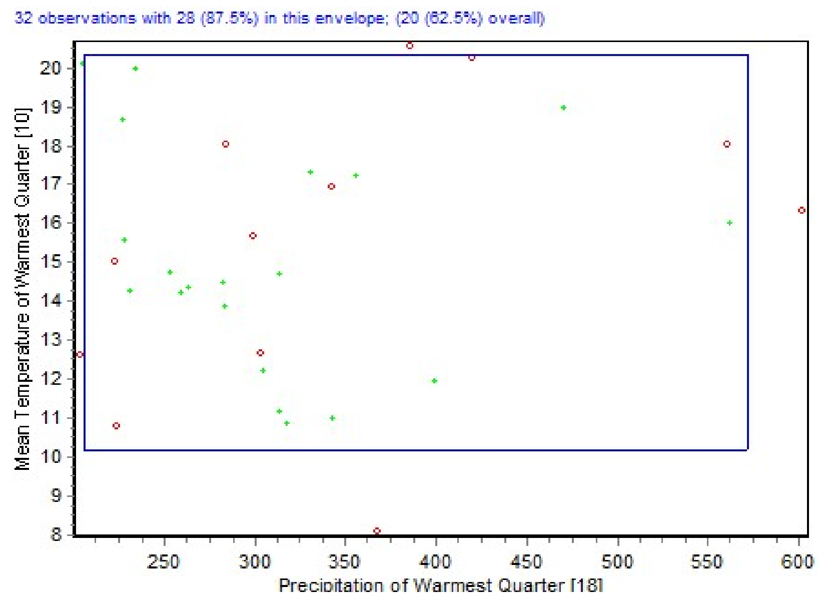


Figure 4.17 Precipitation of warmest quarter and mean temperature of warmest quarter

The maximum temperature of the warmest months ranging from 15 to 30 ^{o}c, and an altitudinal ranges from 2200 to 3400 m are found to be the actual suitable areas for the specie (Figure 4.18). Moreover, other bioclimatic variables are presented in Table 4.31

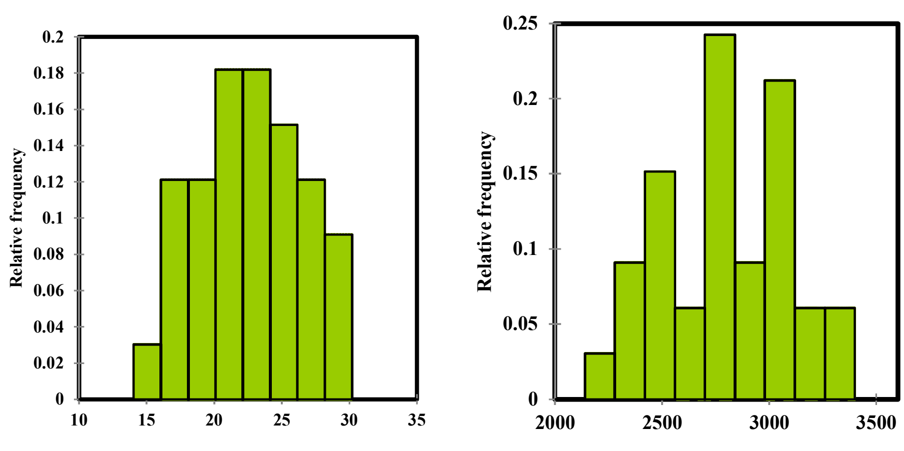


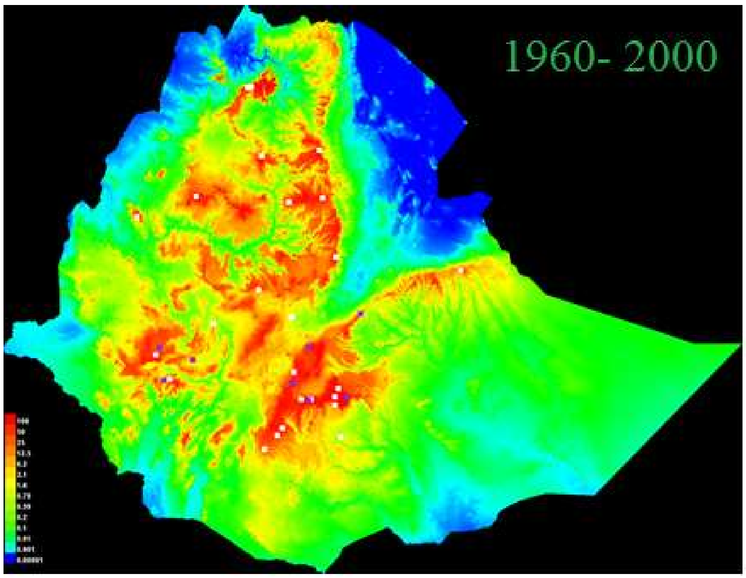
Figure 4.18 Max temperature of warmest month (left) and elevation above sea level

Table 4.31 The realized niches of *Hagenia abyssinica* using the current climate data

Code	Variable	Minimum	Maximum	Mean	Std. deviation
alt	Altitude	22.000	3350.000	2767.000	312.033
bio1	Annual Mean Temperature	6.725	19.613	13.946	3.234
bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	11.633	15.458	13.557	1.085
bio3	Isothermality (BIO2/BIO7) (* 100)	70.479	81.755	76.700	2.921
bio4	Temperature Seasonality (standard deviation *100)	61.143	135.587	89.501	22.608
bio5	Max Temperature of Warmest Month	14.200	29.200	22.791	3.721
bio6	Min Temperature of Coldest Month	-0.500	10.400	5.082	3.009
bio7	Temperature Annual Range (BIO5-BIO6	14.500	20.500	17.709	1.651
bio8	Mean Temperature of Wettest Quarter	6.183	19.467	13.639	3.168
bio9	Mean Temperature of Driest Quarter	6.850	19.767	13.496	3.393
bio10	Mean Temperature of Warmest Quarter	7.600	20.550	15.119	3.291
bio11	Mean Temperature of Coldest Quarter	6.167	18.800	12.979	3.257
bio12	Annual Precipitation	946.000	1985.000	1333.394	347.765
bio13	Precipitation of Wettest Month	137.000	434.000	249.273	82.111
bio14	Precipitation of Driest Month	2.000	45.000	19.636	11.280
bio15	Precipitation Seasonality (Coefficient of Variation)	43.989	130.290	74.055	28.752
bio16	Precipitation of Wettest Quarter	373.000	1099.000	642.636	192.293
bio17	Precipitation of Driest Quarter	8.000	175.000	84.455	44.286
bio18	Precipitation of Warmest Quarter	204.000	602.000	323.394	104.438
bio19	Precipitation of Coldest Quarter	21.000	1077.000	313.061	298.437

4.5.3 Modelling the potential distribution of *Hagenia abyssinica*

Figure 4.19 shows the representation of the MaxEnt model for *Hagenia abyssinica*. In this model, warmer colours show areas with better-predicted conditions. White dots show the present locations used for training, while violet dots show test locations.



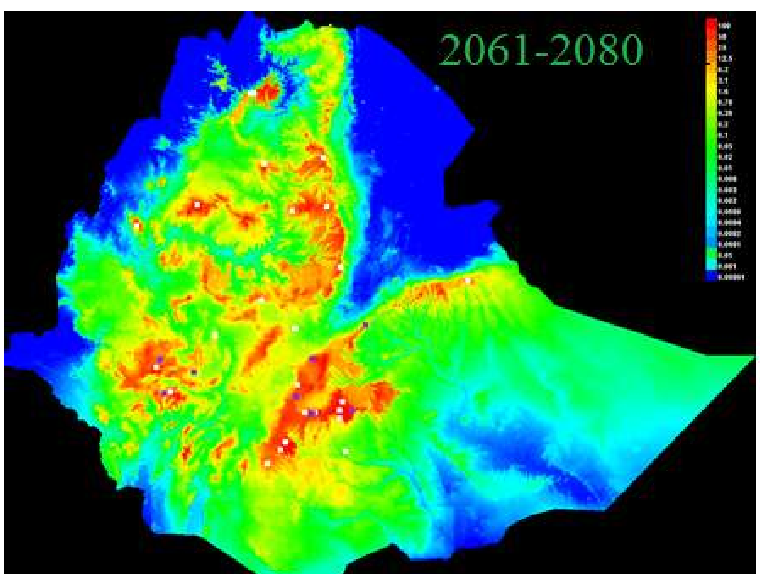


Figure 4.19 Representation of the MaxEnt model for *Hagenia abyssinica* of the two periods: current condition (1960-2000) and future climate (2070-2080).

To conceptualize this outputs, determine the location of *Hagenia abyssinica* and define conservation strategies for the species, Ethiopian administration (shp, shx, dbf) files and the potential distribution map that was generated in MaxEnt have been imported to DIVA -GIS. Those files were opened, visualized and the results were interpreted as highlands of Arsi (ONRS), Sidama (SNNP), Jima (ONRS), South Wollo (ANRS), North Wollo (ANRS), Southern Tigray (TNRS), North Gonder (ANRS), Awi (ANRS), East Gojam (ANRS), West Shewa (ONRS), Keffa (SNNP) and East Harerghe (ONRS). These areas were predicted to be potentially suitable for the species under the current condition (1960-2000).

In contrast, the model has also represented that lowland areas of the country such as Afar, Gambela, South Omo, Somali and North Gonder (Metma) that were poorly predicted for the survival and adaptation of *Hagenia abyssinica*. These are categorized as areas outside the realized niche of the species.

4.5.4 Ranking of predictor variables

There is more than one way of ranking the contribution of variables in the modelling of species distribution. However, if we are using the highly correlated environmental variables, due attention should be given during the interpretation of the predictor’s contribution.

The following Table 4.32 shows estimates of relative contributions of the environmental variables to the MaxEnt model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted.

Table 4.32 Output from analysis of variable contribution

Variable	Percent contribution	Permutation importance
bio10	45	90.5
bio5	26.4	0
bio11	9.2	0
bio6	3.5	0
altitude	3.3	0
Eth cover	3.1	1.1
bio12	3	0.7
bio9	2.7	0
bio18	2.1	0.5
bio4	0.8	4.6
bio3	0.4	1.5
bio2	0.3	0.4
bio14	0.2	0.5
bio17	0	0
bio1	0	0

The model was re-evaluated on the permuted data (Table 4.32). Variables bio 7, bio 13, bio 15, bio 16 and bio 19 were omitted in modelling. bio 10, bio 5, bio 11, bio 6, altitude, land cover and bio 12 were found to have more percentage contribution than any other variables. Moreover, bio 10 and bio 4 have the highest permutation importance.

Figure 4.20 shows the results of the Jackknife test of variable importance to the model. The environmental variable with highest gain when used in isolation is bio10, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain at most when omitted is bio12, which in turn appears to have the most information that is not present in the other variables.

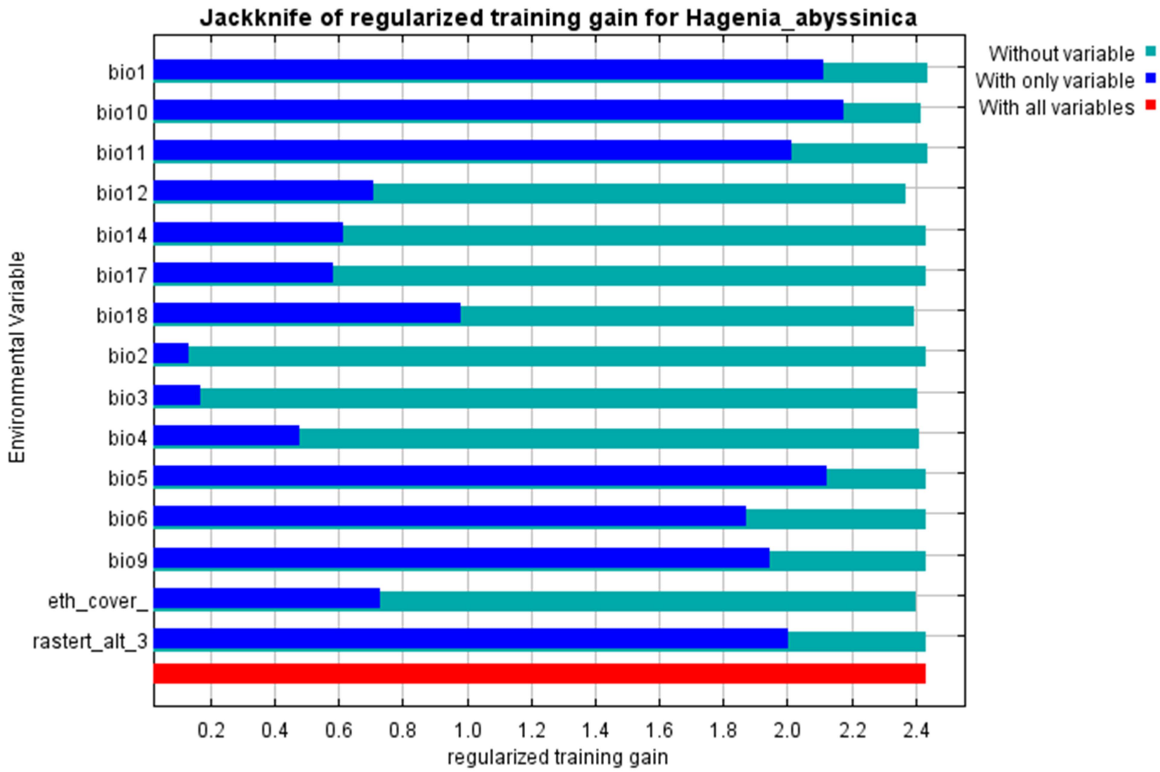


Figure 4.20 Jackknife of regularized training gain for *Hagenia abyssinica*

Figure 4.21 shows the same Jackknife test using test gain instead of training gain. Conclusions concerning the identification of which variables most important in influencing the species adaptation were done using the test data.

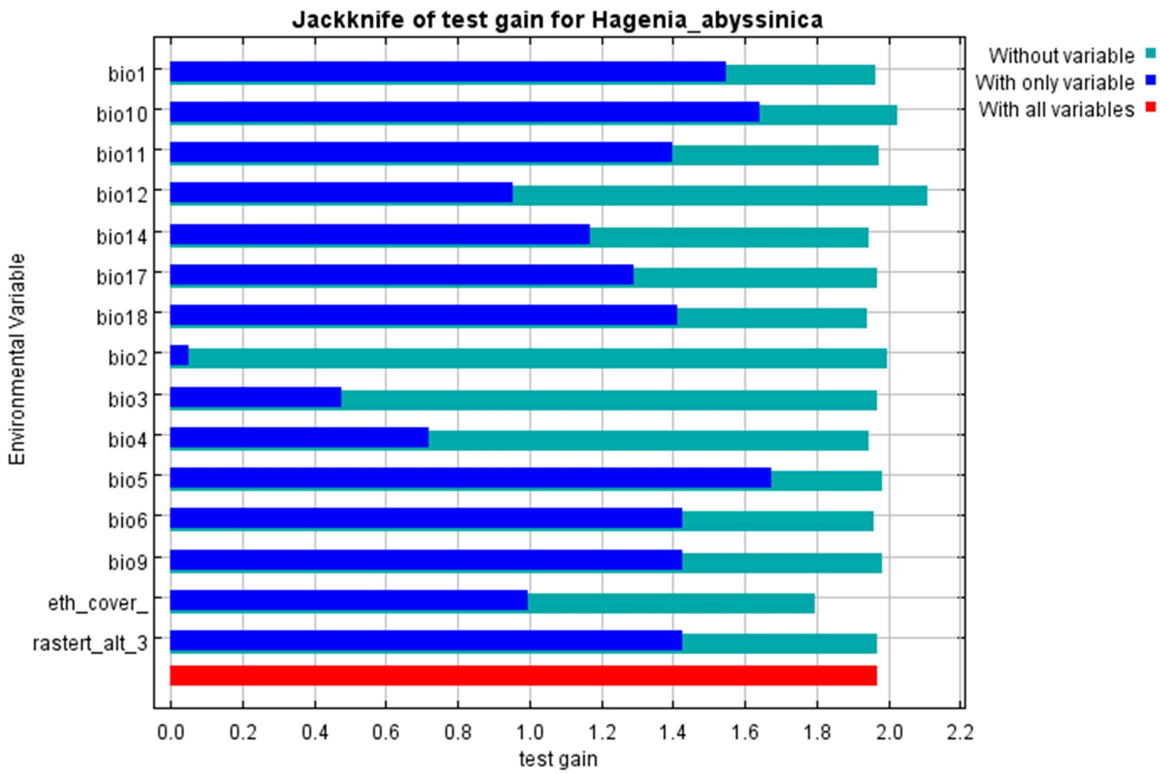


Figure 4.21 Jackknife of test gain for *Hagenia abyssinica*

In Jackknife of test gains for the *Hagenia abyssinica* (Figure 4.21), blue bars showed the gain achieved from predictor only. Green bars showed how much the total gain was diminished without the given predictor. Red bar indicated the gain achieved when utilizing all predictors. Therefore, the Jackknife results showed that the environmental variables with highest gain were maximum temperature of warmest month (bio 5), mean temperature of warmest quarter (bio10) and mean annual temperature (bio 1), which were found to be very important for predicting the distribution of *Hagenia abyssinica* in Ethiopia.

On the other hand, soil texture, bio 2, bio 3, and bio 4 were lowest test gain when environmental variables solely used and these variables were found to be inferior for prediction as compared to bio 10, bio 1 and bio 5 variables.

Lastly, we have the same jackknife test, using AUC on test data as presented in Figure 4.22.

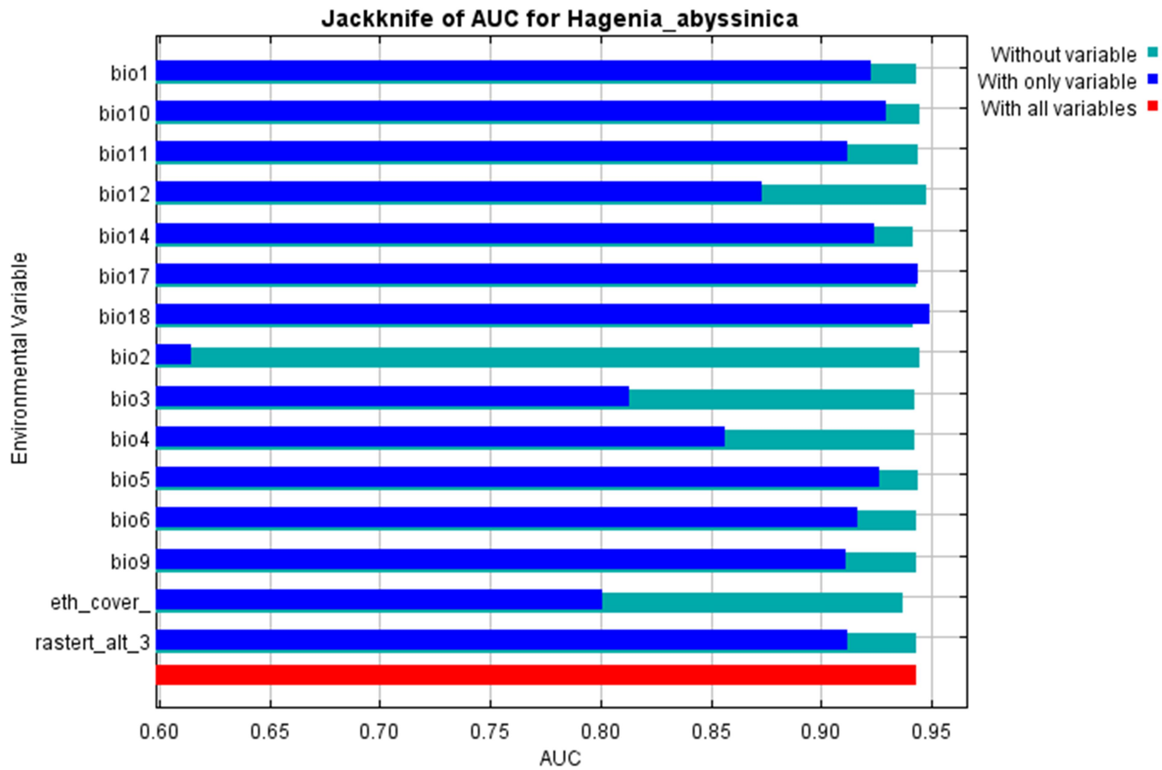


Figure 4.22 Jackknife AUC for *Hagenia abyssinica*

When only one variable was tested using AUC, the corresponding value was obtained from the model. bio18 (AUC=0.9489), bio17 (AUC= 0.9436), bio10 (AUC=0.9293), bio5 (AUC=0.9263) and bio14 (AUC=0.9238) were the five highest variables in AUC.

4.5.5 Modelling the impact of climate change on species' distribution

The second set of questions was aimed to evaluate the distribution of *Hagenia abyssinica* under the future climate. The outputs could help us to determine the most at-risk populations and to identify where the conservation of genetic resources require urgent measures.

For this study, the predicted climate of the year 2070 (averaged for 2061-2080) was used as future climate data. Two types of analysis software were used, namely, MaxEnt and DIVA - GIS softwares (Sawada et al., 2014). MaxEnt helps to predict the potential distribution of a species under current and future climatic conditions, and DIVA -GIS to examine the impact of climate change on the species.

Binary raster maps under the current climate and future projection were generated in MaxEnt under ASCII format (*.asc), the outputs imported to DIVA -GIS to examine the impact of climate change on a species, the pixel values re-classed and then the overlaying of future likely distribution on the current potential distribution map as outlined in (Scheldeman and Zonneveld, 2010) . The study areas were divided into four kinds depending on the level of climate change impacts, namely; (1) high impact areas, areas where a species potentially occurs in the present climate but which will not be suitable anymore in the future, (2) areas outside of the realized niche, areas that are neither suitable under current nor under future conditions, (3) low impact areas, areas where the species can potentially occur in both present and future climates and (4) new suitable areas, areas where a species could potentially occur in the future climate but which are not suitable for natural occurrence under current conditions.

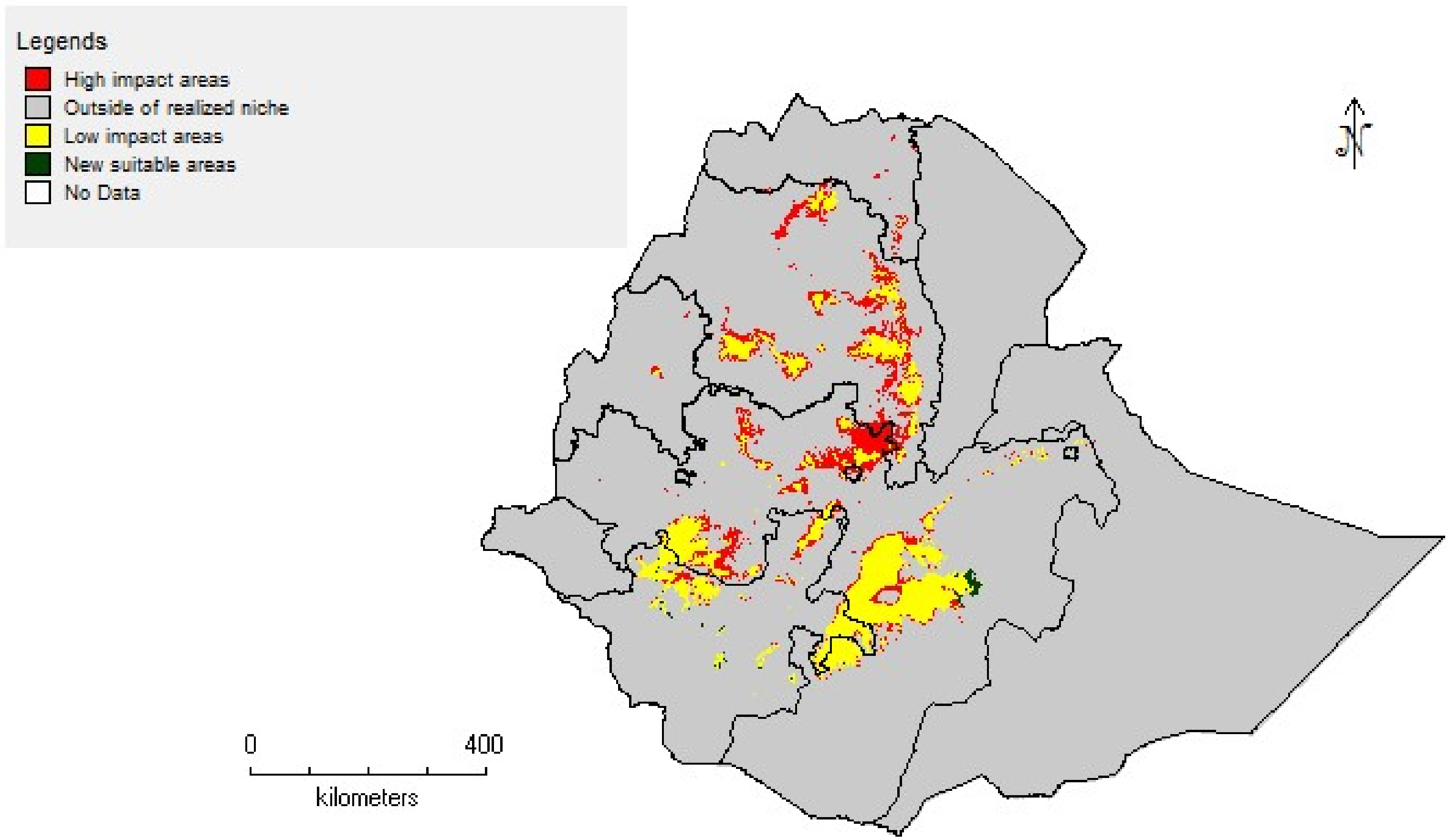


Figure 4.23 Distribution *of Hagenia abyssinica* in the year 2070

The red colour indicated high impacted areas due to climate change (Figure 4.23). Further analysis was carried out to realize location of the highly impacted areas in terms of administration boundaries of Ethiopa. At present, *Hagenia abyssinica* population are situated in North Shewa Zone (Wuchale District), North Wollo Zone (Meket and Guba Lafto Districts), South Wollo Zone (Desie Zuria District), West Shewa Zone (Adda Berga District), North Gonder Zone (Janamora District), Southern Tigray Zone (Ambalage and Ofla Districts), Central Tigray Zone (Degua Temben District) and Metekel Zone (Dangur District). However, in these aforementioned areas, the species is found to be highly vulnerable and hence affected by climate change. The newly suitable areas such in Bale zone (Ginir, Goro and Gololcha Districts) and Benchi Maji zone (Meanit Goldiiya District) are expected to be suitable for *Hagenia abyssinica* occurrence due to the climate change expected by the year 2070.

In order to quantify the size of areas delineated in relation with the predicted climate change as shown in Figure 4.23, further analysis was employed using DIVA - GIS. After importing and manipulating the map with grid format and subsequent ranging of potential impacts, the size of the area was produced and presented in Table 4.33. The size of the area in ground was derived from value of pixel cell size (1km*1km).

Table 4.33 Range of impact of climate change on *Hagenia abyssinica*

Range	Area (km square)	Percentage
High impact areas	39025	2.91%
Outside of realized niche	1238724	92.49%
Low impact areas	59987	4.48%
New suitable areas	1578	0.12%

The majority (93%) of the areas in Ethiopia were found outside of the realized niche for the species, whereas about 2.9% and 4.4% of areas were predicted as high and low impact areas, respectively (Figure 4.23). On the other hand, 0.12% (1578 km^2) area was identified as the new suitable for the adaptation of the species in the future due to the inevitable climate change predicted to occur in the area.

CHAPTER FIVE

5 DISCUSSION

5.1 Land Use/Land Cover Change

In all the periods considered, agriculture land constituted the predominant type of land-cover in the landscape. 33, 6298 ha, 33,199.56 ha, and 39,541.9 ha that contributes to 67.27%, 68.32%, and 80.08% of the total area in the year 1972, 1986, and 2015, respectively. Several reports have shown that crop land accounted for more than 65% of the total study area in South Wollo, Ethiopia (Kebrom Tekle and Hedlund, 2000; Belay Tegene, 2002; Abate Shiferaw, 2011).

Change in forestland

In the year 1972, only 5% of the area was covered with forest. This figure was found to be lower than the forest coverage of the country average (Reusing, 2000). Hence, the area has experienced a long history of deforestation (Hurni, 1988; Zewdu Eshetu, 2002).

Forest area has increased by 5.58% from 2778.4 ha in 1972 and reached 5542 ha in 1986. The rate of change was estimated to be 212.59 ha per year. Although these results differ from some published studies Kebrom Tekle and Hedlund (2000), they are consistent with those of Curmmey (1998) and Dessalegn Rahmato (1991). This increment in the size of forest coverage was due to the afforestation programs that were launched on degraded and mountainous areas.

Investigation of such LULC changes revealed that less than 33% of the 5542.1 ha of forest in 1986 remained unchanged. The forest loss of 50 ha per year is equivalent to 0.03% of the national annual forest cover loss (163,000 ha) as reported by (Reusing, 2000).

The present study has confirmed that, the coverage of forestland in the study area had expanded at the expense of shrub and agricultural land in the year 1972. These results differ from some published studies (Kebrom Tekle and Hedlund, 2000), 2000), who reported increment of bare area and settlements at the expense of shrub land and forests between 1958 and 1986 in Kalu area of South Wollo, Ethiopia.

There were records on the increments of forest coverage in some parts of Ethiopia. This was due to application of various interventions, such as, an implementation of community based forest management in Belete-Gera Regional Forest Priority Area (Takahashi and Todo, 2011), *Jatropha curcas* plantation establishments in Bati and Mieso district North Wollo (Habtamu Ayele, 2011) and Eucalyptus plantations in Silte zone (Abebe Mengaw, 2015), were responsible for an increment in size of forests area. Similarly, woody vegetation cover increased in Northern Ethiopia over the period 1868–2008. This essentially occurred after 1961 following the establishment of *Juniperus procera* and Eucalyptus forest plantation in this area (Meire et al., 2012). So that, much care is required when extrapolating results of land use land cover change studies at a regional scale

LULC transition matrix has confirmed the occurrence of significant land use/land cover dynamics in the study area. For example, conversion of land uses to agriculture land was very common in the area. In addition, conversion of land from agriculture to other land use types except to water bodies was observed in the study area. Regarding the assessment of forest loss in the study area between the years 1986 to 2015, more than 54% was converted mainly to agriculture land and only about 11.8% was reforested. Other studies conducted elsewhere in south Wollo found that forests were shifted mainly to cultivated land (Kebrom Tekle and Hedlund, 2000; Belay Tegene, 2002; Abate Shiferaw, 2011).

The drastic loss of forest resources in the area had occurred during the years from 1986 to 2015. Pankhurst (2001) attributed to this reality to the absence of restrictive and binding laws during the final year of the *Derge* and during the transition period, has caused severe damage on the forest resources of Yegof due to the rampant illegal cuttings and sales of woods extracted from it. This is believed to cause a massive destruction of the forest resource of the area. The study further supported the idea that the impact of "Poor peasants and returnees encroached on Yegof forest" as forwarded by Pankhurst (2001).

Change in shrub land

More than 69% of shrub land from 1972 to 2015 was converted into agriculture land. Studies elsewhere in Ethiopia likewise reported that shrub land were replaced mainly to agricultural land and are used to satisfy the need of the alarmingly increasing human population in the country (Eyayu Molla et al., 2010).

The trend of shrub land decline (8015 ha) in the study area similar with the general pattern of shrub land shrinkage in Ethiopia over the last few hundred years (Belay

Tegene, 2002; Amanuel Abate and Mulugeta Lemenih, 2014; Gebrekidan Worku et al., 2014).

Generally, the size of forestland, shrub land, and grassland has showed a continuous decline. This is believed to be caused by the expansion of the agriculture and settlement at the expense of these forest, shrub, and grassland.

5.2 Spatial Composition and Configuration

The landscape was dominated by agriculture land. The numbers of agriculture land was increased during 1973 -1986 followed by the reduction of this land use class in the year 2015. These results supported the findings of Terefe Tolessa, et al. (2016).

On forestland, the selected fragmentations metric (Aggregation metrics, Shape metrics and Area and Edge metrics) are vital to understand forest fragmentation in the area have revealed that the forest has experienced severe fragmentation in the year 2015 than 1972 and 1986. In the year 1986, the vegetation (forest and shrub) showed improvement in its coverage. The forest was relatively less fragmented in the year 1986 as compared with that of the year 1972 and 2015. This study has supported those ideas recognizing the increment of the forest resource in the area following the establishment of plantation activities in 1970s (Dessalegn Rahmato, 1991; Baharu Zewude, 1998).

The value of Interspersion and Juxtaposition Index (IJI) for forest patches of the year 1972, 1986, and 2015 was 45.6 %, 55.4%, and 35.7%, respectively. The higher values resulted from landscapes in which the patch types are well interspersed (i.e., equally adjacent to each other), whereas lower values characterize landscapes in which the patch types are poorly interspersed (Mcgarigal and Ene, 2013). It indicated that the forest patches have become further far apart over time and changed from 55.4 in 1986 to 35.7 in 2015. Observation of such a pattern of change in the landscape clearly indicated the level of forest fragmentation occurring in the study area.

The number of forest patches was highest in the year 2015 as compared with that of the 1972 and 1986. Lower numbers of forest patches were observed in the year 1986. A possible explanation for this could be the persistent splitting of the forestland into several smaller patches caused by the use of a clear cutting forest harvesting techniques or the rampant illegal cutting of forests practised in the area. The mean area of the forest patch was 1.1, 1.8, and 0.4 ha of land in the year 1972, 1986 and 2015, respectively. It indicated that the forest was reduced in its size and became more fragmented in the year 2015. These results are consistent with those of Leul Kidane, (2015), whose findings showed an increase in number of patches and reduction in mean patch area for the years between 1986 and 2011. This finding showed that the number of the forest patches in the area is increasing from year to year with a reduction in its coverage due to the ongoing encroachment of the community on the existing forest patches so as to use the land for other purposes. This continual fragmentation of the patches is believed to cause a significant loss in the biodiversity and reduction in the size of the forest unless the concerned bodies take a prompt and appropriate measure.

On shrub land, it was known that this LULC was found at the forefront for conversion to cultivated and grazing land (Terefe Tolessa et al., 2016). In this study, across the study years, the numbers as well as the proportion of shrub patches were reduced in the landscape. Similarly, the mean area of the shrub patch was reduced by 0.8 ha during 1972 to 2015. Shrub land comprised a total of 74.3, 45.2, and 20.2 meters per hectare in the year 1972, 1986 and 2015, respectively. The largest Edge density (ED) was recorded in the year 1972.

The value of ENN for shrub land was higher in the year 2015 as compared with that of 1972 and 1986. In the year 1973, the value of the isolation was increased by 28.4 meters over that of the year 1986; similarly, ENN was incensed by 62.3 meter from the year 1986 to 2015. Whereas, Interspersion and Juxtaposition Index (IJI) of shrub land of the year 1972, 1986 and 2015 was 72.91%, 52.9%, and 41.7%, respectively. The value of IJI was lower in the year 2015. A possible explanation for this might be that some shrub patches were converted into other land uses during the study period.

In conclusion, the number as well as proportion of patches and the mean area showed an increasing rate of fragmentation, and interspersion indicated the isolation of patches. This observation may support the hypothesis describing that the shrub land of the area showed reduction in its size and continued further fragmentation through time.

5.3 Species Diversity, Structure, and Community types

5.3.1 Floristic composition

Yegof forest is one of the few remaining dry Afromontane forests in the northeastern highland plateaus of Ethiopia. Woody species composition, structure, and regeneration patterns of the forest were studied to generate information essential for formulating feasible management options for the forest.

The vegetation of Yegof and its surrounding forest fits into the general patterns of the vegetation zones of the Ethiopian highlands partly similar to Borena-Sayint National Park (BSNP). The natural vegetation of the study area is broadly classified as *Juniperus procera* forest or "dry single dominant Afromontane forest" with *Juniperus procera* and/or *Olea* as dominant species (Friis et al., 2010).

The results of this study show that the forest contains 292 species of vascular plants belonging to 219 genera representing 84 families. When this forest was compared with others dry Afromontane forests, for example with the vegetation of Hugumbirda-Grat-Khassu forest, South Tigray-Northern Ethiopia, which they were recorded of 102 species belonging to 83 genera and 50 families (Leul Kidane et al., 2010) and less diverse with that of BSNP which there were records of 354 vascular plant species (Hussien Adal, 2014).

Another important finding was that the tenth species-rich plant families contribute to 51.71% of the species in Yegof forest and surrounding forest patches. These results seem to be consistent with other research which found sixteen plant families that contributed to 60% of the total plant species in BSNP among which the families, Asteraceae, Fabaceae, Poaceae, Lamiaceae, and Cyperaceae being the five most species-rich plant families in that order (Hussien Adal, 2014). The highest representation of species from the family Asteraceae (40 species, 14.7%) in the Yegof forests could be related to the fact that it is one of the species rich families in the flora area, (Mesfin Tadesse, 2004). Well representation of the Asteraceae family were also obtained in in Ankober (13 species, 9.4%), (Ermias Lulekal, 2014) and in BSNP (30 species ,6%) (Hussien Adal, 2014).

Herbaceous species outnumber in Yegof Forest when compared to the other growth forms. This could be related partly to opening up of the forest due to resource extraction and another explanation might be shallow soil of the study forests (Kebrom Tekle et al., 1997) and the shallow roots of the herbs may relevant for herb than tree (Wright, 2007). this result is in agreement with those obtained by (Hussien Adal, 2014).

5.3.2 Vegetation structure

Analysis of the DBH indicated that the average number of individuals decrease drastically from the lowest size classes to the highest size class. About 51% of the individuals (378.5 individuals per ha) in the Yegof and its surrounding forest patches had DBH value of less than 10 cm which indicates the dominance of small-sized individuals in the forests. The density of individual per ha (DBH,< 2 cm) was highest in Harego and Suki forests than that of the forest of Yegof, while those forests was slightly lower in the values of basal area (Table 4.12). Those forests had lower number of individuals at higher diameter class (DBH >10 cm), successional younger than Yegof forest. In Zengena Forest, for example, about 87% of the individuals had DBH value of less than 10 cm (Desalegn Tadele et al., 2013).

The number of individual's woody species decreased with the increasing diameter classes suggesting a more or less inverted J-shaped population structure . The density of tree species in the forest decreases with increasing Height classes, which show that the forest is in the secondary state of development. This result seems to be consistent with other researches which are found in BSNP (Hussien Adal, 2014).

In the patch of Harego, Biraro, Abuli and Harbu forests, the highest proportions of small-sized and large-sized (a/b ratio) was obtained, which indicates the dominance of small-sized individuals in the forest. This is a result of the excessive cutting, which took place there a long time ago. Whereas, in the Yegof forest, the a/b ratio was 1.8, in relative term, do not differ much, which indicated that this forest has developed under natural conditions being without major disturbances.

The total basal area of woody species in Yegof Forest was 25 m^2ha^{-1}. This value was slightly higher than to basal area (19.4 m^2ha^{-1}.) of Tigray Forest (Ermias Aynekulu et al., 2009), and (23 m^2ha^{-1}.) of Boditi Forest (Haile Yineger et al., 2008), however, the result is low compared with the basal area of other Dry Afromontane forests in Ethiopia. For example, 26 m^2ha^{-1} in Bale Mountains National Park, (Haile Yineger et al., 2008), 64.32 in WWNF (Gebremicael Fisaha et al., 2013) and 45 m^2ha^{-1}. Denkoro Forest (Abate Ayalew et al., 2006).

Further analysis in the case of the density DBH >10 showed that in the forest of Yegof the largest density was obtained from *Olea europaea* subsp. *cuspidata* (48 individuals ha^{-1}) followed by *Olinia rochetiana* and *Carissa spinarum* 33 individuals ha^{-1}, and 41 individuals ha^{-1}, respectively.

In all forests except, Yegof forest, individuals reaching heights of 25 meter are scarce, which show that the forest is in the secondary state of development. *Podocarpus falcatus, Juniperus procera, Prunus africana, Ekebergia capensis,* and *Acacia abyssinica* were found to be the highest in their height in the forest of Yegof and its surrounding patches. These results are consistent with those of Hussien Adal (2014) in which the study in Borena Sayint National Park, Northern Ethiopia, has verified tree height distribution values were higher for the lower height classes.

The results obtained from the structural analysis as summarized in Table 4.11 indicate *Olea europaea* subsp. *cuspidata, Juniperus procera* and *Olinia rochetiana* to be among the five major species in Abuli, Suki, and Yegof forests; however, their level of dominance is found to vary in each forest. For example, *Juniperus procera* is contributing no less than 26.6%, 12.6%, and 9.9% of the total basal area in Abuli, Suki, and Yegof forests, respectively. Similarly, 25.0%, 21.8% and 6.3% of the total basal area in Suki, Yegof, and Abuli was covered by *Olea europaea* subsp. *cuspidata* and *Juniperus procera* species which were found to occur co-dominant in the forest of Yegof.

Olea europaea subsp. *cuspidata, Olinia rochetiana, Carrisa spinarum, Juniperus procera,* and *Dodonaea angustifolia* were the top five species contributed for more than half of the total IVI in the forest of Yegof, while *Dovyalis caffra ,Croton macrostachyus, Galiniera saxifraga, Hagenia abyssinica* and *Erythrina brucei* were found to lower important values in the forest of Yegof.

Acacia sieberiana, Dovyalis caffra and *Croton macrostachyus*, were found to lowest important values in the patches forest of Abuli. Similarly, *Ziziphus mucronata, Rhus natalensis, Cordia monoica, Ehretia cymosa* and *Rhus natalensis* in the patches forest of Harbu; *Ficus sur, Rhus retinorrhoea* and *Capparis tomentosa* were in the patches forest of Erkis; *Pittosporum viridiflorum, Bersama abyssinica* and *Juniperus procera* in the patches forest of Biraro; *Acacia sieberiana, Acacia seyal,* and *Juniperus procera* of patches forest Harego received lower IVI.

The basal area contribution of the most important species in the forests ranges from 67.0 % to 41.9%, the largest being in Abuli and the lowest in the forest of Harego. In terms of IVI high density and high frequency coupled with high basal area indicates the overall dominance of a species in vegetation.

Some species have combined high density with high frequency, for example, the combination of those parameters in the IVI was observed in some species and forest patches. Forexample, *Olea europaea* subsp. *cuspidata* was found densely and frequently in the forest of Yegof and *Juniperus procera* in the forest of Abuli was very reasonable to receive higher IVI. In contrast, the higher value of *Podocarpus falcatus*, in the forest of Erkis, was largely due to high DBH value of few individual trees in the forest.

Another important finding was that the result shows the presence of more seedlings than saplings and saplings than mature trees, which indicates successful regeneration of forest species in one hand.

Analysis of population structure of most common species of trees and shrubs revealed high variation among species population dynamics within the forest. Accordingly, six population patterns have been observed (J-shaped, bell-shaped, inverted J-shaped, irregular, U-shaped and I -shaped).

Olea europaea subsp. *cuspidata, Dombeya torrida, Allophyllus abyssinicus* and *Bersama abyssinica* and *Galiniera saxifraga* have an inverted J-curve population. Late successional species like, *Olea europaea* subsp. *cuspidate* had high frequency of occurrence in the seedling and sapling than adult stages.

The second pattern was formed by species having irregular distribution over diameter classes. Some DBH classes had small number of individuals while other DBH classes had large number of individuals. This irregular pattern distribution was due to selective cutting by the local people for construction and firewood. Overgrazing, which affects the seedlings under the mother tree, could be another reason for such irregularities. Examples of this pattern are observed in *Myrica salicifolia, Acacia etbaica* and *Acacia sieberiana.*

The third type shows a J - shaped distribution pattern where the number of individuals is low in the first and second DBH classes, but increases toward the higher classes. Such patterns show poor reproduction patterns and hampered regeneration, because either most trees are not producing seeds due to age, or there are losses due to predators after reproduction. This type of regeneration pattern was observed in *Myrica salicifolia* and *Olinia rochetiana* and *Juniperus procera.* This type of population structure is characteristic of shade-tolerant canopy trees that maintain a more or less constant rate of recruitment.

The forth pattern was a U-shaped curve formed by species with few or no individuals in the middle DBH classes, and represented only by the lower and higher DBH classes. Species with this type of population structure was Ekebergia *capensis* and *Ziziphus mucronata*. Sultan Mohammed et al, (2013), also reported similar reasons for this type population structure.

Rhus retinorrhoea and *Nuxia congesta* had bell-shaped structural pattern. This is fifth pattern depicting bell- shaped formed with ample individuals in the middle DBH classes is characterized by few number of the lower and higher DBH classes.

Hagenia abyssinica, Erythrina brucei, and *Podocarpus falcatus* represented no reproduction and complete absence of individuals in regeneration and intermediate classes.

5.3.3 Community types

The plant communities in the study site can be broadly classified as Dry Afromontane forest type.

Juniperus procera community is located between 1900 and 2800 masl and 35 plots. A total of 161 species have associated with community. *Juniperus procera, Olinia rochetiana, Bersama abyssinica, Galiniera saxifrage, Nuxia congesta* and *Myrica salicifolia* are the dominate trees. The indicator species of the community were *Arthraxon prionodes, Arthraxon prionodes* and *Juniperus procera.* This community type was also captured by (Kebrom Tekle et al., 1997) as secondary forests, most of which are found at high altitude and have been protected for more than 20 years.

Community type II is located between 1800 and 2900 masl with 42 plots and 182 species associated to it. *Olinia rochetiana* and *Olea europaea* was found to be an indicator species in this community.

Community type III is found at relatively mid altitude. The community was comprised of 46 plots and 189 species. *Dodonaea angustifolia, Euclea racemosa,* and *Olea europaea* subsp. *cuspidata were* the dominant trees. *Euclea racemosa* and *Dodonaea angustifolia* are regenerating. Indicator species of the community was *Maesa lanceolate.* These results confirm the association between *Dodonaea angustifolia* and *Euclea racemosa* in the area (Getachew Tadesse et al., 2008).

Community type V is found at relatively lower altitude. It was composed of 75 species from 25 sampled plots. This community type is found in the upland drainages, valleys, and plainy landforms. *Acacia seyal, Dichrostachys cinerea* and *Acacia brevispica* were indicator species in this community. Surprisingly, *Lantana camara* was found to be the dominant shrubs in same plots of this community. Chatanga, (2007) studied the impact of *Lantana camara* on native vegetation in Zimbabwe, according to him, basal area decreased significantly with increase in *L. camara*-infestation; whereas, soil potassium and moisture levels were highest in uninvaded area (Desalegn Tadele, 2014) has also confirmed that this species has produced allelochemicals - inhibitory effects on the growth of some plant species in Ethiopia.

Ethiopia has the obligation to prevent and control such alien species from its tertiaries.' Therefore, efforts should be made to eradicate and control spread, awareness raising activities that are geared towards mobilizing the public to control the spread should be carried out.

Community III had higher species richness (182 species), higher Shannon (H' = 4.32) and evenness (E = 0.32) values than community IV that had relatively lower species richness (72 species) with higher H' = 3.57 and E = 0.30. Evenness is constrained between 0 and 1.0 with 1.0 representing a situation in which, all species are equally abundant (Magurran, 2005).

Shannon diversity was found (4.16) in Yegof and (3.60) lowest in Harbu. This could be due to variation in their size forest area. There is evidence in Ethiopia, large forest contained the greatest numbers of species (Aerts et al., 2006).

Species evenness is generally highest at the lower elevation (2100- 2400 masl), while values are lowest at higher elevations (> 2700 masl.). Species richness and diversity doesn't it follow a liner relationship along the elevation gradient which is explained by liner regression model, but the r^2 value is below 0.5. Though the relation is found to be direct, the fuzzy set ordination for elevation was $r^2 = 0.73$ (p value of 0.01). Hence, the value has indicated that elevation has brought an affects on the distribution of species in the study area. There are some evidences in Ethiopia; a pronounced shift in species composition (Alemayehu Wassie et al., 2010; Ermias Aynekulu et al., 2012). The records in Bonga Forest, Ethiopia supports the notion of the importance of altitude as one of the main determinants of plant species distribution patterns in tropical forests (Schmitt et al., 2010).

5.4 Human-Forest Interactions

Several reports have shown that the forest of Yegof has experienced long history of deforestation. This study has tried to capture the recent history of the forest. On the subject of the status of the forest quality, the forest is getting deteriorating in its quality as confirmed by the majority of the respondents. However, variation of perception about size of the forest area was also recorded. Hence, 41% of the respondents feel that the size of forest area was increased, while 22% of the respondents indicated that the size was reduced. The divergent views of the respondents can be attributed to their differences in accesses to forest (distance) and age of the respondent and thus result in them to have lesser knowledge of the previous forest situations in the area. These results and justifications seem to be consistent with other research works, which were recognizing the presence of diversified views by the respondents on the perceived status of forest in North-Western Ethiopia (Mulugeta Lemenih et al., 2012).

The second question in this research was ‘who were agents responsible for the deforestation? The response to this question was “youth and landless farmers” were issued by the majority of the respondents. They also added, “Youth and landless farmers have started to make a living from sales of firewood and timber out of the forest.” Farmers also used the forest mainly for their own firewood source and farm tools. The study conducted by Belay Tegene (2002) has also confirmed that charcoal production and firewood were the major causes responsible for the destruction of vegetation in northern Ethiopia.

With respect to the question which land use gained the land from forest conversion, it was found that 63% and 28% of the respondents pinpointed that the forest was converted into a shrub and agriculture land, respectively. As mentioned in the literature review, these results were further supporting the notion of forest conversion in the area.

Agriculture land in the study area was remained unchanged during the last 30 years, as testified by 76.2 % of respondents. These results were found consistent with the idea raised by Crummey (1998) explaining no significant expansion of the cultivated area was observed for the last 60 years.

Fuelwood harvesting is the major cause of deforestation in the area. The majority of the households interviewed stated that the dominant source of household‘s energy consumption in the area comes from fuelwood. Animal dung and crop residues were used as the source of household energy ranked second and third next to fuelwood. These results were consistent with (Abebe Damte, 2010).

Regarding fuelwood sources, of the total respondents, 52% (n=147), 23% (n=65), and 20% (n=58) used to collect fuelwood from farmland, forest, and homestead, respectively. The remaining households were used to collected fuelwood from community woodlot and grazing land. Household those situated near the forest were found to be favoured to use of fuelwood from the forest (Abebe Damte, 2010).

As pointed out in the reviewed literature section, governments of Ethiopia, both in the past and at present, tried to implement different intervention measures to maintain the remaining forests but most of the economic policies introduced were rather aggravating the rate of forest destruction till the present time. In the final year of the *Derge* and during the transition period, with the lack of restrictions, the sale of wood from state forests became a major survival strategy for the community. This could cause a massive destruction of the forest resource of the area. Poor peasants and returnees encroached on forests and grazing areas, cutting wood for sale to urban areas. The findings of this investigation complement those of earlier studies argued that the extraction of wood for construction and fuel is still occurring in the area.

On preferred intervention for managing forest resources, the result from the model has confirmed that, distance from the forest, a total number of livestock unit owned by the household and farm size were found negative in influencing the probability of choosing the conservation option over the forest harvesting using clearcutting.

Family size, education levels, and sex were positively and significantly influencing the probability of choosing the re-afforestation and harvesting over the forest harvesting using clearcutting. The model has also showed that, overall percentage of the model prediction was 79.1 %. Using the output of this model is very appropriate. Among the forest intervention option, conserving the remaining forest was favoured by most respondents based on the predicted corrected value of 84.5%.

5.5 Modelling of the Distribution of Hagenia abyssinica

5.5.1 The realized niche of *Hagenia abyssinica*

The results of this study have indicated that *Hagenia abyssinica* is grown in those areas receiving an annual precipitation ranging between 946 -1985 mm with mean annual temperature between 6.7-19.6 ^{0}C. In addition, the species are found in those areas received a maximum temperature value ranging between 10 to 20 ^{0}c during the warmest quarter seasons of the year and 220 to 570 mm precipitation received in the warmest quarter.

The populations are also located within an altitudinal range between 2,200 to 3,350 masl, This data are partly consistent with those of Hedberg (1989) and White (1983), who demarcated the possible altitudinal ranges conducive for the existence the species to be in between 2450 to 3250 and 1800 to 3400 masl, respectively.

With regards to soil preference, the species grow in Luvisols, Nitisols, Leptosols and Cambisols. Loam, sandy loam, clay loam and clay soil texture class with pH values of 5.3 to 7.7 are ideal for the growth of this species. Generally, an area having a similar range of environmental conditions can be taken as the realized niche of *Hagenia Abyssinica*.

5.5.2 Modelling the potential distribution of *Hagenia abyssinica*

Very little was found in the literature related to clarifying the question of what the current and likely future distribution of *Hagenia abyssinica*l. However, the evidence obtained from pollen records has suggested that the species has shifted its natural range during postglacial recolonization. Regarding the trend, postglacial recolonization of *Hagenia* was first traced in the south and later spread to the north in Ethiopia (Taye Bekele et al., 2009). Such species appear to be most at risk due to climate change (Huggett, 1998).

The omission on test samples is a very good match to the predicted omission rate . The predicted omission rate is a straight line, by definition of the cumulative output format. Phillips (2017) has suggested that when the test omission line lies well below the predicted omission line shows, training data are considered not independent. The receiver operating characteristic (ROC) analysis have showed that, both models were excellent and found significantly better-than the random performance (Scheldeman and van Zonneveld, 2010).

Potential distribution map of the species in Ethiopia has identified using MaxEnt model and as a result, the highlands of Arsi, Sidama Jima, South Wollo, North Wollo, Southern Tigray, North Gonder, Awi, East Gojam, West Shewa, Keffa, and East Harerghe were found to be better-predicted suitable areas. These findings agreed with those recorded species obtained in TU, GD, WU, GJ, WG, SU, AR, BAF, HA, KF and SD floristic region by Hedberg (1989) and Friis et al. (2010).

5.5.3 Selecting most fitted environmental variables

The application of species distribution modelling is also capable of answering the question, which variables matter most for the species being modelled and outlined the possible ways in which MaxEnt could be used to address the issues raised (Phillips et al., 2006). After following the procedures, the environmental variables namely, bio18, bio17, bio10, bio5 and bio14 were the five variables with the highest value of AUC. Those variables are found to be excellent in predicting the distribution of *Hagenia abyssinica* in Ethiopia

5.5.4 Distribution of *Hagenia abyssinica* under climate change

The second set of questions were organized and tested to quantify the distribution of *Hagenia abyssinica* under the predicted future climatic conditions of the country. For this study, future climate variables of the year 2070 (averaged for 2061-2080) were used for projecting the future species distribution in Ethiopia.

The representation of the MaxEnt model for future *Hagenia abyssinica* distribution prediction used colour code such as warmer colours that showed areas with better-predicted conditions; white dots, the presence locations used for training, while violet dots showed test locations. These map code are similarly likely to be workable (Phillips, 2010).

The model has predicted four levels of climate change impacts: high impact areas, new suitable areas, area outside of the realized and low impact areas on *Hagenia abyssinica* populations. Among the studied populations, *a Hagenia abyssinica* population that is found in the study area found to be highly affected by climate change. These results seem to be consistent with other research which found 25–41% of the currently suitable area for the African plant species would be became not suitable by the year 2085 (Lovett et al., 2005).

The model has also predicted that the majority of the land mass in Ethiopia would be outside of the realized niche zone; whereas, about 2.9% and 4.4% of the country's land mass is expected to be high and low impact areas, respectively. On the other hand, 0.12% (1578 km^2) area will become the new suitable area due to the predicted climate change.

Collect germplasm before existing stands disappear under the prevailing climate changes and improving the connectivity between fragmented populations to ensure gene flow of adaptive genes was the general recommendation to safeguard the extinction of endangered species in an area (Hijmans et al., 2012). An alternative viable option to would be facilitating their migration or transfer to a newly suitable area such as in Bale zone (Ginir, Goro and Gololcha District), and Benchi Maji zone (Meanit Goldiiya District) as these areas are predicted to be suitable for the climate change expected by the year 2070 for *Hagenia abyssinica*.

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CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Land use/land cover change

The landscape inventory data were collected over an area of 49,381.47 ha, which is centred in Mountain Yegof Forest, near the Komblolcha Town, South Wollo Administrative Zone in the Amhara Regional State of Ethiopia. This study shows the LULC change occurring in this landscape for the last 43 years.

In all the periods considered, agriculture land constituted the predominant type of LULC in the landscape. These results are consistent with (Belay Tegene, 2002) findings which showed that only cropland accounted for more than 65% of the total catchment area of south Wollo, Ethiopa.

The expansion of agriculture land in the area (5,912.05 ha) was observed between the year 1972 to 2015. This expansion in the aerial coverage was mainly from the conversion of shrub land. Similarly, an increment in settlements (3,619.71 ha) was materialized at the expense of other land use systems.

Forest shows a slight expansion in the aerial coverage due to the conversion of agriculture land, and shrub land in the area. Forest of the area was increased due to the afforestation programs that were launched on degraded and mountain area. However, Amogne Eshetu, (2014) and (Pankhurst, 2001) have argued that, the afforestation process has posed a threat to peasant livelihoods and resulted conflicts between the state forest and the local communities.

Regarding identifying the period when a significant forest destruction has occurred in the area, the years ranging from 1986 to 2015 were the worst in relation to the loss of significant amount of resources in Yegof. Pankhurst (2001) has also confirmed that, the final year of the *Derge* and the transition was a period considered to be critical periods for a massive destruction of the forest resource in the area.

6.1.2 Forest fragmentation

This study has examined the magnitude of the forest fragmentation in Yegof landscape during the year 1972, 1986, and 2015. Comparing the result of forest management activities such as open access situation (1972); plantations establishment and protection (1986) and clearcutting (2015) between these stated years, ultimately facilitates the determination of most severely impacted factor regarding the management options implemented.

The fragmentations metrics have revealed that the forest was highly fragmented in the year 2015 than that of 1972 and 1986. This is due to the extraction of wood for construction and fuelwood and clear-cutting forest harvesting operations practiced in the area. This observation supported the hypothesis that ravels the impact of using clearcutting techniques in forest harvesting which is believed to aggravate the severity of fragmentation observed in the area.

During *Derge's* regime in 1986, the forest was relatively less fragmented as compared with that of the year 1972 and 2015. Possible explanations for this might be resulted from the implementation of afforestation program by the government of the time in the area and the efforts of the forest guards in patrolling and protecting the forest from illegal forest harvesting.

Regarding shrub land of the area, the number as well as proportion of patch and the mean area showed an increased rate of fragmentation, and interspersion indicated increment in isolation of patches. This observation investigation supported the hypothesis formulated earlier that describe the reduction of the size of shrub land that was also observed entirely in the study year.

6.1.3 Species diversity, structure and community types

The findings reported in this paper are very important bases for initiation of conservation intervention in those studied forest and patch forests. Despite variation in species composition and diversity, the Yegof and its surrounding forest patches are rich in diversity and abundance of plant species, and are home for twenty-one endemic species.

The plant communities in the study site can be broadly classified as dry Afromontane forest types. More specifically, the *community type I, II ,III* and *IV* are dry single-dominant Afromontane forest with *Juniperus procera* and *Olea europaea* subsp. *cuspidata* as dominant species (Friis et al., 2010). Other characterizing species are *Euclea racemosa*, *Grewia ferruginea,* and *Rhus natalensis* (Friis et al., 2010). These species also widely occurred in community I, II , III and IV types, whereas, in community V, *Acacia bervispica- Dichrostachys cinerea -Acacia seyal*, is Afromontane woodland, wooded grassland and grassland with Acacia (Fabacea) as dominant wood (Friis et al., 2010).

The plant communities identified in this study could be also used as milestone for conservation planning and management of the remained forest patch of the area. Community III and Yegof forest has relatively highest diversity and evenness values than community IV and Harbu forest patch.

This study has identified that, the density of tree species in the forest decreases with increasing DBH and Height classes, which show that the forest of Yegof and the surrounding patches are in the secondary state of development.

Elevation significantly influenced the composition of plant communities and diversity of species in Yegof and surrounding patches.

The forests of Yegof and Borena Sayint National Park show a higher similarity to each other than to any other forests. This may be due to geographical proximity to each other has contributed to harboured relatively similar species composition.

6.1.4 Human-forest interactions

In this investigation, the aim was to assess the status of the forest under different forest management schemes. A limitation of this study is that forest has experienced a long history of deforestation starting about 2450 BC (Hurni, 1988), however in this study to draw such long period of information was very difficult. Therefore, in this study, the recent history of the forest dynamics was tried to captured

In terms of forest quality, nearly all respondents feel that Yegof Forest is getting declining in its quality, whereas, on of size of the forest area, this study has captured divergent views of the respondents. This could be attributed to their differences in accesses to the forest (distance) and age of the respondent and thus lesser knowledge of the previous forest situations in the area.

The reduction of the quality of the forest, as expressed by the respondent, is attributed to the increase in the demand for fuel and construction woods in the surrounding towns, which heavily dependent on fuelwood for energy consumption, are major cause of deforestation.

Fuelwood consumption, construction, and agriculture land expansion was ranked accordingly by the respondents based on the basis of their severity towards the sustainability of the forest resources.

This research has several practical applications in identifying the major agents responsible for the deforestation occurred in the area and after diagnosing the real causes of problems in the forest; it is easy for recommending best solutions so as to reverse the situation. Firstly, youth and landless farmers were issued as agents of deforestation. Secondly, youth and landless has started to make a living from sales of firewood and timber out of the forest. Farmers also used the forest mainly for their own firewood source and farm tools. In general, the major drivers of deforestation were identified by the respondents based on their effects and described as follows:- (i) low legal enforcement on penalizing the wrong doer; (ii) lower agricultural productivity and food insecurity imposed in harvesting products from forest; (iii) poor forest governance and (iv) high fuelwood energy demand. The findings of this study could be used for policy maker to avert the deforestation problem in the area and implementing the appropriate corrective measures that are compatible with the interest of the community and geographical features of the area.

Amhara National Regional State Forestry Enterprise has takeover the Yegof forest under Regulation No. 70/2009. The Enterprise has started harvesting of the forest using clear felling system. The evidence from this study suggests that this harvesting system brought a conflicted situation with the demand and aspiration of local community.

The Enterprise in pursuant of this regulation, have the following objectives: (1) to accelerate the economic and social development of the region by extensively developing and producing forest and forest products as well as by increasing value to same; (2) to reduce the level of unemployment and thereby ensure sustainable gains of the Regional Community by creating wider job opportunities; (3) to narrow the ever growing gap between supply and demand in wood and wood product at regional as well as national levels; and (4) to enhance foreign exchange capacity by producing forest and forest products, with an increasing value, exporting same and substituting the imported ones. When ones can evaluate the objectives, pursuant to acquire economic return. The essences of the establishment of the enterprise seem only for the attainment of financial profit, without compromising the need of conserving biodiversity at the same time harvesting forest produces. The forest might be degraded further sooner or later.

The forest enterprise has started harvesting of forest products using clearcutting method. This harvesting method has brought conflict with demand and aspiration of the community. The local community fear of degradation, desertification, loss of bio diversity, and loss of fuelwood sources after the implementation of forest harvesting using clearcutting method.

Regarding to preferred intervention for managing forest resources, distance from the forest, the total number of livestock unit owned by the household and farm size negatively influenced the probability of choosing the conservation option over the forest harvesting using clearcutting. Family size, reads and writes and sex positively and significantly influenced the probability of choosing the reafforestation and harvesting over the forest harvesting using clearcutting.

In conclusion, the result from the model showed that, overall percentage of the model was 79.1%. Most respondents based on the predicted corrected value of 84.5% favoured using this model, among the forest intervention option, conserving the remaining forest. So that, the enterprise not compromising the need of conserving biodiversity while harvesting forest produces. As second option, the Enterprise has to establish its own new forest plantation on open and degraded area instead of harvesting using clear felling of the already established forest resources.

6.1.5 Modelling of *Hagenia abyssinica*

MaxEnt species distribution model was used to assess current and the likely future distribution range of *Hagenia abyssinica* population in Ethiopia. The parameters used for evaluating the predictive ability of the models generated by MaxEnt was the Area Under Curve (AUC) evaluated and the red (training) line showed a higher AUC than the blue (testing) line. Hence, the red line showed the "fit" of the model to the training data that indicated the real test of the models predictive power. Moreover, the blue line does not falls below the turquoise line then this indicates that the model performs better than a random model.

The current and likely future distributions of *Hagenia abyssinica* were predicted and the required information was presented in the form of maps. However, the maps comprised only qualitative information whereas, quantitative information regarding current conditions and likely future distribution is very vital for stakeholders in setting conservation action.

For the production of quantitative information, the map of MaxEnt model was transported into DIVA -GIS Version 7.5.0.0 (Sawada et al., 2014) for further analysis. The information embedded in the map is ready for further quantitative analysis. Therefore, the further quantitative analysis should be done for the integration of the application of other spatial analysis software.

The probability distribution of *Hagenia abyssinica* modelled by the MaxEnt program appeared to be a reliable and stable model based on the diagnostic tests conducted within MaxEnt. This analysis predicted the potential distribution of *Hagenia abyssinica*.

The model also identified where suitable environments for the species are likely to occur under climate change. The suitable areas for the species will be narrowed by the year 2070 with shifting to other suitable area due to the influenced climatic variables mainly temperature and precipitation. This study has quantified about 59,987 km^2 area as a low impact area for the species under current conditions and will remain habitat under future climates; 39,025 km^2 area has been identified as the possible high impact areas or declining habitat due to climate change. The model has also determined 1,238,724 km^2 as areas that are unsuitable now and under future climates. The current study found that 15,751 km^2 of the area will be modified as a new suitable area for *Hagenia abyssinica* due to climate change.

6.2 Recommendations

Based on the results of the study, discussion and conclusions; the following recommendations are made

- *Lantana camara* is found to be dominating the native species in the forest patch of Harbu; such invasive species is known with its significant negative impact on the biodiversity. Mitigation measures in fighting the expansion of the species in the area should be started.
- Enrichment planting for species that have low densities or broken population structures is required, for those which are economical and ecological valued species, For instance. *Ziziphus spina-christi, Cordia africana, Prunus africana, Podocarpus falcatus, Hagenia abyssinica* and *Erythrina brucei*.
- Tree improvements intervention shloud be started for *Olea europaea* subsp. *cuspidata, Juniperus procera,* and *Olinia rochetiana* which are found in the forest of Abuli, Suki, and Yegof; *Acacia brevispica* and *Dichrostachys cinerea* occurred in the forest patch of Harbu; and *Myrsine africana, Dodonaea angusifolia* and *Carissa spinarum* in the forest of Harego. From those populations, mother plants can be selected following the out line of forest improvement procedures. These interventions can lead to obtain a recognized seed production area for further forest development activities.
- To reduce the rate of deforestation, alternative energy sources should be made available for the local community.

- Create alternative job opportunities with appropriate corrective and rehabilitation procedures for these identified agents' of disforestation to earn an income for their livelihood.
- Currently, the forest enterprise has started harvesting of forest products using clearcutting method. This harvesting method has brought conflict with demand and aspiration of the local community. So that, the enterprise should not compromise the need of conserving biodiversity while harvesting forest produces.
- *Hagenia abyssinica* populations that are found in the study area was found to be highly affected by climate change. So that, launching provenance trials in the area for the selection of highly adaptive individuals under the effects of climate change is indispensable.

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8 APPENDICES

Annex 1 List of plants recorded in Yegof Forest and its surrounding Forest Patches

Habit: Tree (T), Shrub (S), Herb (H), Name of the forest/ patch where the species are found,where A = Abuli; B = Biraro; H= Harego; M=Harbu; R=Erkis; S =Suki; Y= Yegof

Scientific name	Family name	Habit	Locations	Coll. No
Abutilon angulatum (Guill. & Perr.) Mast.	Malvaceae	H	M	325
Acacia abyssinica Hochst. ex Benth	Fabaceae	T	YSRHBA	279
Acacia albida Del.	Fabaceae	T	M	12
Acacia brevispica Harms	Fabaceae	S	SHBA	225
Acacia etbaica Schweinf.	Fabaceae	T	SRHBA	138
Acacia lahai Steud. & Hochst. er Benth.	Fabaceae	T	BM	276
Acacia negrii Pic.-Serm.	Fabaceae	T	BS	240
Acacia nilotica (L.) Willd. ex Del.	Fabaceae	T	M	80
Acacia seyal Del.	Fabaceae	T	BHS	250
Acacia sieberiana DC.	Fabaceae	T	YBS	203
Achyranthes aspera L.	Amaranthaceae	H	BH	238
Acmella caulirhiza Del.	Asteraceae	H	BH	201
Adiantum poiretti L.	Pteridaceae	H	SY	326
Agava americana L.	Agavaceae	S	B	13
Agave sisalana Perrine ex Engl.	Agavaceae	S	B	14
Ageratum conyzoid L.	Asteraceae	H	YS	192

Scientific name	Family name	Habit	Locations	Coll. No
Albizia schimperiana Oliv.	Fabaceae	T	R	270
Alchemilla abyssinica Fresen.	Rosaceae	H	Y	148
Alchemilla pedata A. Rich.	Rosaceae	H	Y	278
Allophyllus abyssinicus (Hochst.) Radik.	Sapindaceae	T	YSRHA	257
Aloe camperi Schweinfurth	Aloaceae	S	YSRBHA	15
Aloe monticola Reynolds	Aloaceae	H	YRH	221
Aloe pulcherrima Gilbert & Sebsebe	Aloaceae	S	YRHB	16
Aloe sinana Reynolds	Aloaceae	H	YS	19
Amaranthus graecizans L.	Amaranthaceae	H	BS	118
Andropogon abyssinicus Fresen	Poaceae	H	YSRHB	136
Anethum graveolens L.	Apiaceae	H	YS	18
Anthemis tigreensis L.	Asteraceae	H	YR	261
Anthoxanthum aethopicum I. Hedberg	Poaceae	H	S	23
Argyrolobium arabicum (Decne.) Iaub. & Spach	Fabaceae	H	YR	265
Artemisia abyssinica Sch. Bip. ex A. Rich.	Asteraceae	H	YSRHA	251
Arthraxon prionodes (Steud.) Dandy	Poaceae	H	YSRMHB	180
Asparagus africanus Lam.	Asparagaceae	L	YSRMH	34
Asplenium ethiopicum (Brum.f.) Bech.	Aspleniaceae	H	YSRMA	280
Asplenium monanthes L.	Aspleniaceae	H	Y	281
Asplenium protensum Schrad.	Aspleniaceae	H	YR	282
Asystasia gangetica (L.)	Acanthaceae	H	BH	30

Scientific name	Family name	Habit	Locations	Coll. No
Barleria ventricosa Hochst. ex Nees	Acanthaceae	H	YS	127
Berberis holstii Engl.	Berberidaceae	S	YH	283
Bersama abyssinica Fresen.	Melianthaceae	T	YRH	63
Bidens pilosa L.	Asteraceae	H	M	44
Bromus leptoclados Nees	Poaceae	H	YSRBA	284
Buddleja polystachya Fresen.	Loganiaceae	S	YRB	285
Caesalpinia decapetala (Roth) Alston	Fabaceae	L	YHA	286
Calotrops procera (Ait.) Ait.f	Asclepiadaceae	S	M	287
Calpurnia aurea (Ait.) Benth.	Fabaceae	S	YRMHBA	288
Canthium lactescens Hiern	Rubiaceae	S	M	289
Capparis persicifolia Lam.	Capparidaceae	H	YBA	20
Cardiospermum halicacabum L.	Sapindaceae	L	Y	187
Carduus nyassanus (S. Moore) R.E. Fries	Asteraceae	H	YS	85
Carduus schimperi Sch. Bip. ex A. Rich.	Asteraceae	H	H	87
Carissa spinarum L.	Apocynaceae	S	YSRMHBA	2
Cassia siamea Lam.	Caesalpinioideae	S	SA	100
Cassipourea malosana (Baker) Alston	Rhizophoracea	T	A	290
Caylusia abyssinica (Fresen.) Fisch. & Mey.	Resedaceae	H	YSR	291
Celtis africana Burm. f.	Ulmaceae	T	YSR	195
Cheilanthus farinosa (Forssk.) Kaulf.	Sinopteridaceae	H	Y	204
Cineraria abyssinica Sch. Bip.ex A.Rich	Asteraceae	H	YS	146
Cineraria deltoidea Sond.	Asteraceae	H	YSRBA	98

Scientific name	Family name	Habit	Locations	Coll. No
Clematis hirsuta Perro & Guill	Ranunculaceae	L	YSRBA	165
Clematis simensis Fresen.	Ranunculaceae	L	YSR	232
Clerodendrum alatum Gurke	Lamiaceae	H	YNB	103
Clerodendrum myricoides (Hochst.) Vatke	Asteraceae	S	YHBS	293
Clutia abyssinica Jaub. & Spach.	Euphorbiaceae	H	YRMBA	7
Colutea abyssinica Kunth. & Bouche	Fabaceae	S	M	294
Combretum molle R. Br. ex G. Don	Combretaceae	T	YSR	295
Commelina africana L.	Commelinaceae	H	M	164
Commiphora schimperi (Berg) Engl.	Burseraceae	T	R	296
Conium maculatum L.	Apiaceae	H	R	297
Conyza abyssinica Sch. Bip. ex A. Rich.	Asteraceae	H	R	298
Conyza bonariensis (L.) Cronq.	Asteraceae	H	YSMA	299
Conyza hochstetteri Sch. Bip. ex A. Rich.	Asteraceae	H	YSRA	189
Cordia africana Lam.	Boraginaceae	T	M	81
Cordia monoica Roxb.	Boraginaceae	S	AM	197
Cotula abyssinica Sch. Bip. ex A. Rich	Asteraceae	H	YSRBA	102
Crassocephalum macropappum (Sch. Bip. ex A. Rich.) S. Moore	Asteraceae	H	Y	82
Craterostigma pumilum Hochst.	Scrophulariaceae	H	YR	181
Crepis rueppellii Sch. Bip.	Asteraceae	H	YR	327
Crinum abyssinicum Hochst. ex A. Rich.	Amarlyllidaceae	H	R	104
Crisium vulgare (Savi) Ten.	Asteraceae	H	YSRA	249

Scientific name	Family name	Habit	Locations	Coll. No
Crotalaria lachnophora Hochst. ex A. Rich.	Fabaceae	H	YHRA	230
Croton macrostachyus Del.	Euphorbiaceae	T	BM	75
Cupressus lusitanica Miller	Cupressaceae	T	YAR	60
Cussonia holstii Harms ex Engl.	Araliaceae	T	SHA	226
Cynodon dactylon (L.) Pers.	Poaceae	H	YSR	150
Cynoglossum coeruleum Hochst. ex A.DC. in DC.	Boraginaceae	H	YSB	40
Cynoglossum lanceolatum Forssk.	Boraginaceae	H	Y	213
Cyperus fischerianus A. Rich	Cyperaceae	H	B	6
Cyphostemma adenocaule (Steud. ex A. Rich.) Descoings ex Wild & Drummond	Vitaceae	L	B	113
Datura stramonium L.	Solanaceae	H	B	76
Dichondra repens J. R. & G. Forst.	Convolvulaceae	H	M	91
Dichrostachys cinerea (L.) Wight &Am.	Fabaceae	S	YSBA	202
Diplolaphium africanum Fresen.	Apiaceae	H	RH	292
Discopodium penninervium Hochst.	Solanaceae	T	SHMRBA	4
Dodonaea angustifolia L.f.	Sapindaceae	S	YSRMB	79
Dombeya torrida (J. F. Gmel.) P. Bamps	Sterculiaceae	S	YSRB	8
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	S	YSRA	32
Dovyalis caffra (Hook. f & Harv.) Hook. f	Flacourtiaceae	S	YHA	314
Echinops longisetus A. Rich.	Asteraceae	S	YSR	31
Ehretia cymosa Thonn.	Boraginaceae	S	YR	49

Scientific name	Family name	Habit	Locations	Coll. No
Ekebergia capensis Spamn.	Meliaceae	T	YRA	105
Eleusine floccifolia (Forssk.) Spreng.	Poaceae	H	Y	154
Epilobum hirsutum L.	Onagraceae	H	YA	241
Eragrostis racemosa (Thunb.) Steud.	Poaceae	H	YRA	242
Eragrostis schweinferthii Chiov.	Poaceae	H	YRA	237
Erica arborea L.	Ericaceae	S	YSRA	24
Erythrina brucei Schweinf.	Fabaceae	T	YBR	86
Eucalyptus camaldulensis Dehnh	Myrtaceae	T	BH	51
Eucalyptus citriodora Hook.	Myrtaceae	T	Y	57
Eucalyptus globulus Labill.	Myrtaceae	T	YSRA	39
Euclea racemosa Murr.	Ebenaceae	S	YSRH MBA	64
Euphorbia abyssinica Gmel.	Euphorbiaceae	T	YSRH	109
Euphorbia candelabrum Kotschy	Euphorbiaceae	T	YSRH B	107
Euphorbia dumalis S. Carter	Euphorbiaceae	S	H	38
Euphorbia tirucalli L.	Euphorbiaceae	S	YS	149
Ferula communis L.	Apiaceae	H	Y	222
Ficus glumosa Del.	Moraceae	T	YR	309
Ficus sur Forssk.	Moraceae	T	YR	58
Ficus thonningii Blume	Moraceae	T	YS	236
Ficus vasta Forssk.	Moraceae	T	Y	175
Flueggea virosa (Willd.) Voigt.	Euphorbiaceae	S	M	160
Foeniculum vulgare Mill.	Apiaceae	H	YSRM HA	301

Scientific name	Family name	Habit	Locations	Coll. No
Galiniera saxifraga (Hochst.) Bridson	Rubiaceae	T	YSRHA	227
Galinsoga parviflora Cav.	Asteraceae	H	BH	199
Galinsoga quadriradiata Ruiz. & Pavon	Asteraceae	H	B	124
Galium aparinoides Forssk.	Rubiaceae	H	YH	111
Galium thunbergianum Eckl. & Zeyh.	Rubiaceae	H	YA	310
Geranium aculeolatum Oliv.	Geraniaceae	H	YRA	191
Geranium arabicum Forssk.	Geraniaceae	H	M	224
Gerbera piloselloides (L.) Cass.	Asteraceae	H	Y	319
Gomphocarpus fruticosus (L.) Ail. f	Asclepiadaceae	H	Y	130
Gomphocarpus purpurascens A. Rich.	Asclepiadaceae	S	M	246
Grewia bicolor Juss.	Tiliaceae	S	M	29
Grewia ferruginea Hochst. ex A. Rich.	Tiliaceae	S	M	22
Grewia flavescens Hochst. ex A. Rich.	Tiliaceae	S	M	196
Grewia mollis Juss.	Tiliaceae	S	M	128
Grewia trichocarpa Hochst. ex A. Rich.	Tiliaceae	S	M	206
Grewia villosa Willd.	Tiliaceae	S	YS	207
Guizotia scabra (Vis.) Chiov.	Asteraceae	H	YH	137
Hagenia abyssinica (Bruce) J.F.Gmel.	Rosaceae	T	Y	71
Halleria lucidal L.	Scrophulariaceae	T	YR	21
Haplocarpha rueppellii (Sch .Bip.) Beauv.	Asteraceae	H	YA	155
Haplocarpha schimperi (Sch. Bip.) Beauv.	Asteraceae	H	Y	119
Harpachne schimperi Hochst. ex A. Rich.	Poaceae	H	Y	316

Scientific name	Family name	Habit	Locations	Coll. No
Helichrysum conglobatum (Viv.) Steudel.	Asteraceae	H	Y	11
Helichrysum schimperi (Sch.Bip. ex A. Rich.) Moeser	Asteraceae	H	Y	229
Helichrysum stenopterum DC	Asteraceae	H	YRS	134
Heracleum abyssinicum (Boiss.) Norman	Apiaceae	H	YA	305
Heteromorpha arborescens (Spreng.) Cham. & Schltdl.	Apiaceae	S	YRBHM	243
Hibiscus ludwigil Eckl. & Zeyh.	Malvaceae	S	YRHBM	116
Hibiscus macranthus Hochst. ex A. Rich.	Malvaceae	S	MA	234
Hibiscus ovalifolius (Forssk.) Vahl	Malvaceae	S	M	133
Hippocratea africana (Willd.) Loes.	Celastraceae	L	YR	143
Hygrophila schulli (Hamilt.) M.R. & S.M. Almeida	Acanthaceae	H	YSB	244
Hyparrhenia anthistirioides (Hochst. ex A. Rich.) Stapf	Poaceae	H	BSY	177
Hyparrhenia coieotricha (Steud.) W. D. Clayton	Poaceae	H	R	193
Hyparrhenia hirta (L.) Stapf	Poaceae	H	YSMHB	41
Hyparrhenia variabilis Stapf	Poaceae	H	YH	94
Hypericum peplidifolium A. Rich.	Guttiferae	H	YB	320
Hypericum quartinianum A. Rich.	Guttiferae	S	Y	108
Hypericum revolutum Vahl	Guttiferae	S	YSH	312

Scientific name	Family name	Habit	Locations	Coll. No
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	H	YRMHB	115
Hypoestes triflora (Forssk.) Roem. & Schult.	Acanthaceae	H	YRMHBA	97
Impatiens tinctoria A. Rich.	Balsaminaceae	H	YH	46
Indigofera arrecta Hochst. ex A. Rich.	Fabaceae	H	Y	89
Inula confertiflora A. Rich.	Asteraceae	S	Y	110
Jasminum abyssinicum Hochst. ex DC.	Oleaceae	H	YSRMHB	145
Jasminum grandiflorum L.	Oleaceae	H	YSRMHB	140
Juniperus procera L.	Cupressaceae	T	YSRBA	166
Justicia ladanoides Lam.	Acanthaceae	H	YSRB	167
Justicia schimperiana (Hochst. ex Nees) T. Anders.	Acanthaceae	H	YSRA	65
Kalanchoe marmorata Bak.	Crassulaceae	H	YSRA	220
Kalanchoe petitiana A. Rich.	Crassulaceae	H	YSH	135
Kalanchoe quartiniana A. Rich.	Crassulaceae	H	YSH	132
Kleinia abyssinica (A. Rich.) A. Berger	Asteraceae	H	YSRH	219
Kniphofia foliosa Hochst.	Asphodelaceae	H	YSB	61
Laggera alata (D. Don) Oliv.	Asteraceae	H	YSBH	96
Laggera crispata (Vahl) Hepper & Wood	Asteraceae	H	YS	245
Laggera tomentosa (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	H	SY	153
Lantana camara L.	Verbenaceae	S	M	185
Lapeirousia abyssinica (R. Br. ex A. Rich.)	Lapeirousia	H	M	122

Scientific name	Family name	Habit	Locations	Coll. No
Barker				
Launaea intybacea (Jacq.) Beauv.	Asteraceae	H	M	208
Linum trigynum L.	Linaceae	H	YRA	112
Lippia adoensis Hochst. ex Walp.	Verbenaceae	S	YSHRA	168
Lotus discolour E. Mey.	Fabaceae	H	HY	92
Maesa lanceolata Forssk.	Myrsinaceae	T	YSRBA	36
Malva verticilata L.	Malvaceae	H	YS	186
Maytenus arbutifolia (A. Rich.) Wilczek.	Celastraceae	S	YSRHB	121
Maytenus senegalensis (Lam.) Exell	Celastraceae	S	YSRHB	25
Maytenus undata (Thunb.) Blakelock	Celastraceae	S	Y	144
Medicago polymorpha L.	Fabaceae	H	YSBA	239
Melinis repens (Willd.) Zizka	Poaceae	H	YSBRA	178
Merendera schimperiana Hochst.	Colchicaceae	H	YS	139
Momordica foetida Schumach.	Cucurbitaceae	H	YSH	26
Myrica salicifolia A.Rich.	Myricaceae	T	YSR	183
Myrsine africana L.	Myrsinaceae	S	YSRHB	45
Nicandra physaloides (L.) Gaertn.	Solanaceae	H	YSRA	235
Nuxia congesta R. Br. ex Fresen.	Loganiaceae	T	YSRBA	209
Ocimum lamiifolium Hochst. ex Benth.	Lamiaceae	S	SMBH	9
Olea europaea subsp. *cuspidata* (Wall. ex DC.) Cifferri	Oleaceae	T	YSRHBA	27
Olinia rochetiana A. Juss.	Oliniaceae	T	YSRHA	322

Scientific name	Family name	Habit	Locations	Coll. No
Opuntia ficus indica (L.) Miller	Cactaceae	S	M	307
Osyris quadripartite Decne	Santalaceae	S	YBHMSRA	5
Otostegia fruticosa (Forssk.) Schweinf. ex Penzig	Lamiaceae	S	YBHSRA	302
Otostegia integriflia Benth.	Lamiaceae	S	Y	169
Parthenium hysterophorus L.	Asteraceae	H	YA	10
Pavetta abyssinica Fresen.	Rubiaceae	S	YA	67
Pelargonium multibracteatum Hochst. ex A. Rich.	Geraniaceae	H	Y	131
Pennisetum thunbergii Kunth	Poaceae	H	YB	171
Pentaschistis pictigluma (Steud.) Pilg.	Poaceae	H	YS	321
Peperomia abyssinica Miq.	Piperaceae	H	YSRB	52
Periploca linearifolia Quart. Dill. & A. Rich.	Asclepiadaceae	L	YS	228
Physalis peruviana L.	Solanaceae	H	YSRH	90
Phytolacca dodecandra L 'Herit	Phytolaccacea	H	Y	120
Pimpinella hirtella (Hochst.) A. Rich.	Apiaceae	H	Y	125
Pinus patula D. Don.	Pinaceae	T	Y	68
Pinus radiata D. Don.	Pinaceae	T	Y	93
Pithecellobium dulce (Roxb.) Benth.	Fabaceae	T	M	205
Pittosporum viridiflorum Sims	Pittosporaceae	S	YSRHBA	313
Plantago lanceolata L.	Plantaginaceae	H	YS	151
Plectranthus lanuginosus (Hochst. ex Benth.)	Lamiaceae	H	YHB	231

Scientific name	Family name	Habit	Locations	Coll. No
Agnew				
Plectranthus punctatus (L.f.) L'Her.	Lamiaceae	H	YBA	217
Plumbago zeylanica L.	Plumbaginaceae	H	H	188
Podocarpus falcatus(Thun) Mirb.	Podocarpaceae	T	R	78
Polygala steudneri Chod.	Polygalaceae	H	YSRHBA	259
Premna schimperi Engl.	Lamiaceae	S	YRMB	300
Prunus africana (Hook.f.) Kalkm.	Rosaceae	T	YR	210
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	S	SRMHBA	318
Pterolobium stellatum (Forssk.) Brenan	Fabaceae	L	YSRMHBA	152
Rhamnus prinoides L'Herit.	Rhamnaceae	S	Y	72
Rhamnus staddo A. Rich.	Rhamnaceae	S	Y	69
Rhoicissus tridentata (L.f) Wild & Drummond	Vitaceae	L	Y	198
Rhus glutinosa A. Rich	Anacardiaceae	S	YSRHA	1
Rhus natalensis Krauss	Anacardiaceae	S	M	156
Rhus retinorrhoea Oliv.	Anacardiaceae	T	YSRHBA	53
Rhus vulgaris Meikle	Anacardiaceae	S	YSRHBA	17
Ricinus communis L.	Euphorbiaceae	H	YRHA	157
Rosa abyssinica Lindley	Rosaceae	S	YSA	70
Rubia cordifolia L.	Rubiaceae	H	YSHA	28
Rubus steudneri Schweinf.	Rosaceae	S	Y	50
Rumex nepalensis Spreng.	Polygonaceae	H	YH	33

Scientific name	Family name	Habit	Locations	Coll. No
Rumex nervosus Vahl	Polygonaceae	S	RMHBA	59
Ruta chalepensis L.	Rutaceae	H	Y	158
Salix mucronata Willd.	Salicaceae	S	SR	200
Salvia merjamie Forssk.	Lamiaceae	H	YSRH	82
Salvia nilotica Jacq.	Lamiaceae	H	YSRHA	106
Satureja abyssinica (Benth.) Briq.	Lamiaceae	H	YR	172
Satureja paradox (Vatke) Engl. ex Seybold	Lamiaceae	H	YSRA	117
Satureja punctata (Benth.) Briq.	Lamiaceae	H	YSRBA	252
Satureja simensis (Benth.) Briq.	Lamiaceae	H	YRH	161
Scabiosa columbaria L.	Dipsacaceae	H	RY	253
Schefflera abyssinica (Hochst. ex A. Rich.) Harms	Araliaceae	T	R	162
Schinus molle L.	Anacardiaceae	T	Y	66
Senecio lyratus Forssk.	Asteraceae	H	YRHBA	254
Senra incana Cay.	Malvaceae	S	Y	174
Sesbania sesban (L.) Merr.	Fabaceae	S	Y	73
Setaria sphacelata(Schumach.) Moss	Poaceae	H	YHS	184
Sida rhombifolia L.	Malvaceae	H	YSB	163
Sida schimperiana Hochst. ex A. Rich.	Malvaceae	S	Y	3
Snowdenia petitiana (A. Rich.) C. E. Hubb.	Poaceae	H	Y	247
Solanecio gigas (Vatke) C. Jeffrey	Asteraceae	S	YM	77
Solanum anguivi Lam.	Solanaceae	S	YH	147

Scientific name	Family name	Habit	Locations	Coll. No
Solanum dasyphyllum Schumach.	Solanaceae	H	YRA	159
Solanum marginatum L.f.	Solanaceae	S	YSRA	56
Solanum nigrum L.	Solanaceae	H	YSRHBA	47
Stephania abyssinica (Dillon & A. Rich.) Walp	Menispermaceae	H	B	197
Tagetes minuta L.	Asteraceae	H	M	37
Terminalia schimperiana ex A. Rich.	Combretaceae	T	M	170
Thalictrum rhynchocarpum Dill. & A. Rich.	Ranunculaceae	H	Y	233
Thymus schimperi Ronniger	Lamiaceae	H	YA	35
Toddalina asiatica (L.) Lam.	Rutaceae	S	YHR	255
Torilis arvensis (Hudson) Link	Apiaceae	H	YS	223
Tragia cinerea (pax) Gilbert& Radcl.-Smith	Euphorbiaceae	H	YA	319
Trifolium campestre Schreb.	Fabaceae	H	YSRH	116
Trifolium schimperir A. Rich.	Fabaceae	H	Y	173
Trifolium steudneri Schweinf.	Fabaceae	H	Y	176
Turraea holstii Gurke	Meliaceae	S	SR	141
Urera hypselodendron (A. Rich.) Wedd.	Urticaceae	L	RH	182
Urtica simensis Steudel	Urticaceae	H	YB	54
Verbascum sinaiticum Benth.	Scrophulariaceae	H	YSRHBA	48
Vernonia amygdalina Del.	Asteraceae	S	RHA	74
Vernonia bipontini Vatke.	Asteraceae	T	YBH	194
Vernonia leopoldi (Sch.Bip. ex Walp.) Vatke	Asteraceae	H	YSRA	129

Scientific name	Family name	Habit	Locations	Coll. No
Vernonia rueppellii Sch. Bip. ex Walp.	Asteraceae	S	YSRHA	318
Viscum tuberculatum A. Rich.	Viscaceae	S	YSAH	95
Withania somnifera (L.) Dunal	Solanaceae	S	YSHA	88
Xanthium spinosum L.	Asteraceae	H	BM	317
Xanthium strumarium L.	Asteraceae	H	B	179
Zehneria scabra (Linn. f.) Sond.	Cucurbitaceae	H	YSBM	43
Ziziphus mucronata Mill.	Rhamnaceae	T	M	203
Ziziphus spina-christi (L.) Desf.	Rhamnaceae	T	M	256

Where A = Abuli; B = Biraro; H= Harego; M=Harbu; R=Rrkis; S =Suki; Y= Yegof

Annex 2 Plant species endemic to Ethiopia and their IUCN Red List Categories

Scientific Name	Family	Habit	Category
Acacia negrii Pic.-Serm.	Fabaceae	Tree	VU
Aloe monticola Reynolds	Aloaceae	Herb	
Aloe pulcherrima Gilbert & Sebsebe	Aloaceae	Shrub	EN
Aloe sinana Reynolds	Aloaceae	Herb	
Anthoxanthum aethopicum I. Hedberg	Poaceae	Grass	
Cineraria abyssinica Sch. Bip.ex A.Rich	Asteraceae	Herb	
Crassocephalum macropappum (Sch. Bip. ex A. Rich.) S. Moore	Asteraceae	Herb	
Echinops longisetus A. Rich.	Asteraceae	Herb	LC
Erythrina brucei Schweinf.	Fabaceae	Tree	
Euphorbia dumalis S. Carter	Euphorbiaceae	Shrub	LC
Festuca macrophylla Hochst. ex A. Rich.	Poaceae	Grass	VU
Inula confertiflora A. Rich.	Asteraceae	Shrub	NT
Kniphofia foliosa Hochst.	Asphodelaceae	Herb	LC
Laggera tomentosa (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	Herb	NT
Lippia adoensis Hochst. ex Walp.	Verbenaceae	Herb	LC
Satureja paradox (Vatke) Engl. ex Seybold	Lamiaceae	Herb	NT
Solanecio gigas (Vatke) C. Jeffrey	Asteraceae	Shrub	LC
Trifolium schimperir A. Rich.	Fabaceae	Herb	
Urtica simensis Steudel	Urticaceae	Herb	LC
Vernonia leopoldi (Sch.Bip. ex Walp.) Vatke	Asteraceae	Herb	
Rhus glutinosa ssp. glutinosa A. Rich	Anacardiaceae	Shrub	

Where VU= Venerable, EN= Endanger, LC=Less concerned,

Annex 3 Importance Value index, showing minval=2.25, used to naming community types

	Community 1	Community 2	Community 3	Community 4	Community 5
Juniperus procera	5.2	.	.	.	.
Laggera tomentosa	2.33	.	.	.	.
Lippia adoensis	.	2.25	.	.	.
Clutia abyssinica	.	.	3	.	.
Diplolaphium africanum	2.5	.	.	.	.
Nuxia congesta	2.25	.	.	3	.
Justicia ladanoides	.	.	.	2.5	.
Clematis hirsuta	2.4	.	.	.	.
Geranium aculeolatum	.	2.33	.	.	.
Olinia rochetiana	2.78	2.94	.	.	.
Rosa abyssinica	2.4	.	2.5	.	.
Olea europaea	.	3.73	.	2.71	.
Haplocarpha schimperi	.	.	2.5	.	.
Erica arborea	.	2.6	.	3	.
Dichondra repens	.	2.33	.	.	.
Rhus glutinosa	.	2.38	2.25	.	.
Verbascum sinaiticum	.	.	2.33	.	.
Epilobum hirsutum	.	.	2.33	.	.
Allophyllus abyssinicus	.	.	2.25	.	.
Myrica salicifolia	.	.	.	2.5	.
Bersama abyssinica	.	2.33	2.4	.	.
Osyris quadripartita	2.62	2.5	2.57	.	.
Clerodendron alatum	.	3	.	.	.
Andropogon abyssinicus	.	.	2.25	2.4	.
Hypoestes triflora	2.67	.	.	.	.
Eleusine floccifolia	.	2.33	.	.	.
Galiniera saxifraga	3	.	.	2.5	.
Maesa lanceolata	.	.	2.3	.	.
Dodonaea angustifolia	2.33	2.71	2.4	2.62	.
Carissa spinarum	2.45	.	3	2.56	2.45
Hyparrhenia hirta	2.33	3	.	.	.
Euphorbia candelabrum	.	2.25	3	.	.

	Community 1	Community 2	Community 3	Community 4	Community 5
Myrsine africana	2.6	.	.	2.77	.
Ekebergia capeosis	.	.	2.57	.	.
Ehretia cymosa	.	.	2.33	.	.
Calpurnia aurea	.	.	.	.	2.4
Hyparrhenia coieotricha	.	.	2.33	.	.
Maytenus senegalensls	.	.	2.33	.	.
Conyza hochstetteri	.	.	.	.	2.5
Jasminum abyssinicum	.	2.5	.	.	3
Jasminum grandiflorum	.	2.4	.	.	2.5
Buddleja polystachya	.	.	.	2.25	.
Euclea racemosa	.	.	.	2.68	2.37
Pterolobium stellatum	.	.	.	2.5	3.1
Capparis persicifolia 1	.	.	.	.	3
Acacia seyal	.	.	.	.	3.27
Dichrostachys cinerea	.	.	.	.	3.69
Calotrpis procera	.	.	.	.	3
Grewia flavescens	.	.	.	.	2.43
Acacia brevispica	.	.	.	.	3.38
Abutilon angulatum	.	.	.	.	2.33
Grewia bicolor	.	.	.	.	3
Terminalia schimperiana	.	.	.	.	2.33
Grewia ferruginea	.	.	.	.	2.5

	Community 1	Community 2	Community 3	Community 4
Juniperus procera	5.2	.	.	.
Laggera tomentosa	2.33	.	.	.
Lippia adoensis	.	2.25	.	.
Clutia abyssinica	.	.	3	.
Diplolaphium africanum	2.5	.	.	.
Nuxia congesta	2.25	.	2.25	.
Clematis hirsuta	2.4	.	.	.
Geranium aculeolatum	.	2.33	.	.

	Community 1	Community 2	Community 3	Community 4
Olinia rochetiana	2.78	2.94	.	.
Rosa abyssinica	2.4	.	2.25	.
Olea europaea	.	3.73	.	.
Haplocarpha schimperi	.	.	2.5	.
Erica arborea	.	2.6	.	.
Dichondra repens	.	2.33	.	.
Rhus glutinosa	.	2.38	.	.
Epilobum hirsutum	.	.	2.33	.
Bersama abyssinica	.	2.33	2.4	.
Osyris quadripartita	2.62	2.5	2.29	.
Clerodendron alatum	.	3	.	.
Andropogon abyssinicus	.	.	2.33	.
Hypoestes triflora	2.67	.	.	.
Eleusine floccifolia	.	2.33	.	.
Galiniera saxifraga	3	.	.	.
Maesa lanceolata	.	.	2.25	.
Dodonaea angustifolia	2.33	2.71	2.58	.
Carissa spinarum	2.45	.	2.65	2.45
Hyparrhenia hirta	2.33	3	.	.
Euphorbia candelabrum	.	2.25	.	.
Myrsine africana	2.6	.	2.56	.
Ekebergia capeosis	.	.	2.57	.
Ehretia cymosa	.	.	2.33	.
Calpurnia aurea	.	.	.	2.4
Hyparrhenia coieotricha	.	.	2.33	.
Conyza hochstetteri	.	.	.	2.5
Jasminum abyssinicum	.	2.5	.	3
Jasminum grandiflorum	.	2.4	.	2.5
Euclea racemosa	.	.	2.68	2.37
Pterolobium stellatum	.	.	.	3.1
Capparis persicifolia	.	.	.	3
Acacia seyal	.	.	.	3.27
Dichrostachys cinerea	.	.	.	3.69
Calotrpis procera	.	.	.	3
Grewia flavescens	.	.	.	2.43
Acacia brevispica	.	.	.	3.38
Abutilon angulatum	.	.	.	2.33
Grewia bicolor	.	.	.	3
Terminalia schimperiana	.	.	.	2.33
Grewia ferruginea	.	.	.	2.5

Annex 4 Indicator value index of the community types in Yegof and its surrounding forest

Annex 5 Data sheet (herbs, shrubs, trees)

No	Local name of the plant	Habit	Tree or canopy layer	Height*		DB H*	Count	Cl, CW , % ground cover	Remarks
				H	Hc				

* if applicable; H = tree height; Hc = height to the base of the crown; Cl = crown length Cw = crown width

Annex 6 Data sheet (seedlings, saplings)

No	Local name	No Saplings	Seedlings	Remark

Annex 7 Questioners

I. **Economic and Demographic Background**

1) Family size:_________________________
2) Length of time in dwelling; ____________
3) Ethnicity:___________________________
4) Composition of household _____________
5) Education categories; (1) Illiterate ,(2) Adult education, (3) Primary (4) Secondary (5) College (6) Others (specify)
6) Distance of household from the forest ______
7) Occupation of head of household; __________
8) Size of farm (ha):______________________
9) Main crops and times of harvest :_____________
10) Livestock: number of cows, goats, chickens, other

II. **Land use land cover change profile**

1) Do you recognize LULC changes in of your area? Yes ; (B) No ; (C) Indifferent (specify)____________-
2) if your answer is 'YES'(No 1), would you try to specify the period in which a changes in LULC were rcognized? (A) Within 10 years ; (B) 10 -20 years; (C) 20 – 30 years (D) Before 30 years; (E) Other (specify)
3) If your answer is 'YES' (No 1) , how do you rate the land cover drivers so far you recognized in your area. (1) climate-related change (long- and short term), (2) burning / fire activities, (3) cutting and clearing of forests (deforestation), (4) grazing activities (intensification of rangelands), (5) agricultural encroachments (farming activities), (6) fuelwood consumption, urban expansions (urbanization),(7) natural successional processes and regeneration" Others (specify).
4) Who is doing deforestation? (A) Small farmers (B) Town dwellers (C) Loggers (D) Cattle ranchers?; (E) Others (specify)
5) Types and sources of fuel (wood, charcoal, agricultural residues, dung,) _
6) What types and sources of animal feed ____________

III. Perception towards forest conservation and management under different forest management regimes

1) Do you notify any changes regarding the management of the local forest governance? _______________
2) Who was/is responsible in the development/management of the forests?______________
3) How do you see the overall activities of the local forest manager?________________
4) What types of forest management interventions you remember regarding local forest administration?_________________
5) Are you happy with the current interventions of the forest manager?

   (1) Yes, (2), No; If your answer is "No, what will be an appropriate forest management intervention ___________________
6) Do you believe that conserving the forest area is important (1) Yes; 2) No; (3). No idea; If yes, why do you think so? ____________________

B. Check list for Informal Survey

1) Importance of Yegof forest conservation,
2) LULC changes of the area.
3) Perception on forest development, and harvesting of forest product