



**The Forest Patches of Gurage Mountains: Floristic Composition,
Ecology and Anthropogenic Influences**

By Tamru Demsis Temam

**A Thesis Submitted to Department of Plant Biology and Biodiversity
Management**

**Presented in Fulfilment of the Requirement for the Degree of Doctor of
Philosophy (Biology: Botanical Science)**

**Addis Ababa University
Addis Ababa, Ethiopia**

**December 2013
Addis Ababa**

ADDIS ABABA UNIVERSITY

GRADUATE PROGRAMMES

This is to certify that the thesis prepared by Tamru Demsis Temam, entitled: *The Forest Patches of Gurage Mountains: Floristic Composition, Ecology and Anthropogenic Influences* and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy (Biology: Botanical Science) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Board:

Name	Signature	Date
1. <u>Dr Kristoffer Hylander</u> (Examiner)	<u>Kristoffer Hylander</u>	<u>07/06/13</u>
2. <u>Dr Tamrat Bekele</u> (Examiner)	<u>Tamrat Bekele</u>	<u>Jan 30, 2014</u>
3. <u>Prof Sebsebe Demissew</u> (Advisor)	<u>Sebsebe Demissew</u>	<u>03/02/2014</u>
4. <u>Prof Zerihun Woldu</u> (Advisor)	<u>Zerihun Woldu</u>	<u>03/02/2014</u>

Emmanuel Ketseera

Chair of Department or Graduate Programme Coordinator

Table of Contents

Acronyms.....	viii
Acknowledgements.....	ix
Abstract.....	x
CHAPTER ONE.....	1
1. Introduction.....	1
1.1 Background and Justification.....	1
1.2 Research objectives.....	4
1.3 Research questions.....	5
CHAPTER TWO.....	6
2. Literature Review.....	6
2.1 Vegetation and its attributes.....	6
2.2 Measures of species richness and estimation of 'true' species richness	6
2.3 Perspectives on plant community organization.....	9
2.4 The ecological application of generalized linear modeling	21
2.5 The Vegetations of Ethiopia	23
CHAPTER THREE.....	26
3. Materials and methods	26
3.1 Materials	26
3.2 Methods.....	26
3.2.1 Location and description of the study area	26
3.2.2 Research approach and site selection.....	31
3.2.3 Vegetation sampling	32
3.2.4 Vegetation and environmental variables data collection.....	34
3.2.5 Soil sampling and analysis of physical and chemical properties	35
3.2.6 Method used for collection of disturbance data	36
3.2.7 Method used for collection of data on causal factors of vegetation loss and degradation	36
3.2.8 Vegetation and environmental data analysis.....	38
CHAPTER FOUR.....	40
4. Results.....	40
4.1 Attributes of plant communities in the study area	40

4.1.1 Floristic composition and species richness	40
4.1.2 Species abundance and occurrence in the study area.....	43
4.1.3 Plot level species richness variation in the study area	45
4.1.4 Structural Analysis.....	46
4.1.4.1 Growth forms	46
4.1.4.2 Height class distribution.....	46
4.1.4.3 DBH class distribution	49
4.1.4.4 Basal area of most important trees	51
4.1.4.5 Species population structure	52
4.2 Plant endemism in the study area.....	54
4.3 Classification of the vegetation of the study area	55
4.4.1 Similarity between community types in the study area	65
4.4.2 Floristic similarity between the forest patches of Gurage Mountains and other forests in Ethiopia.....	65
4.4.4 Expected and estimated species richness of the communities	66
4.5 Relationship between plant communities and environmental variables	71
4.5.1 Canonical Correspondence Analysis	71
4.5.2 Analysis of Variance.....	74
4.5.2.1 Relation between topographic variables and the plant communities	75
4.5.2.2 Relation between edaphic variables and the plant communities	77
4.5.2.3 Relation between disturbance and the plant communities	80
4.6 Relation between environmental variables and species richness	81
4.6.1 Relation between disturbance and plant species richness	89
4.6.2 Relation between altitude and plant species richness	90
4.6.3 Relation between pH and species richness	91
4.7 Causes of forest loss and degradation in the study area.....	92
4.7.1 Expansion of agricultural land	92
4.8.2 High population pressure	96
4.7.3 Wood extraction	98
4.7.4 Institutional drivers	102
4.8.5 Grazing.....	105

CHAPTER FIVE	106
5. DISCUSSION, CONCLUSION AND RECOMMENDATION	106
5.1 Discussion	106
5.2. Conclusion and recommendations	117
References.....	119
Annexes	139

List of Tables

Table 1: Land use/cover of the study Weredas.....30

Table 2: The subcatchments in the Weredas included in the present study.....31

Table 3: Sites selected for the study.....32

Table 4: Height class distribution of woody plants in Gurage Mountains (in %)......47

Table 5: Comparison of height class distribution of woody plants in the Gurage Mountains with other
afromontane forests of Ethiopia.....49

Table 6: Comparison of DBH class distribution of woody plants in the Gurage Mountains with other
afromontane forests of Ethiopia.....50

Table 7: Basal area of the most important trees in the each of the plant communities identified in the study
area.....51

Table 8: Plants endemic to Ethiopia which were recorded in the study area.....54

Table 9: The correlation between axis scores from NMDS and environmental variables.....58

Table 10: Species with significant indicator values in each community.....59

Table 11: Jaccard similarity between communities.....65

Table 12: Jaccard similarity between forest patches of Gurage Mountains and other forests in Ethiopia.....66

Table 13: The expected species richness of the plant communities in the study area based on bample-based
rarefaction.....67

Table 14: Variables with significant impact on plant distribution patterns.....71

Table 15: Correlation between the variables and ordination axes.....73

Table 16: Analysis of variance table (using altitude as response).....75

Table 17: Analysis of variance table (using slope as response).....77

Table 18: Analysis of variance table (using clay as response).....77

Table 19: Analysis of variance table (using sand as response).....78

Table 20: Analysis of variance table (using pH as response).....79

Table 21: Analysis of variance table (using disturbance as response).....80

Table 22: AIC, Deviance and Corresponding F-values if one variable was added to the null model.....81

Table 23: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model
with disturbance.....83

Table 24: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model
with disturbance and altitude.....85

Table 25: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model
with disturbance, altitude and pH.....86

Table 26: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model
with disturbance, altitude , pH & slope.....87

List of Figures

Figure 1: Location map of the study area.....	27
Figure 2: Agro-ecological zones of Gurage Zone.....	28
Figure 3: Climate diagram of the study area.....	29
Figure 4: Plot design.....	34
Figure 5: Percentage of plant families in the study area.....	41
Figure 6: Species accumulation curve of the study area.....	42
Figure 7: Rank/abundance or dominance curve of the species in the study area.....	43
Figure 8: Abundance vs. occurrence of the species in the study area.....	44
Figure 9: Plot level variation in species richness.....	45
Figure 10: The percentage of different growth forms in the flora of Gurage Mountains.....	46
Figure 11: Percentage of woody plants of different height class in the study area.....	47
Figure 12: Percentage of plants of different DBH classes in the study area.....	50
Figure 13: The population structure of the dominant trees in the Gurage Mountains.....	52
Figure 14: Dendrogram of the Vegetation of Gurage Mountains.....	56
Figure 15: The configuration of the plots in NMDS ordination diagram.....	57
Figure 16: A joint plot of sample-based rarefaction curves of the communities in the study area.....	68
Figure 17: Observed and estimated species richness of each community.....	69
Figure 18: Ordination diagram displaying the first two ordination axes of CCA.....	72
Figure 19: Boxplot of community types vs. altitude.....	75
Figure 20: Boxplot of community types vs. steepness of slope.....	76
Figure 21: Boxplot of community types vs. clay content of the soil.....	77
Figure 22: Boxplot of community types vs. sand content of the soil.....	78
Figure 23: Boxplot of community types vs. pH of the soil.....	79
Figure 24: Boxplot of community types vs. disturbance.....	80
Figure 25: Disturbance vs. species richness pattern in the study area.....	89
Figure 26: Altitude vs. species richness pattern in the study area.....	90
Figure 27: Soil pH vs. species richness pattern in the study area.....	91
Figure 28: The gradual increase in agricultural land demand in the study area.....	93
Figure 29: Agricultural land expansion into Zemute forest, Sodo Wereda.....	94
Figure 30: Forest land in Mirab Imbor but now converted to agricultural land.....	95
Figure 31: The gradual increase in population number of the study area.....	97
Figure 32: The number housing units in towns of the study area by type of fuels used for cooking.....	99
Figure 33: Forest destruction for fuel wood (Arusi forest, Sodo Wereda).....	100
Figure 34: Forest destruction for charcoal production (Zemute forest, Sodo Wereda).....	101
Figure 35: Fuelwood sellers (Mirab Imbor, Mesqan Wereda).....	102

Acronyms

AIC	Akaike Information Criterion
CSA	Central Statistical Agency of Ethiopia
EMA	Ethiopian Mapping Authority
FoB	Facts on Biodiversity
GFC	Global Forest Coalition
GLM	Generalized Linear Modelling
GZEDEC	Gurage Zone Finance and Economic Development Coordination office
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
SNNPRS	Southern Nations, Nationalities and Peoples' Regional State
Sobs	Observed species richness

Acknowledgements

First and foremost I would like to extend sincere gratitude to my supervisors Prof. Sebsebe Demissew and Prof. Zerihun Woldu for their constructive guidance. Had it not been for their tireless supervision, timely completion of the study could have been hardly possible. I am also thankful to Dilla University for sponsoring my study. The farmers in the study area were keen to provide genuine information on drivers of forest loss and degradation in their locality. Hence, I would like to use this opportunity to extend my earnest gratitude for their cooperation.

Abstract

Degradation of vegetation cover is considered as one of the most serious environmental problems facing Ethiopia and the world at large. Studies revealed that the vegetation resources of Ethiopia are disappearing much faster than the efforts made to document the information and propose mitigation programs. Hence, the present study was conceived to investigate floristic composition, patterns of plant distribution, environmental variables that account for these patterns and to explore factors that lead to loss of forest cover in the Gurage Mountains. Stratified preferential sampling was used to collect floristic data. Plot size of 40 x 40 m was used for vegetation sampling. The altitude of each main plot was recorded using Garmin GPS. Soil samples were taken at corners of the 20 x 20 m subplots and composite samples were made. Intensity of anthropogenic disturbance in each plot was estimated by considering the following parameters: number of trees and shrubs cut, foot trails, seedlings trampled as well as grazing/browsing intensity. Focus group interview was used to identify factors that account for loss of vegetation cover in the study area. Data from central statistical agency of Ethiopia were used to supplement the data from the interview. Cluster analysis was used to identify plant community types in the study area. Canonical correspondence analysis was to investigate the relation between environmental variables and the plant communities. In addition, ANOVA was used to examine the relationship between the plant communities and environmental variables. Generalized linear modeling was used to relate species richness patterns of the Gurage Mountains to the measured explanatory variables. A total of 339 plant species belonging to 89 families were encountered in the study area. About 10 % of the plants were endemic to Ethiopia. Canonical correspondence analysis revealed that altitude, slope, disturbance, soil clay, sand and pH had significant relation with the plant communities. Analysis of variance verified that altitude, slope, disturbance, soil pH, clay and sand content of the soil were significantly related to the plant communities. Generalized linear modeling showed that disturbance, altitude, pH and slope were the most important factors influencing the plant species richness pattern of the Gurage Mountains. Expansion of agricultural land, population pressure, wood extraction, institutional weaknesses and grazing were the main drivers for forest loss and degradation in the study area. Overall, the forest patches studied are characterized by high floristic diversity and house a good number of endemic plants. Immediate conservation intervention is recommended for the recovery and sustainable use of the remnant forest patches.

CHAPTER ONE

1. Introduction

1.1 Background and Justification

Myers (1988) described biodiversity hotspots as biologically rich areas characterized both by high levels of plant endemism and by serious levels of habitat loss. A region must meet two criteria to qualify as a hotspot: it must contain at least 1,500 species of vascular plants ($> 0.5\%$ of the world's total) as endemics, and it has to have lost at least 70% of its original habitat (Myers *et al.*, 2000; Mittermeier *et al.*, 2011). Given these criteria, 34 regions now meet the hotspot criteria and collectively comprise about 50% of vascular plants as endemics (see Mittermeier *et al.*, 2011). As such regions are characterized by high levels of plant endemism and severe habitat loss; they deserve priority in nature conservation endeavors.

The Eastern Afromontane biodiversity hotspot is one of the 34 biodiversity hotspots, which was first recognized as globally important for species conservation by Mittermeier *et al.* (2004) when the number of global hotspots was increased from 25 to 34. It includes mountain ranges in Eastern Africa and the Arabian Peninsula, which contain about 7,600 plant species, of which more than 2,350 are endemic. More than 1000 plant species in the Eastern Afromontane are highly threatened (BirdLife International, 2012). Ethiopian highlands, which belong to the Eastern Afromontane biodiversity hotspot, harbor an estimated 5,200 plant species, of which at least 200 are endemic. Nearly 40 percent of the Eastern Afromontane Biodiversity hotspot occurs in Ethiopia (see BirdLife International, 2012). Thus, the Ethiopian highlands include part of the world's biodiversity hotspots but one of the most degraded ones (Mckee, 2007). This is partly because of the fact that the majority of subsistence agriculture practicing population in Ethiopia resides in the highlands.

The 34 hotspots once covered an area of 23.7 million km^2 i.e. about 15.9% of Earth's land surface. However, because of the severe habitat destruction, the natural vegetation in these areas is now reduced to 2.3 percent (3.4 million km^2) of the world's land area (Mittermeier *et al.*,

2011). For instance, most of the original forests and grasslands in the Eastern afro-montane hotspot have been converted to agricultural land (BirdLife International, 2012). Similarly, the Ethiopian Highlands have experienced considerable conversion of natural habitat to agriculture and much of the original natural forests of Ethiopia now exist only as small remnants in southwest part of the country, steep escarpments of the Rift Valley, river gorges and the cold Afro-alpine plateaus (Williams *et al.*, 2004; BirdLife International, 2012). These parts of the country are relatively less accessible for encroachment into the natural forests.

The human population in the biodiversity hotspots is highly dependent on natural resources and ecosystem services (BirdLife International, 2012). Therefore, loss of biodiversity has severe consequences on the rural poor who depend upon ecosystem services for their livelihoods and it poses a significant barrier to meeting the Millennium Development Goals (e.g. eradicating extreme poverty and hunger, ensuring environmental sustainability) (GreenFacts, 2007). Various studies (e.g. GFC, 2010; Kanninen *et al.*, 2008; Roper and Roberts, 2006) showed that human-induced land use change has led to land degradation and also destroyed watersheds, affecting water supplies. One fifth of total annual carbon emissions now come from land-use change (Kanninen *et al.*, 2008) making deforestation the second most important contributor (next to fossil fuels) to global warming (Contreras-Hermosilla, 2000; Slingenberg *et al.*, 2009). Naeem *et al.* (1999) argued that plant production and ecosystem resistance to environmental perturbations such as drought may decline as biodiversity is reduced (i.e. biodiversity reduction can lead to decrease in probability of getting species that can cope up environmental perturbations). Similarly, FoB (2005) also argued that vulnerability to natural disasters increases with intensification of biodiversity degradation. Hence, biodiversity loss has emerged as an issue of both scientific and political concern (Pausas and Austin, 2001) and safeguarding biodiversity is now a major focus of world conservation strategies (Burns, 1995). This is because of the fact that failure to stop or abate the alarming loss of biodiversity and the consequential socioeconomic and environmental challenges can have far-reaching negative effects on human wellbeing.

Biodiversity declines are high in areas where natural ecosystems are being converted to croplands, timber plantations and other managed ecosystems (Naeem *et al.*, 1999). 15 percent of

the world's forests and woodlands were cleared between 1850 and 1980 (Roper and Roberts, 2006). Studies (e.g. Boahene, 1998; Contreras-Hermosilla, 2000; Yengoh, 2008) revealed that most contemporary conversion of natural ecosystems to other land uses is taking place in developing countries, mainly in tropical areas. The top 20 deforesting countries (Ethiopia included and ranked 20th) accounted for 156 million ha or approximately 80% of all of the natural tropical forest lost from 1990 to 2005 (see Roper and Roberts, 2006). The possible reasons for the high rate of deforestation in these countries include high dependence on fuelwood for household energy and encroachments into forest lands for subsistence agriculture.

In sum, biological diversity is experiencing a high rate of depletion despite its enormous importance to our own survival (Stoll-Kleemann and O'riordan, 2002; Gbetnkom, 2008) and the current loss of biodiversity and the resultant changes in the environment, according to FoB (2005); GreenFacts (2007), are faster than ever before in human history. Naeem *et al.* (1999) predicted that nearly half of all species could be extinct within 100 years even at the lowest estimated current extinction rate; which would be comparable in magnitude to the five mass extinction events in the 3.5 billion year history of life on earth. The fastest rates of extinction in the world are occurring in the tropical forests (Slingenberg *et al.*, 2009). The implication is that urgent and appropriate conservation measures are needed to combat the depletion of biodiversity.

The escalating demand for forest products and forest land in Ethiopia has put the remaining patches of forests on the verge of extermination (EMA, 1988). Demel Teketay (2001) reported that one of the major challenges facing Ethiopia is environmental degradation, manifested in the degradation of land and water resources as well as loss of biodiversity. Similarly, Teshome Soromessa *et al.* (2004) asserted that the vegetation resources of Ethiopia are disappearing at alarming rate even before we have a chance to study and document them. In their study in Central Rift Valley of Ethiopia, Jansen *et al.* (2007) reported an increasing trend in conversion of natural vegetations to agricultural lands. Hence, investigations on the vegetation resources of the country are inevitably needed in order to ensure sustainable management of the remnant vegetation and to abate the actual and potential consequences of loss of vegetation.

Concerns about increasing loss of biodiversity and the resulting degradation of ecosystem services have stimulated several studies (Naeem *et al.*, 1999). Specifically, a central concern of vegetation ecologists has been investigation of the factors that affect species distributions and community composition (Motzkin *et al.*, 1999) and correlation of vegetation with environmental factors (Carleton, 1984). However, there was limited study on floristic composition, pattern of plant distribution and factors that account for vegetation loss in the Gurage Mountains.

Descriptions of the floristic composition and structure of plant communities are essential for understanding ecological systems (Grossman *et al.*, 1998). Likewise, Enright (1982); Hamilton (2005) stated that investigation of floristic composition and other pertinent features such as size class can give ecologists insights into the state and stability of the vegetation of a site. Various researchers (e.g. Burns, 1995; Slik *et al.*, 2003; Colwell *et al.*, 2004; Adomou, 2005; Knollová *et al.*, 2005; Brown *et al.*, 2007; Reddy *et al.*, 2007) also underscored that investigations on vegetation composition, distribution patterns and on the factors that account for plant distribution patterns is an important input for conservation planning. Furthermore, vegetation conservation requires understanding of the factors that account for loss of vegetation (Contreras-Hermosilla, 2000). Measures to mitigate loss of vegetation can hardly succeed if they do not address the real causes (see GFC, 2010). Therefore, location specific studies on drivers of vegetation loss are essential for conservation planning. In light of these arguments, the present study was conceived to investigate floristic composition, patterns of plant distribution, environmental variables that account for these patterns and to explore factors that cause loss of vegetation in the Gurage Mountains.

1.2 Research objectives

As indicated in section 1.1 above, conversion of natural vegetation to other land uses is taking place in Ethiopia at an alarming rate. Investigations that can generate knowledge on floristic composition, patterns of plant community distribution as well as exploration of factors that contribute to loss of vegetation could serve as an important basis for conservation of the remaining vegetation. To this end, the present study in the Gurage Mountains aims to:

- explore and document floristic composition of the study area;
- identify the main plant community types in the study area;
- describe plant community attributes (species richness, structure and dominance) ;
- investigate main environmental factors that influence patterns of species distribution and richness;
- explore causal factors for vegetation loss and degradation;
- recommend actions that need to be taken for sustainable vegetation management in the study area.

1.3 Research questions

To realize the aforementioned objectives, the following research questions were addressed:

- Which plant species are found in the Gurage Mountains?
- Do plant species assemblages in the Gurage Mountains segregate in community types?
- What are the main plant community types in the study area?
- How are the plant communities in the study area characterized in terms of species richness, structure and dominance?
- What are the environmental variables most important in explaining variations in plant community types and species richness in the study area?
- What are factors that account for loss of vegetation in the study area?
- Given the information generated in the present study, how could the vegetation in the study area be rehabilitated?

CHAPTER TWO

2. Literature Review

In this chapter, the most important concepts in the present study namely vegetation and measures of species richness are described. Besides, perspectives on plant community organization and the implication of these perspectives on quantitative plant ecology are explained. The application of generalized linear modeling in vegetation ecology is briefly described. Finally, a brief overview of the vegetation of Ethiopia is presented in this chapter.

2.1 Vegetation and its attributes

Pignatti (1996) envisaged vegetation as a system consisting of different plant life forms (herbs, shrubs, trees). Vegetation science came into being for two main reasons: to describe structures of the plants and to investigate processes which influence the patterns of composition and emergent properties (e.g. species richness) (Austin and Smith, 1989). Similarly, Noy-Meir and van der Maarel (1987) and later on van der Maarel (2005) reported that plant ecologists have been interested in various aspects of vegetation such as structure, physiognomy, diversity, spatial variation in species composition. Vegetation structure is defined as the vertical arrangement of vascular plants (Schulz *et al.*, 2009) and structural analysis may involve computation of basal area, DBH and height class distributions (Elouard and Krishnan, 1999). The structural analysis can give some insight on the regeneration status of the vegetation of an area.

2.2 Measures of species richness and estimation of 'true' species richness

Magurran (2004) considered species richness as an iconic measure of biodiversity. Species richness can be defined as the number of species in a sample unit / the total number of species within a community/ (see McCune and Grace, 2002; Brown *et al.*, 2007; Colwell, 2009a). It is the simplest concept to describe community diversity (Gotelli and Colwell, 2001; Chao, 2005; Brown *et al.*, 2007), and forms the basis of many ecological models of community structure (Gotelli and Colwell, 2001). It is just a measure of the number of species present in a given area without considering the number of individuals in each species.

Whittaker (1972) classified species richness measures into alpha, beta and gamma diversity. Ecologists (such as McCune and Grace, 2002; Brown *et al.*, 2007; Colwell, 2009a; Schulz *et al.*, 2009) defined alpha diversity as small-scale species richness and it consists of a count of species within homogeneous area. The small scale could range from a 1 m² sample of grassland herbs to a 1000 m² stand of trees depending on the size of plants to be studied (Brown *et al.*, 2007). Beta diversity can be conceived as the change in species composition from one area to the next along a gradient and provides information about how diversity changes along environmental gradients (see McCune and Grace, 2002; Brown *et al.*, 2007; Colwell, 2009a; Schulz *et al.*, 2009). Jaccard index of similarity and the closely related Sørensen index are commonly used for assessing compositional similarity of assemblages (Magurran, 2004). There are also other similarity indices that are based on the same information: the number of species shared by two samples and the number of species unique to each of them (Magurran, 2004; Chao *et al.*, 2005). Gamma diversity reflects both the alpha diversity of sites within the region and the rate of change in richness between those sites (beta diversity) (Brown *et al.*, 2007). It measures of the diversity across habitats within a region.

Many species richness indices have been developed to measure biodiversity (e.g see Magurran, 2004). Alternative to species richness indices, a statistical technique known as rarefaction can be used for comparison of species richness between communities (Ludwig and Reynolds, 1988). Colwell (2009a) defined rarefaction (also called interpolated species accumulation curve) as the statistical expectation of the number of species in a study as a function of the accumulated number of individuals or samples, based on re-sampling from an observed sample set. Species accumulation curve shows the rate at which new species are found (Magurran, 2004) and generates the expected number of species in a small collection of *n* individuals (or *n* samples) drawn at random from the large pool of *N* individuals (or *N* samples) (Gotelli and Colwell, 2001; Hersperger and Wohlgemuth, 2004; Colwell, 2009b; Schulz *et al.*, 2009). Rarefaction, according to Gotelli and Colwell (2001), is a method for interpolating to smaller samples and estimating species richness in the rising part of the taxon sampling curve. EstimateS (Colwell, 2006) computes expected species accumulation curves (sample-based rarefaction curves), with 95% confidence intervals (Colwell, 2009b). Rarefaction is, therefore, a method for estimation of the

number of species expected in a random sample of individuals taken from a collection. For example, the expected number of species in a small collection of 20 sample plots drawn at random from the large pool of 50 sample plots could be estimated using rarefaction curves.

When comparing the species richness of two or more regions, sample size differences must be taken into account. This is because regions with more sample units, and thus a larger total sample area would include more species than regions with lower sample units (Gotelli and Colwell, 2001). Hence, direct comparison of the number of species recorded in different sampling intensities is not appropriate. Rarefaction produces appropriate/smooth curves that facilitate species richness comparison (Gotelli and Colwell, 2001). Rarefaction curve, as noted in preceding section, is a method that is used to estimate the number of species that would be found if sampling effort was reduced to a specified level. This allows comparisons amongst communities where sampling effort is unequal. The rarefaction methods are, therefore, particularly useful for comparing species richness among communities when the sampled areas are unequal or have been inventoried with unequal effort (Ludwig and Reynolds, 1988; Hersperger and Wohlgemuth, 2004; Colwell, 2009a; Schulz *et al.*, 2009). Such types of methods help to standardize different samples from different communities to a common sample size and hence to make species richness comparison at comparable sampling intensity.

The task of assessing biodiversity also requires that we make the most out of what we know through the use of estimation and extrapolation (Colwell and Coddington, 1994). The global climate change, habitat transformation and the pervasive extinction have made extrapolation and prediction a vital component of biodiversity research. Similarly, Ugland *et al.* (2003) argued that one of the most important goals of field studies in ecology is to estimate how many species of a given taxon (of all taxa) occur in an area. The reason for increasing interest in species richness estimation in ecological studies is that it is almost impossible to detect all species and their relative abundances with a limited number of samples (Chao *et al.*, 2005). In other words, there are unencountered species in almost every taxonomic survey or species inventory (Chao, 2005; Mao *et al.* 2005). Colwell (2009a) stated that even for flowering plants not all species that are actually present are equally easy to detect. The species richness estimates acknowledge that some

species go unnoticed in species inventories (Schulz *et al.*, 2009). Hence, with the exception of very well-known groups in very well-known places, species richness must be estimated based on samples (Schulz *et al.*, 2009). These estimates of species richness are particularly essential in biotic inventories where it is impractical to completely sample species rich communities such as tropical plant communities (see Gotelli and Colwell, 2001). In vegetation studies, sample plots are investigated to make inference on the plant species richness of a given area. Nevertheless, some of the existing plant species in the area may not be encountered in those sample plots. The richness estimation methods are, therefore, of paramount importance to estimate the existing yet unencountered species.

Colwell (2009a) defined a richness estimator as a statistical estimate of the true species richness of a community or larger sampling universe, including unobserved species, based on sample data. Chao estimators, jackknife, abundance-based coverage estimator (ACE) and Bootstrap are the commonly used richness estimators (Gotelli and Colwell, 2001; Chao *et al.*, 2005; Colwell, 2009b). According to Gotelli and Colwell (2001), these estimators use information on the distribution of rare species in the assemblage: those represented by only one (singletons), two (doubletons) or a few individuals. The higher the number of rare species in a dataset, the more likely it is that other species are present that were not represented in the dataset (Gotelli and Colwell, 2001). Either abundance data or incidence samples are required for species richness estimation as estimates of unseen species are based on the number of rare species observed within samples (Chao *et al.*, 2005). These estimators help to predict relatively 'true' number of species in a given area based on sample data and hence help to minimize the risk of underestimation of the species richness of the area.

2.3 Perspectives on plant community organization

Ecological studies help to uncover which species associate with which other species and why (McCune and Grace, 2002) and to recognize and quantify environmental factors influencing the distribution and abundance of plant species within and among ecosystems (Palmer and Dixon, 1990; Grossman *et al.*, 1998; McCune and Grace, 2002; Pellerin *et al.*, 2009). The identification

of the factors that influence the distribution and abundance of plant species is an important input for conservation planning.

Attempts to understand the natural world have been aimed at different levels: genes, species, communities and ecosystems; and attempts to conserve biological diversity can be focused at each of these levels as well (Grossman *et al.*, 1998). Conservationists consider ecological communities as vital elements of conservation. This is because ecological communities are extremely important conservation targets in areas where species patterns and ecological processes are scantily understood. By describing, tracking and preserving these ecological communities, it is likely to protect a set of interactions not easily identified and protected through other means (Grossman *et al.*, 1998). However, the word community has been conceived in different ways by ecologists. Some consider community as an abstract group of organisms (implying a high level of integration among its parts that could be called organismal or quasi-organismal) while others use the concrete community concept (having an implication that community is just a collection of organisms found at a given place and time). Each of the perspectives on patterns of plant community organization is briefly described below.

Organismal unit perspective

The organismal view point of plant communities was proposed by Clements (1916). Clements envisaged community as a type of complex organism with its own life and structure as well as its own spatial and temporal limits. Supporting Clements's view, Daubenmire (1966) argued that communities are integrated wholes, such that repeatable combinations of species consistently occur together, and all communities are successional destined to stable endpoints (i.e. climax communities).

The implication of this concept of a complex organism is considerable interrelationship between the species of a community which, in growing together, sufficiently change an environment to form intuitively recognizable and recurring vegetation grouping (Anderson, 1965). The proponents of this perspective consider plant communities as a synchronized group of species

which usually occur together forming aggregations that can be subjectively recognized in the field i.e. the proponents contend that they can recognize homogeneous vegetation types intuitively (e.g. McIntosh, 1966; Richard *et al.*, 1966). They consider community as a distinct whole having constant composition and ecological relationships, and visibly separate in space and time from other such communities (Scott, 1995; Grossman *et al.*, 1998). It assumes that species belonging to a community are closely associated with one another and form a discrete community.

Brown and Lomolino (1998) noted that the proponents of this perspective compare individual organisms and species in a community to the cells and tissues of an organism, and the process of secondary succession is equated to the growth and development of an organism. All communities, according to this perspective, are successional directed to stable endpoints (Grossman *et al.*, 1998). They also assume that the community-unit comprises dominant species, e.g. trees, and other species (shrubs, herbs) that have adapted to live in association with the dominants and with each other. Competition between dominants leads to sharp boundaries between the communities (Austin, 1985). In other words, the existence of such communities is attributed to the competition and exclusion of less competitive ones by the dominant species.

According to the organismal view point of communities, when species' distributions are plotted along some gradient whose rate of change is constant, there exist groups of species which replace themselves along the chosen gradient (Shiple & Keddy, 1987). Within each grouping most species have similar distributions and the end of one group coincides with the beginning of another. Similarly, Collins *et al.* (1993) maintained that Clement's model of vegetation can be depicted graphically as a series of non-overlapping groups of species response curves along an environmental gradient. This implies that the ecological limits of distribution of each species are assumed to coincide with the distribution of the community as a whole. It assumes that each community is separated from the other by sharp vegetational transition.

Callaway (1997) pointed out various evidences of the organismal view point of communities. He argued that the abundance, fitness and local survival of species are not merely due to abiotic

conditions and competition, but are also affected by positive interactions within the plant community and indirect positive interactions with consumers and mutualists. Plants have many kinds of positive effects on other plants including favorable alteration of light, temperature, soil moisture, soil nutrients, soil oxygenation and indirect mechanisms such as protection from herbivores, attraction of shared pollinators and beneficial changes in soil mycorrhizal or microbial communities. If the distributions and abundances of species are enhanced by the presence of others their organization is not simply a "coincidence" of similar adaptation to the abiotic environment. Hence, the common occurrence of positive interactions suggests that plant species may not always be distributed independently of each other (Callaway, 1997). Thus, the occurrence of a wide range of interactions among species suggests that the survival of a species depends not only on adaptation to abiotic environment but also biotic interactions which in turn can have a strong influence on plant community organization.

The organismal perspective of plant community organization can help to address questions like: "Does the species play an important role in the ecosystem in which it lives? Do other species depend on it for their survival? Will its loss substantially alter the functioning of the ecosystem?" (Callaway, 1997). The implication is that some interdependence may be expected in natural systems. Thus, the significance of independence-interdependence issue is not simply academic: it can have far-reaching implications on how we conserve and utilize resources. For example, conservationists claim that organisms in natural communities are interdependent and the loss of seemingly insignificant species may have important effects on other species. Failure to appreciate such interdependencies among members of a community can have an enormous consequence on conservation of biodiversity (Callaway, 1997). However, the organismal concept of the community can be accepted only with many limitations, because the relationships in the community are much weaker than in living individuals (Pignatti, 1996). Though organisms in natural communities are interdependent, their relationships may not be as strong as portrayed by the organismal community organization perspective.

Shipley & Keddy (1987) noted that the Clementsian perspective was accepted by the majority of ecologists during the first part of twenty century. However, the works of various ecologists (e.g.

Curtis and McIntosh, 1951; Whittaker, 1951, 1956; Curtis, 1959) brought the attention of the majority community ecologists to the individualistic-continuum perspective of community organization. This transition to an individualistic viewpoint of communities was because of the fact that the observed patterns of species replacements along a gradient in gradient analysis studies were not compatible with the patterns predicted by Clements (Shipley & Keddy 1987; Callaway, 1997). In gradient analysis studies, plant species are arranged independently of one another along environmental gradients. Thus, with the advent of gradient analysis techniques a second perspective on plant community organization, individualistic-continuum perspective, was proposed.

The 'individualistic-continuum' perspective

In contrast to Clement's concept of the community as a discrete and highly integrated unit, Gleason (1939) envisaged a community as the coexistence of independent individuals and species in the same place at the same time. In other words, communities were considered just as a collection of species with similar adaptations to the abiotic environment. The guiding principle for this perspective, thus, was Gleason's individualistic hypothesis i.e. "Each species is distributed in its own way, according to its own genetic, physiological and life-cycle characteristics and its way of relating to both physical environment and interactions with other species; hence no two species are alike in distribution". This perspective is built on the basis of the principal significance of the abiotic environment in community organization (Callaway, 1997). For proponents of this perspective, species combinations were created by the individual responses of species to the environment and by chance events of dispersal following environmental variation and disturbance (Noy-Meir and van der Maarel, 1987). Hence, it undermines the possible impacts of biotic interactions in plant community formations.

According to this perspective, plant species could not form integrated communities because of their individualistic behavior (van der Maarel, 2005). It maintains that species change along environmental gradients with no distinct separation lines or with no visibly separated zones (Austin, 1985; Grossman *et al.*, 1998). This viewpoint, therefore, does not accept the notion that

the vegetation of each community in a given area is separated by sharp vegetational transition from other communities.

Proponents of this perspective (e.g. Curtis and McIntosh, 1951; Whittaker 1951, 1956; Curtis, 1959) envisaged a vegetation continuum as a continuously changing series of communities. The term continuum has been used in vegetation studies as an uninterrupted series of communities, with no sharp transitions apparent between communities (Austin, 1985). For proponents of this perspective any similarity in composition of communities is conceived to relate to either coincidence of response to environmental factors, or one or more of the species being the major determinant of environment for other species (Scott, 1995). Thus, similarity in capability to adapt to environmental factors, rather than strong interdependency among plant species, is considered as main factor for similarity in plant community composition in the individualistic perspective.

The empirical justifications for Gleason's individualistic perspective developed when plant ecologists (e.g. Whittaker, 1951, 1956; Curtis, 1959) conducted gradient analyses studies. In gradient analysis studies, plant species were found to be arranged independently of one another along environmental gradients (Callaway, 1997). There is now some consensus (Grossman *et al.*, 1998) that the continuum concept offers a more realistic view of vegetation pattern. However, species' distributions can be affected by a variety of factors in addition to responses to environmental gradients such as species interactions, disturbances, and past history. Hence, there is also consensus that species distributions are structured to some extent by interactions with each other and their environment such that certain combinations of species do recur (Grossman *et al.*, 1998) leading to a third (synthesis) perspective on pattern of community organization, which is intermediate view between the organismal and the continuum perspectives.

The synthesis perspective: A synthesis of the individualistic and organismal perspectives

The concept of plant community has been a debatable topic and the debate suggests that field data on vegetation composition along environmental gradients have more clumping or grouping than would be in agreement with the continuum concept, and more variation than would be consistent with the organismal concept (Scott, 1995). Similarly, Grossman *et al.* (1998) reported

that species do not have distributions that are just individualistic; nor are there organismal assemblages of species. Although there is continuous variation in species composition along an environmental gradient in some places the level of compositional change is low (within a vegetation type) whereas in other places the level of compositional change is high (transitional areas between vegetation types) (Grossman *et al.*, 1998). Kimmins (1997) proclaimed that this synthesis perspective “recognizes the reality of continuous species distributions, but emphasizes interactions between species that lead to relative discontinuities between assemblages of species”.

In sum, the organismal perspective envisions rapid replacement of species along environmental gradients and considers communities as having a high degree of internal organizations, which jointly modify the environment with sharp delimitation from other communities. On the other hand, the individualistic-continuum perspective underscores the prime importance of environmental factors in plant community formation. The synthesis perspective recognizes the importance of both biotic interactions and environmental factors on plant communities. These perspectives have had implications on choice of quantitative methods in plant ecology.

Implications of the perspectives on quantitative plant ecology

Ecologists such as ter Braak (1986); Noy-Meir and van der Maarel (1987); Kent and Ballard (1988); van der Maarel (2005) indicated that multivariate data analysis is used to examine associations among species and to elucidate species responses to environmental factors. Community ecology inquiries, therefore, require inferring species-environment relationships from community composition and environmental data (Kenkel, 2006; Kamrani *et al.*, 2010). Many techniques for data reduction have been developed in vegetation ecology, which can be grouped into two: classification and ordination.

Vegetation classification involves an arrangement of communities into classes. Implied in this approach is the assumption that there is some discontinuity in species composition between samples of vegetation in the field. Conversely, ordination is based on the assertion that there are

no such discontinuities in natural vegetation, except where there may be discontinuities in the physical environment (Anderson, 1965). Thus, classification an important tool in searching for patterns when data show major discontinuities while ordination is more efficient when the continuous character is strongly developed (Mucina, 1997). Thus, classification assumes that communities consist of discrete entities whereas ordination does not produce distinct groups, which can be classified.

Ecologists favoring the organismal viewpoint proposed classifications while those favoring the continuum concept approved ordination methods. There were also other ecologists who argued that the choice of methods may depend upon the convenience of the user than on preconceptions as to continuity or discontinuity: "If the prime requirement is to produce vegetation units, then classificatory methods are more applicable. Classification techniques may not work well on more continuous vegetation data". Therefore, a method of vegetation analysis should be judged by how well it achieves its end (McIntosh, 1966). Stated differently, the choice of vegetation data analysis method should be based on the objectives of the user rather than on preconceptions as to continuity or discontinuity of plant communities.

However, it should be noted that there is no tension between the individualistic-continuum perspective and classification and hence classification can be done with no assumption that natural plant communities are distinct groupings of plant species (Grossman *et al.*, 1998). Legendre and Legendre (1998) suggested that ordinations may always be used as complement to cluster analysis. Hence, the current trend is 'complementary analysis': the application of both classification and ordination methods to get a significant interpretation of ecological data. This involves a joint application of classification and ordination techniques in analysis of the same data set. This strategy is used when the objectives are both the identification of vegetation types and appreciation of the causal environmental gradients. Though there are situations when either classification or ordination should be used on its own, substantial benefit can be gained from a 'complementary analysis' using both techniques (Kent and Ballard, 1988).

Classification and ordination

Classification is based on the premise that objects are adequately similar to be put in the same group and to recognize distinctions between groups. In other words, given a large group of objects, ecological clustering methods are used to identify clusters of related objects (Legendre and Legendre, 1998). Classification, therefore, involves partitioning the collection of objects in the study. It imposes a discontinuous structure onto the data set, though the objects have originally been sampled from a continuum (Legendre and Legendre, 1998). Similarly, Grossman *et al.* (1998) affirmed that classification requires the supposition that it is sensible to separate a continuum of variation in vegetation composition and structure into a series of classes. Thus, species belonging to the same class have higher similarity than species belonging to other classes.

To identify the characteristic species of the classes, Dufrêne and Legendre (1997) presented a method (an indicator index) which helps to find indicator species and species assemblages characterizing groups of sites which combines the relative abundance and relative frequency of a species in the various groups of sites. Dufrêne and Legendre (1997) defined indicator species as the characteristic species of each group, found mostly in a single group of the typology and occur in the majority of the sites belonging to that group. If all individuals of a species are found in a single group of sites and if the species occurs in all sites of that group then its indicator value is maximum. Randomization procedure is used to evaluate the statistical significance of the species indicator values (Dufrêne and Legendre, 1997). Indicator species are, therefore, faithful to a particular class of sites. However, it does not necessarily mean that an indicator species exclusively occurs in a particular class only.

Ordination involves arranging vegetation samples or species along one or more ecological gradients (abstract axes) which represent a large portion of the variability of the multidimensional data in a space with lower dimensionality relative to the original data set (Austin, 1985; Legendre and Legendre, 1998; ter Braak and Prentice, 2004; Kenkel, 2006). These ordination methods are used in exploratory data analysis, both to search for and summarize

underlying trends, and to examine interrelationships amongst variables. In other words, interpretation of ordination axes leads to the generation of hypotheses regarding possible causal factors determining the underlying data structure (Kenkel, 2006). Ordination does not produce distinct groups, which can be classified; it rather shows the interrelationship amongst species that are controlled by environmental gradients. Species with similar environmental adaptations/site conditions appear close together in ordination diagram. Whereas species that differ greatly in the environmental adaptations appear far apart in the ordination diagrams. Ordinations can be of two types: unconstrained and constrained ordinations.

Unconstrained ordination is used to examine environmental causes of vegetation patterns by arranging plots based on their floristic similarity along axes of variation in composition. Species data are used to construct the axes of the ordination diagrams. The relationship between the plots and environmental gradients is assessed by either correlating the axes with environmental variables or by determining the relationship of all the measured environmental variables with the ordination space. Unconstrained ordination leads to a multidimensional picture of the relationships between stands of vegetation based on their floristic similarity to each other (in the case of a plot ordination), or between species based on their concurrence in vegetation plots (in the case of a species ordination). Ordination axes can be considered as latent / hypothetical environmental variables, constructed in such a way as to optimize the fit of the species data to a particular (linear or unimodal) statistical model of how species abundance varies along gradients. These latent variables are constructed without reference to environmental measurements, but they can subsequently be compared with real environmental data (Legendre and Legendre, 1998). Unconstrained ordination can help us to address several questions in community ecology: e.g. to find the configuration of samples in the ordination space so that the distances of samples in this space correspond best to the dissimilarities of their species composition (Lepš & Šmilauer, 1999). Non-metric Multidimensional Scaling (NMDS) is one of unconstrained (indirect) ordination methods. NMDS is able to deal with any kind of species response model. NMDS maps observed community dissimilarities nonlinearly onto ordination space and it can handle nonlinear species responses of any shape (Oksanen, 2007).

Constrained ordination is used to examine the relationship between two sets of variables measured on the same sampling units: species composition-abundance data set and environmental factors data set. In these approaches, environmental variables are used in the construction of the ordination and hence are called constrained ordination because the positions of the samples in the ordination are constrained by the environmental variables. The objective of the constrained ordination is to verify the extent to which the environmental data determines biotic composition and to get information as to which variables contribute most strongly to the relationship (Kenkel, 2006). Thus, in constrained ordination, patterns of species distribution are described as a function of measured environmental variables (Austin, 1985; ter Braak and Prentice, 2004). Lepš and Šmilauer (1999) stated that the gradients constrained ordination methods tend to find are restricted and these gradients are linear combinations of the submitted explanatory (environmental) variables.

Canonical correspondence analysis (CCA) (ter Braak, 1986) is one of the most commonly used constrained ordination techniques (Quinn and Keough, 2002). It is powerful tool in detecting relationships between species composition and environmental variables (ter Braak, 1986; ter Braak and Prentice, 2004). CCA helps to detect the patterns of variation in community composition that can be explained best by the measured environmental variables. CCA ordination axes are chosen in the light of measured environmental variables by imposing the extra restriction that the axes be linear combinations of environmental variables. In this way community variation can be directly related to environmental variation (ter Braak, 1986).

Given a response matrix Y and an explanatory matrix X , one is constrained by the other and both are examined simultaneously in CCA. This allows testing a priori hypotheses by bringing all of the variance of Y that is directly related to X and allowing formal tests of the hypotheses. CCA, thus, combines the concepts of ordination and regression (White and Hood, 2004). CCA leads to an ordination diagram in which points represent species and sites, and vectors represent environmental variables (ter Braak, 1986). According to ter Braak (1986), such a diagram shows the patterns of variation in community composition that can be explained by the environmental variables and also visualizes the "centers" of the species distributions along each of the

environmental variables. Small angles between vectors and pointing the same direction imply positive correlations between variables, and arrows pointing in opposite directions are negatively correlated.

Sites close to each other in ordination diagram have similar vegetation whereas sites distant from each other in ordination diagram have dissimilar vegetation (Quinn and Keough, 2002; Zuur *et al.*, 2007). In other words, distances between species in ordination diagrams are estimates of their degree of resemblance in terms of their distribution. Ordination diagram can be explained using ecological knowledge on studied sites, or knowledge on the ecological characteristics of species. There are various ways of overlaying environmental information onto ordination diagrams. The most popular method of interpretation is to fit environmental vectors onto ordination (Oksanen, 2004; 2007). Vegan package (Oksanen *et al.*, 2007) in R has functions such as `envfit` for fitting environmental variables. It can add vectors into an ordination plot, and it tests the significance of fitted factors with permutation tests. The fitted vectors are arrows. The arrows point to the direction of most rapid change in the environmental variable and the length of the arrow is proportional to the correlation between ordination axes and environmental variable (Oksanen, 2004; 2007). The longer the arrow representing a particular environmental variable in an ordination diagram, the higher the influence of the environmental variable on the plant distribution.

Canonical coefficients and intraset correlations can be used for interpreting the ordination axes; both of which relate to the rate of change in community composition per unit change in the corresponding environmental variable. The canonical coefficients define the ordination axes as linear combinations of the environmental variables and the intraset correlations are the correlation coefficients between the environmental variables and these ordination axes. By looking at the signs and magnitudes of the intraset correlations and of the canonical coefficients, it is possible to deduce the relative importance of each environmental variable for predicting the community composition. If the environmental variables relate strongly to the first few ordination axes, they can explain most of the variation in the species composition. However, if the environmental variables do not relate strongly to the first few axes, they cannot account for the

most of the variation, but they may still explain some of the remaining variation which can be considerable (ter Braak, 1986). In sum, ordination helps to test hypothesis about the relationships between community composition and environmental factors. It also helps to identify the direction of influence of environmental variables as well as the proportion variability in community composition which can be explained by the measured environmental variables.

2.4 The ecological application of generalized linear modeling

One of the crucial questions in community ecology is "what controls species diversity?" (McCune and Grace, 2002) and investigations on patterns of species richness is of great help in addressing the conservation of biological diversity. Such studies are required to ensure appropriate land use and biological conservation (Pausas and Carreras, 1995). Species richness varies in space and time as well as on different scales. New insights into richness controlling factors can be obtained by studying ecosystems in which the variation along ecological gradients is well known (Økland *et al.*, 2008). To this end, the modeling of species richness over environmental gradients has become an important part of biodiversity research (Brocque and Rodney, 2003). Species richness can be modeled at the community level or at the individual level. In the first case, species richness is predicted by a set of environmental parameters calibrated by one single model (direct approach) whereas in the second case, individual species are modeled separately as a function of environmental variables (Steinmann *et al.*, 2009).

The intention of the statistical modeling in ecology is to provide a mathematical basis for interpretation, examining such parameters as "fit" (do the measured predictors sufficiently explain the response?), "strength" of association (is the relationship between the response and the predictors significant?), and to determine the contributions of the different variables. Statistical models in ecology may be explanatory or predictive models. Explanatory models help to verify the strength of the statistical relationship between a response (e.g. presence of plant species) and one or more explanatory variables (e.g. precipitation, soil type). On the contrary, predictive models give statistical relationship between the response and predictor variables for use in predicting the probability of species occurrence or estimating numbers of an organism at new, previously unsampled locations (Guisan *et al.*, 2002). Statistical models could, therefore, be

used in ecology to get insight into the relation between response and predictor variables as well as to make inference on the strength of the relationships.

Given a large number of potential explanatory variables (e.g. topographic and edaphic variables), according to van Belle *et al.* (2004), it is possible to select a smaller subset that explains the variability in the dependent variable (e.g. species richness). One or more of 'predictor' variables in a multiple regression do not account for, beyond an amount consistent with chance, the explanation of the variability in the dependent variable. Hence, a much smaller subset of the predictor variables that explains much of the variability and gives a much simpler model are preferred. Simple models are preferred because they may be used more readily, and when applied in a different setting, become more accurate than a model with a large number of variables (van Belle *et al.*, 2004). Given a response variable Y with a large number of potential predictor variables X , how should we choose a "best" subset of variables to explain the Y variability? Generalized linear models (GLM) (Nelder and Wedderburn, 1972) can be used to address such a question. It is an approach for selection or identification of few predictor variables with strongest influence on response variable from a range of predictor variables.

The relationships between species richness and environmental variables can, thus, be investigated through generalized linear models; whereby species richness is considered as a dependent variable (Brocque and Buckney, 2003; Zuur *et al.*, 2007). GLM can help to determine the amount of variation in species richness that could be significantly explained by the measured environmental variables. The explanatory variables with the strongest contributions can be chosen by backward elimination, forward selection or stepwise procedure (Legendre and Legendre, 1998; Brocque and Buckney, 2003; Zuur *et al.*, 2007). However, the three strategies do not necessarily lead to the same selection of explanatory variables. When explanatory variables are highly correlated with each other a forward selection and a backward selection might give different results due to covariability (Zuur *et al.*, 2007).

In the backward selection procedure, all variables are initially included and, at each step, the variable that contributes the least to explaining the response variable is removed, until all

explanatory variables remaining in the model have a significant partial regression coefficient. The forward selection method, first applies bivariate linear regression using each explanatory variable in turn. The variable with the lowest AIC (Akaike Information Criteria) (if AIC is used as criterion for evaluating the goodness-of-fit) is selected, and a multiple linear regression model is applied using the selected variable and each of the remaining variables in turn. The variable that gives the lowest AIC in combination with the first selected variable is then selected, and the process is repeated until the AIC starts to increase (Legendre and Legendre, 1998; Brocque and Buckney, 2003; Zuur *et al.*, 2007). An increase in AIC implies a predictor variable (s) with no significant influence on the response variable is (are) added to the explanatory model.

There are various approaches for selecting the best subset of explanatory variables according to some criteria. The methods that can be used to validate GLM models i.e. to evaluate their goodness-of-fit include statistical criteria such as AIC, adjusted R^2 value, deviance test and F-test. AIC measures the fitness of a model (Brocque and Buckney, 2003; Edvardsen and Økland, 2007; Zuur *et al.*, 2007) and it combines variation explained and number of parameters into one index value (Edvardsen and Økland, 2007). When two models are compared the smaller the AIC, the better is the fit (Bhattarai and Vetaas, 2006; Edvardsen and Økland, 2007; Zuur *et al.*, 2007).

In sum, given a range of predictor variables which can possibly affect species richness, few predictor variables with strongest influence can be selected using GLM. It can also help to make inference on the amount of variation in species richness that is significantly explained by the measured environmental variables. Parameters such as AIC, adjusted R^2 value, deviance test and F-test can be used to make inference on the amount and significance of variation explained by the predictor variables.

2.5 The Vegetations of Ethiopia

Owing to its wide climatic and edaphic variability, Ethiopia has diverse and unique flowering plants. The vegetation of Ethiopia has been described and classified by different authors in different ways. Previous attempts to describe and classify the vegetations of Ethiopia include

those by Logan (1946), Pichi-Sermolli (1957), Friis (1986a), Friis (1992), Sebsebe Demissew et al. (1996), and Friis and Sebsebe Demissew (2001).

The most recent classification of Ethiopian vegetation was proposed by Friis *et al.* (2011) which categorizes the Ethiopian vegetation into the following typologies: Desert and semi-desert scrubland, *Acacia-Commiphora* woodland and bushland, Wooded grassland of Western Gambela Region, *Combretum-Terminalia* woodland and wooded grassland, Dry evergreen Afromontane forest and grassland, Moist evergreen Afromontane forest, Transitional rain forest, Ericaceous belt, Afroalpine belt, Riverine Vegetation; Freshwater lakes, lakeshores, marshes and floodplain vegetation and Salt lakes, salt-lake shores and marsh vegetation. The vegetation of the Gurage Mountains can be categorized into three of these typologies namely dry evergreen afromontane forest (especially the undifferentiated afromontane forest subtype), ericaceous and afroalpine belts of vegetation.

Friis *et al.* (2011) reported that dry evergreen afromontane forests have canopies dominated by *Juniperus procera*, followed by *Olea europaea* subsp.*cuspidata*, etc. In dry evergreen afromontane forests, *Podocarpus falcatus* is found sheltered in valleys. The undifferentiated afromontane forests are either *Juniperus-Podocarpus* forests, or tend towards single dominant *Podocarpus* or *Juniperus* forests. The canopy layer of the undifferentiated afromontane forests is dominated by *Juniperus procera*, *Podocarpus falcatus*, *Olea europaea* subsp.*cuspidata*, and *Croton macrostachyus*. A layer of small to medium trees such as *Allophylus abyssinicus*, *Apodytes dimidiata*, *Bersama abyssinica*, *Celtis africana*, *Dovyalis abyssinica*, *Ekebergia capensis*, *Erythrina brucei*, *Maytenus undata*, *Olinia rochetiana*, *Prunus africana*, etc are common in the undifferentiated afromontane forests. Besides, small trees and shrubs such as *Carissa spinarum*, *Discopodium penninervium*, *Dombeya torrida*, *Halleria lucida*, *Lobelia giberroa*, *Myrsine africana*, *Pittosporum viridiflorum*, *Solanecio gigas* and *Sideroxylon oxyacanthum* are common in undifferentiated afromontane forests. The upper limit of this type of forest, according to, to some extent overlaps with ericaceous belt and hence species such as *Erica arborea*, *Gnidia glauca*, *Hagenia abyssinica*, *Hypericum revolutum*, *Jasminum stans*, *Nuxia congesta*, *Myrsine melanophloeos*, *Rosa abyssinica*, etc are common (Friis *et al.*, 2011).

CHAPTER THREE

The ericaceous belt is characterized by the dominance of shrubby trees such as *Erica arborea*, *Erica trimera*, *Hypericum revolutum*, *Myrsine melanophloeos* and herbs such as *Anthemis tigreensis*, *Haplocarpha rueppellii*, *Helichrysum splendidum*, *H. gofense*, *H. formosissimum*, *Satureja biflora*, *Thymus schimperi*, *Kniphofia foliosa*, etc. The afroalpine belt is characterized by giant Lobelias, cushion-forming species of *Helichrysum*, shrubby species of *Alchemilla*, etc. The presence *Lobelia rhynchopetalum* can be taken as an indicator of the Afroalpine belt (Friis *et al.*, 2011).

CHAPTER THREE

3. Materials and methods

In this chapter, the materials and methods used in the course of the present study are outlined.

3.1 Materials

Garmin GPS, plant presses, meter tape, plastic bags and clinometer were used while collecting floristic and environmental variables data.

3.2 Methods

3.2.1 Location and description of the study area

The study area, the Gurage Mountains, is located in Gurage Zone, Southern Nations, Nationalities and Peoples' Regional State of Ethiopia. The location of the study area is shown in Figure 1.

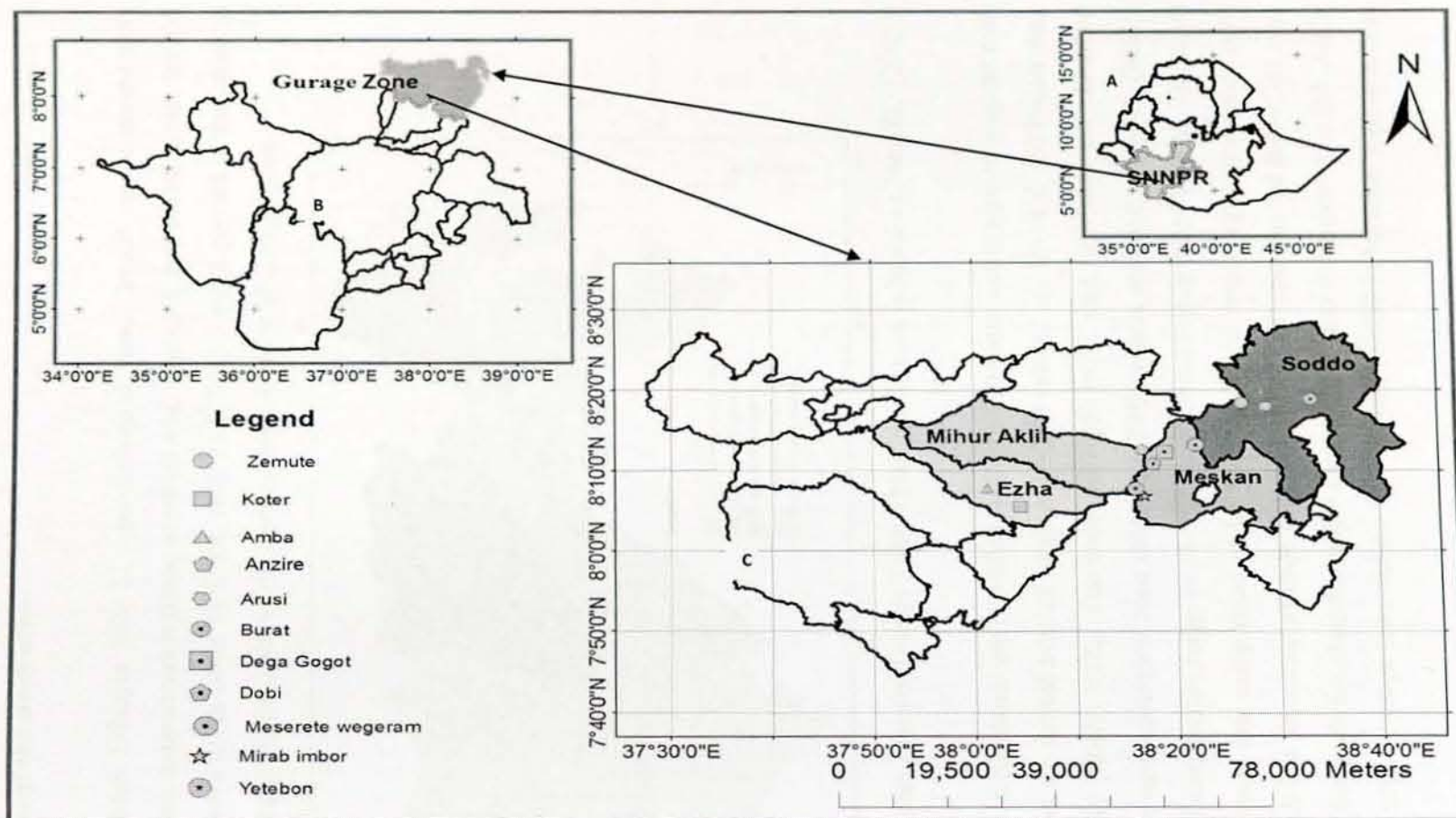


Figure 1: Location map of the study area. A) Regional map of Ethiopia in which Southern Nations, Nationalities and Peoples' Regional State (SNNPRS) is highlighted; B) Zonal map of SNNPRS (Gurage zone highlighted) and C) Wereda map of Gurage zone with the Weredas considered in this study highlighted. Plots 1-8 and 9-16 were sampled from Amba and Koter, respectively (Ezha Wereda). Plots 17-34, 35-44 and 45-52 were sampled from Zemute, Arusi and Burat, respectively (Sodo Wereda). Plots 53- 64, 65-71, 72-76, 77-80 and 81-84 were sampled from Meserete Wegeram, Dega Gogot, Dobi, Mirab Imbor and Yetebon, respectively (Mesqan Wereda). Plots 85-100 were sampled from Anzire (Mohir Wereda).

Agro-ecological zones of the study area

MoARD (2005) divided Ethiopia into 32 agro-ecological zones based on seven-moisture regimes, altitude and six temperature regimes; in which arid, semi-arid, sub-moist, moist, humid, sub-humid and per-humid zones cover 31.5, 3.4, 16.6, 25.6, 6, 16.2 and 1 percent of the country, respectively. Accordingly, Figure 2 shows the agro-ecological zones of Gurage Zone.

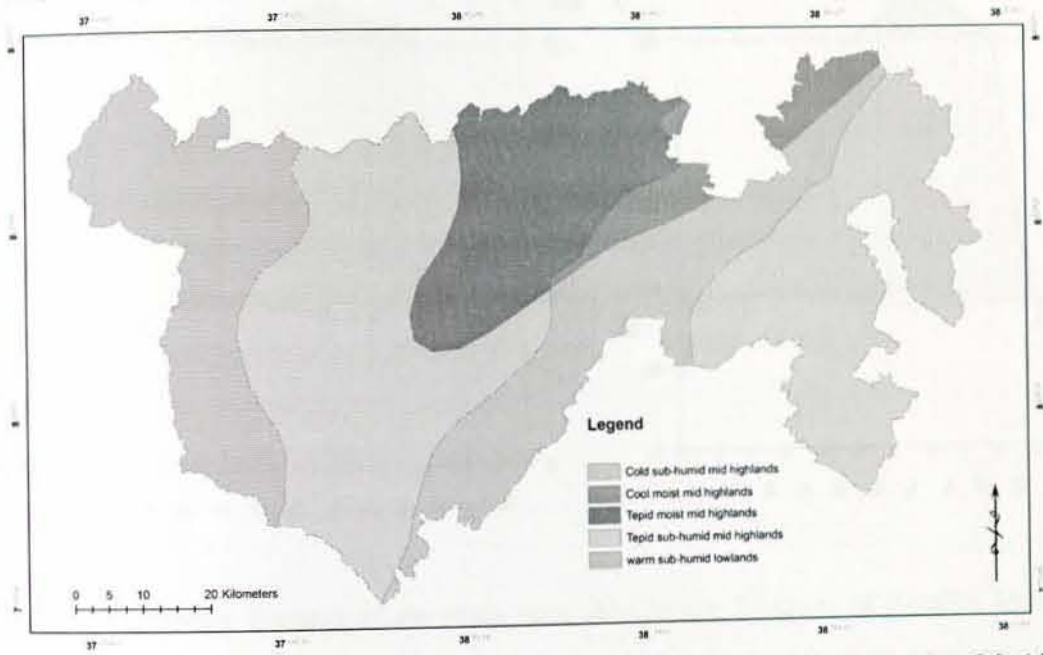


Figure 2: Agro-ecological zones of Gurage Zone. This classification is based on MoARD (2005).

The cold sub-humid mid highlands are classified under the sub-moist major agro-ecological zone (MoARD, 2005) where the annual average temperature and rainfall are 10-14°C and higher than 1000 mm, respectively (MoA, 2000). The cool and tepid moist mid highlands are classified under the moist major agro-ecological zone (MoARD, 2005) which, according to MoA (2000), has an annual average temperature range of 14-18°C and rainfall higher than 900 mm. The tepid sub-humid mid highlands are categorized under the sub-humid major agro-ecological zone (MoARD, 2005) which has an annual average temperature 18-20°C and rainfall 800-1200 mm. The warm sub-humid lowlands are classified under humid major agro-ecological zone (MoARD, 2005) which has an annual average temperature 18-24°C and rainfall is between 900-1000 mm (MoA, 2000).

Figure 3 shows the climate diagrams of two representative sites: Butajira and Imdibir representing the eastern and western parts of the Gurage Mountains, respectively.

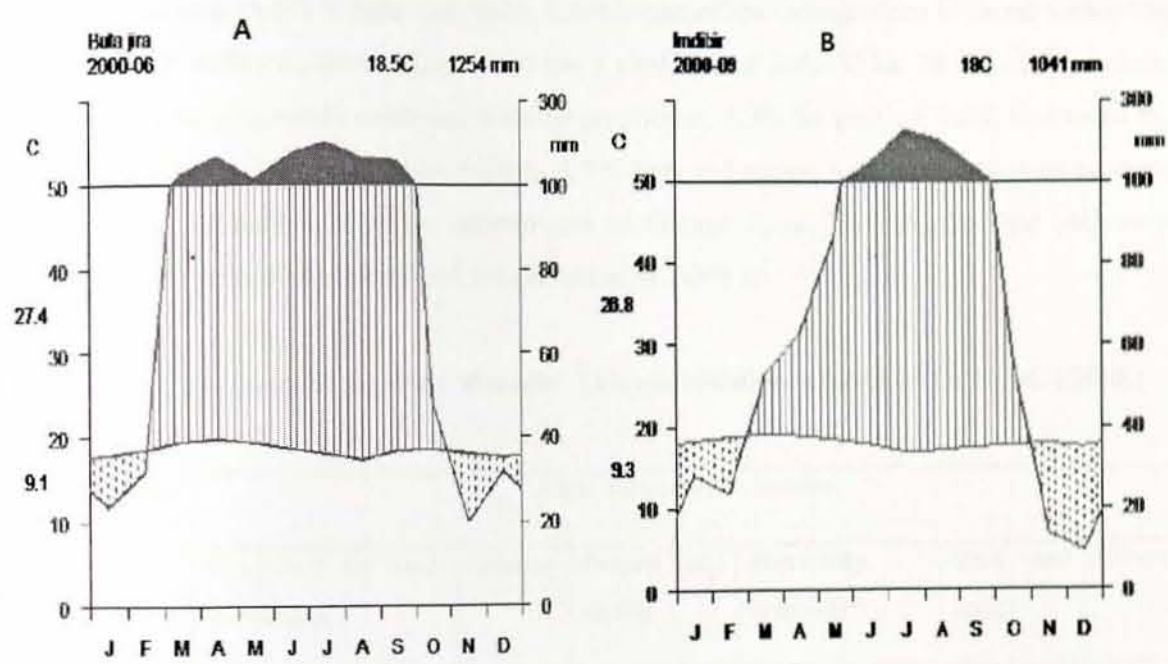


Figure 3: Climate diagram of the study area. A) Climate Diagram of Butajira Meteorological Station (using 2000-2006 Meteorological data), which is located in close proximity to Meserete Wegeram, Dobi, Yetebon, Degagogot and Mirab Imbor study sites (Mesqan Wereda). B) Climate Diagram of Imdibir Meteorological Station (using 2000-2009 Meteorological data), which is located in close proximity to Debane and Koter Gedra (Ezha Wereda) and Mohir Wereda study sites (Data source: National Meteorological Agency of Ethiopia).

Land use/cover of the study area

The land use/cover in the study area includes cropland, grazing land, shrubs, forests and grasses. There is a gradual decrease in forest, shrub and grass covers while there is a gradual increase in cropland. Most of the natural forests in the study area are confined to areas that are relatively inaccessible to human encroachment. There are also some patches of remnant natural vegetation in gorges of Wabe, Kerebe and Megecha Rivers. *Eucalyptus* plantations are common in privately

owned land (GZFEDC, 2008). GZFEDC (2008) also reported that the western part of Gurage Zone is found within Omo-Gibe River Catchment and has an area of 417,272 ha, of which 49.3% is used for agriculture (cultivated), 17.2 % for grazing and 9.8% is covered by forests and shrubs, and the remaining 11.6% is bare and rocky. Eastern part of the Gurage Zone is found within the Ethiopian Rift Valley Lakes catchment and has a total area of 166,050 ha. 74.4% of the eastern part of the Zone is currently cultivated for crop production, 6.3% for grazing, 7.6% is covered by forests and shrubs, 3.3% potentially tillable, 2.5% bare and rocky, and other land uses account for 5.8 % of the total area of the eastern part of Gurage Zone. The specific land use/cover classifications of the Weredas studied are presented in Table 1.

Table 1: Land use/cover of the study Weredas. This clalsification is based on GZFEDC (2008)

No	Wereda	Land use/cover (in hectare)					
		Cultivated for crop production	Grazing	Forests and shrubs	Potentially cultivable	Bare and rocky	Others
1	Sodo	62258	4829	5218	1903	2292	5630
2	Mesqan	36741	3301	6022	2550	1994	4592
3	Ezha	20314	6642	7285	3619	3187	2083
4	Mohir	21056	7148	3757	4604	3117	2438

Rivers originating from the Gurage Mountains

As indicated in the preceding section, the study area is found within the catchments of the Ethiopian Rift Valley Lakes and Omo-Gibe River. Subcatchments within the catchments of the Ethiopian Rift Valley Lakes and Omo-Gibe River as well as the rivers originating from Gurage Mountains are presented in Table 2.

Table 2: The subcatchments in the Weredas included in the present study. The Kebeles considered in this study are bolded.

No	Wereda(s) cover	Sub-catchment	Kebele cover (some)	Tributaries originating from Gurage Moutains
1	Mesqan, Sodo	Meki	Meseret Wegeram, Dega Nurena, Endebuyu, Aymelel, Bono aygede, Amawute lalige, Amawute giftige, etc.	Akamuja, Derek, Lebu, Weldiya
2	Mesqan	Dobena	Mirab Mesqan, Misraq Mesqan, Mirab Imbor, Yetebon, Dobi, Dega Gogot, etc.	Eresha, Erenzaf
3	Mesqan	Asas angerager		Mikaelo, Wurib, Gide, Aborat
4	Ezha, Mohir	Wabe	Ambelta, Mamede, Fenta, Wesherbe, Anzire, Chimbe, etc	Gogina, Omamo, Kereb
5	Ezha	Wunqiye	Koter Gedra, Amba Genet, Bozhebar, etc.	Gotam, Gogob, Qechir, Megecha, Tiliku Haram, Tinishu Haram

Source: GZFEDC (2008)

3.2.2 Research approach and site selection

A reconnaissance survey was conducted in the study area to choose sampling sites, to gain a general understanding of the characteristics of the study area and to devise appropriate data collection methodology and tools. During the reconnaissance survey, information pertaining to location of remnant forest patches was gathered from zonal agriculture and rural development coordination office and field visits. Sites which were chosen for thorough investigation are listed in Table 3. Detailed data on floristic composition, environmental variables as well as on causal factors for vegetation loss and degradation were collected following the reconnaissance survey. Data were collected between September to November 2011 and in September 2013.

Table 3: Sites selected for the study. The location of each site is shown in Figure 1.

No	Place/Forest patch	Wereda	Coordinates		Altitude ranges (in m)	Plot numbers
			Latitude	Longitude		
1	Amba/Debane	Ezha	08°07.514'- 08°07.838'	038°01.825'- 038°01.481'	2291-2410	1-8
2	Koter Gedra	Ezha	08°05.230'- 08°05.610'	038°04.763'- 038°04.698'	2681-2813	9-16
3	Arusi	Sodo	08°17.023'- 08°18.145'	038°29.026'- 038°28.721'	2363-2749	35-44
4	Zemute	Sodo	08°18.169'- 08°18.463'	038°26.606'- 038°26.599'	2382-2738	17-34
5	Burat	Sodo	08°18.360'-08°18. 930'	038°28.895'-038°29. 292'	2312-2704	45-52
6	Meserete- Wegeram	Mesqan	08°11.685'- 08°13.150'	038°22.380'- 038°22.055'	2320-2799	53-64
7	Dobi	Mesqan	08°10.770'- 08°10.888'	038°17.859'- 038°17.931'	2633-2940	72-76
8	Yetebon	Mesqan	08°07.588'- 08°07.746'	038°16.184'- 038°16.059'	2356-2759	81-84
9	Mirab-Imbor	Mesqan	08°06.608'- 08°06.878'	038°16.463'- 038°17.015'	2493-2710	77-80
10	Dega-Gogot	Mesqan	08°11.967'- 08°12.340'	038°19.029'- 038°18.983'	2650-2885	65-71
11	Anzire/Mohir	Mohir	08°12.04'	038°16.44'	2980-3588	85-100

These areas were chosen as they are known to harbor some remnant patches of natural vegetation (as reported by key informants) and which was also confirmed during field visits.

3.2.3 Vegetation sampling

Stratified preferential sampling was used for the purpose of the present study. Stratified sampling is becoming more pervasive in current vegetation ecology. It tries to satisfy both statistician's and ecologist's demands for the representative data set. It starts with a priori definition of strata, i.e., habitats/vegetation types that represent particular statistical sub-populations, within which

sampling sites are located. The advantage of this approach is that one can acquire variable data set with a reasonable representation of plots made in rare vegetation types (Roleèek *et al.*, 2007).

It is used to increase sampling efficiency where the strata are defined based on environmental variables that have been shown in previous studies to influence species composition (Michaelsen *et al.*, 1994). Accordingly, each forest patch in the study areas was stratified based on altitude. Besides, notably dominant plant species at different parts of the vegetation patches were taken into account for stratification. To get information for stratification (i.e. altitude ranges and the dominant species at different parts of the forest patches), each forest patch was thoroughly visited ahead of actual data collection. Besides, research assistants, who were selected from the study area and whose farm is located in the immediate vicinity to the forest patches, were consulted to get information for stratification such as 'vegetation types' in the forest patches. Plots were located in each stratum preferentially. Relatively higher number plots were investigated in forest patches characterized by higher floristic variation, larger area and wider altitude ranges.

A 40 x 40 m plot was used for vegetation sampling. Such a large plot is of course in a range suggested by Sutherland (1998) i.e. 400-2500 m². Large sized plots were used to capture as many species as possible in the same plot since it was assumed that human interference has thinned out the vegetation of the study area. Figure 4 shows the plot design used for data collection on floristic and environmental variables.

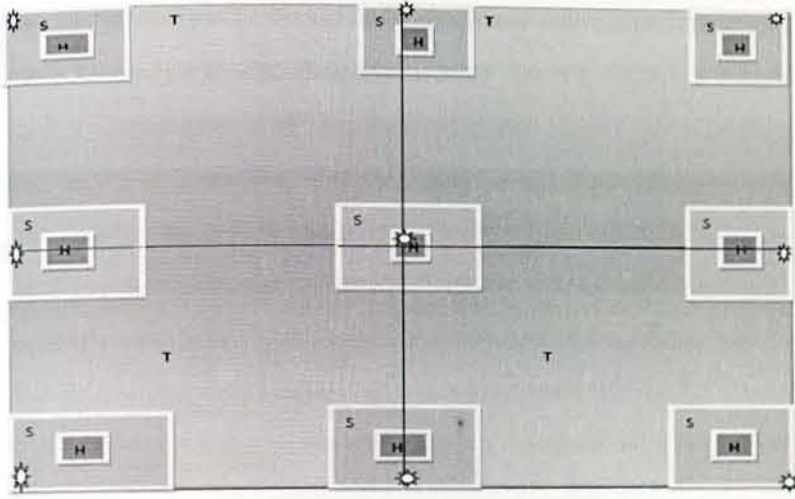


Figure 4: Plot design where T = 20 x 20 m subplots, S = 5 x 5 m subplots and H = 2 x 2 m subplots. ⚙ represents locations where soil samples were collected from each plot.

3.2.4 Vegetation and environmental variables data collection

Nested plot design (Figure 4) was used to survey the under-storey and canopy layer vegetation. As shown in Figure 4, the main (40 x 40 m) plot was divided into four 20 x 20 m subplots (labeled as T). From each 20 x 20 m plot, local name (or voucher specimen code if the local name was not known), diameter at breast height (at 1.30 m above ground), height, number of individuals and cover abundance of all trees having DBH > 5 cm were recorded (based on Tadesse Woldemariam, 2003). The height, number of individuals and cover abundance of shrubs, younger trees and woody climbers with DBH 1.5-5 cm were collected from subplots of size 5 x 5 m (labeled as S) which were laid at nine different locations of the main plot (Figure 5). Within 5 x 5 m subplots, 2 x 2 m plots (labeled as H) were laid to collect cover-abundance data of herbaceous plants. Abundance and frequency trees, shrubs and lianas were summarized on a plot basis. Subplot abundance data were pooled /extrapolated to the main plot by multiplying mean subplot abundance by the ratio of the area of the main and subplot. Cover-abundance values were estimated using the modified Braun Blanquet scales (following van der Maarel, 1979, 2005; Eymann *et al.*, 2010):

- 1 = rare, generally 1-3 individuals and cover less than 5%;
- 2 = few, with less than 5% cover;
- 3 = abundant, with less than 5% cover;
- 4 = very abundant, with less than or equal to 5% cover;
- 5 = $5 < \text{cover} \leq 12\%$;
- 6 = $12.5 < \text{cover} \leq 25\%$;
- 7 = $25 < \text{cover} \leq 50\%$;
- 8 = $50 < \text{cover} \leq 75\%$ and
- 9 = cover $> 75\%$.

Tree height was measured using Suunto clinometers and diameter at breast height using meter tape. Meter tape was used to measure heights of relatively shorter woody plants. Data sheet one (attached as Annex 1) was used to record data on vegetation and environmental variables.

New taxa, which were encountered outside the plots, were also collected but kept separately. Voucher specimens were collected for all plant species and were identified at National Herbarium (ETH). The nomenclature of the plants was based on the published volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Hedberg and Edwards, 1995; Edwards *et al.*, 1995; Edwards *et al.*, 1997; Edwards *et al.*, 2000; Hedberg *et al.*, 2003; Hedberg *et al.*, 2004; Hedberg *et al.*, 2006).

Slope (the degree of inclination or steepness) of each plot was observed using Suunto clinometers. Altitude of each plot was noted using Garmin GPS. Aspect was codified according to Zerihun Woldu *et al.* (1989) and Tamrat Bekele (1994) where North = 0, East = 2, South = 4, West = 2.5, North East = 1, South East = 3, South West = 3.3 and North West = 1.3.

3.2.5 Soil sampling and analysis of physical and chemical properties

Following Zerihun Woldu and Backeus (1991), soil samples were taken from 0-50 cm depth whenever possible. Soil samples were taken at corners of 20 x 20 m subplots and composite samples weighing 1.5-2 Kg were made. Soils samples were collected below the surface layer of leaf litter and below root mass. Soil samples were air dried before laboratory analysis. The soil

samples were analyzed at Ethiopian National Soil Laboratory. The parameters were analyzed following the standard procedures outlined in Allen (1989): total organic matter (Walkely-Black wet oxidation, % dry weight), electrical conductivity and pH (m mhos/l, in 1:1 soil-water suspension), available phosphorous (Bray No.II Method, ppm), total nitrogen (Kjeldahl method) and texture (hydrometer method; parameters clay, sand and silt expressed as % weight).

3.2.6 Method used for collection of disturbance data

Intensity of anthropogenic disturbance in each plot was estimated as a sum (cumulative effect) of following parameters:

- grazing/browsing intensity (which was estimated based on the following scales: 0 = nil; 1 = slight; 2 = moderate; 3 = heavily and 4 = destructive) (based on T
- number of trees and shrubs cut
- number of foot trails
- number of seedlings trampled

Data sheet (Annex 2) was used to record disturbance data in each plot.

3.2.7 Method used for collection of data on causal factors of vegetation loss and degradation

To explore drivers of forest loss and degradation in the study area, qualitative research method (specifically focus group discussion) was applied. Qualitative research was preferred as it helps to understand a given research problem or topic from the perspectives of the local population (Mack *et al.*, 2005). Furthermore, qualitative method is more flexible-that is, it allows greater adaptation of the interaction between the researcher and the study participant than quantitative methods. The respondents have the opportunity to respond more elaborately and in greater detail than is typically the case with quantitative methods. One of the advantages of focus groups is that they yield a large amount of information over a short period of time. They are also effective for exploring a range of perspectives that exist within a community (Mack *et al.*, 2005). For these reasons, focus group discussion, one of the most common qualitative methods, was applied to get farmers insight on causes of deforestation and forest degradation in the study area.

In order to conduct focus group discussions, Mack *et al.* (2005) recommends maintaining confidentiality requires special precautions and emphasis in focus groups. Accordingly, using participants' names during the focus group was avoided and anonymity was assured. The most commonly sampling methods used in qualitative research is purposive /criterion based sampling. Hence, criterion-based selection procedure (LeCompte *et al.*, 1993) was applied for selection of respondents in the present study. It involves selection of group's participants according to preselected criteria relevant to a particular research question. Accordingly, farmers who lived for long in the study sites and those whose farmlands are located in vicinity to the forests were selected as respondents. A sample size in the range of 30 to 50 respondents is sufficient for exploratory and in-depth work (Bernard, 1995). Accordingly, a total of 55 respondents (49 males and 6 females) participated in the focus group discussions.

One advantage of qualitative methods such as focus discussion is that use of open-ended questions and probing gives participants the opportunity to respond in their own words, rather than forcing them to choose from fixed responses, as quantitative methods do. Such questions have the ability to evoke responses that are rich and explanatory in nature (Mack *et al.*, 2005). The following open ended questions were asked (using local language Guragigna) during focus group discussions and data were recorded by note taking:

- How has the vegetation cover of the study area been changing through time?
- What factors account for loss and degradation of vegetation in the study area?
- Which stakeholders are responsible for the change in the vegetation cover?
- Who owns the forest? Who manages the forest?
- What actions should be taken to curb vegetation loss and degradation?
- Are there any indigenous practices that can help in conservation of the vegetation?

Supplementary data were also collected from central statistical agency of Ethiopia. Besides, pertinent proclamations were reviewed to get insight into possible institutional drivers of vegetation loss and degradation.

3.2.8 Vegetation and environmental data analysis

The percentages of various plant families as well as DBH and height classes of woody plants in the study area were summarized in bar graphs. Dominance curve was used to rank the relative abundance of the species identified. Classification and ordination methods were used to describe vegetation types and to examine the relationship between vegetation types and environmental variables. R package (R Development Core Team, 2009) was used for cluster and ordination analysis.

Hierarchical cluster analysis was performed using R. Similarity ratio and Ward's group linkage method were applied for cluster analysis i.e. to determine plots that can be classified into the same groups based on the species data. Indicator species analysis was performed to find indicator species characterizing the communities. Indicator species analysis was performed in R using package labdsv (Roberts, 2012). Interpolated species accumulation curves were used to display the expected number of species in each community type as a function of accumulated number of plots. EstimateS 8.2 software (Colwell, 2006) was used to compute the expected species richness and species richness estimators. The species richness of the plant communities were compared using the interpolated species accumulation curves. Chao1, jackknife, abundance-based coverage estimator (ACE) and Bootstrap were used to estimate of the "true" number of species in each community type. Jaccard index was computed to assess the floristic similarity between the communities. The basal area of the main trees in the study area was computed using the formula $BA = \pi (DBH)^2 / 4$.

Canonical correspondence analysis (CCA) was used for detection of patterns of variation in species distribution and for identification of variables causing those patterns in the study sites. The variables considered were altitude, slope, disturbance, pH, phosphorus, electrical conductivity, sand, silt, clay, total nitrogen, organic carbon and carbon nitrogen ratio. Among these variables, only those with significant impact on species distribution pattern of the study area were used as constraints in CCA. Step wise variable selection (following Guisan *et al.*, 1999; Oksanen, 2007) was applied to identify the environmental variables with significant influence on the plant distribution pattern of the study sites. The relationships between vegetation

and environmental variables were also tested using correlation coefficients between the environmental variables and the plot scores on CCA axes. Furthermore, analysis of variance was used to assess the relationships between plant community types and environmental variables.

Generalized linear modeling was used to relate species richness patterns of the Gurage Mountains to the measured explanatory variables and to find a subset of explanatory variables that explains the species richness variations in the study area best. Akaike Information Criterion (AIC) was used to find optimal model. Besides, deviance and F-tests were used to check the significance of each variable. In the course of generalized linear modeling, the species richness was fitted with generalized linear model (using R) to explore the impact of environmental variables on richness and to determine the amount of variation in species richness that could be explained by the measured environmental variables. Forward model selection procedure was used to select optimal model with best subset of explanatory variables. First, a null model considering only the response variable without any predictive variable was developed. The significance of any change in AIC, F-value and deviance in null model compared to the bivariate model was checked. At each forward selection step, a variable with lowest AIC was selected, and a multiple linear regression model was applied using the selected variable and each of the remaining variables in turn. The variable that gave the lowest AIC in combination with the first selected variable was then selected, and the process was repeated until the AIC started to increase. Significance of each variable retained in the optimal model was tested using the F-test.

CHAPTER FOUR

4. Results

The main findings of the study and inferences from the findings are presented in this chapter. The findings are discussed in the light of ecological studies elsewhere in chapter 5.

4.1 Attributes of plant communities in the study area

4.1.1 Floristic composition and species richness

The forests in the study area harbor plants of high floristic diversity though they are small patches surrounded by mosaics of other land use practices. A total of 339 species were identified from plots studied (see Annex 3 for the list of species). The plants identified belonged to 89 families; of which only two were gymnosperms. Eight families accounted for 55% of the species in the study area. Asteraceae alone accounted for 24% of the species. Figure 5 presents the percentage of species belonging to the different plant families in the Gurage Mountains.

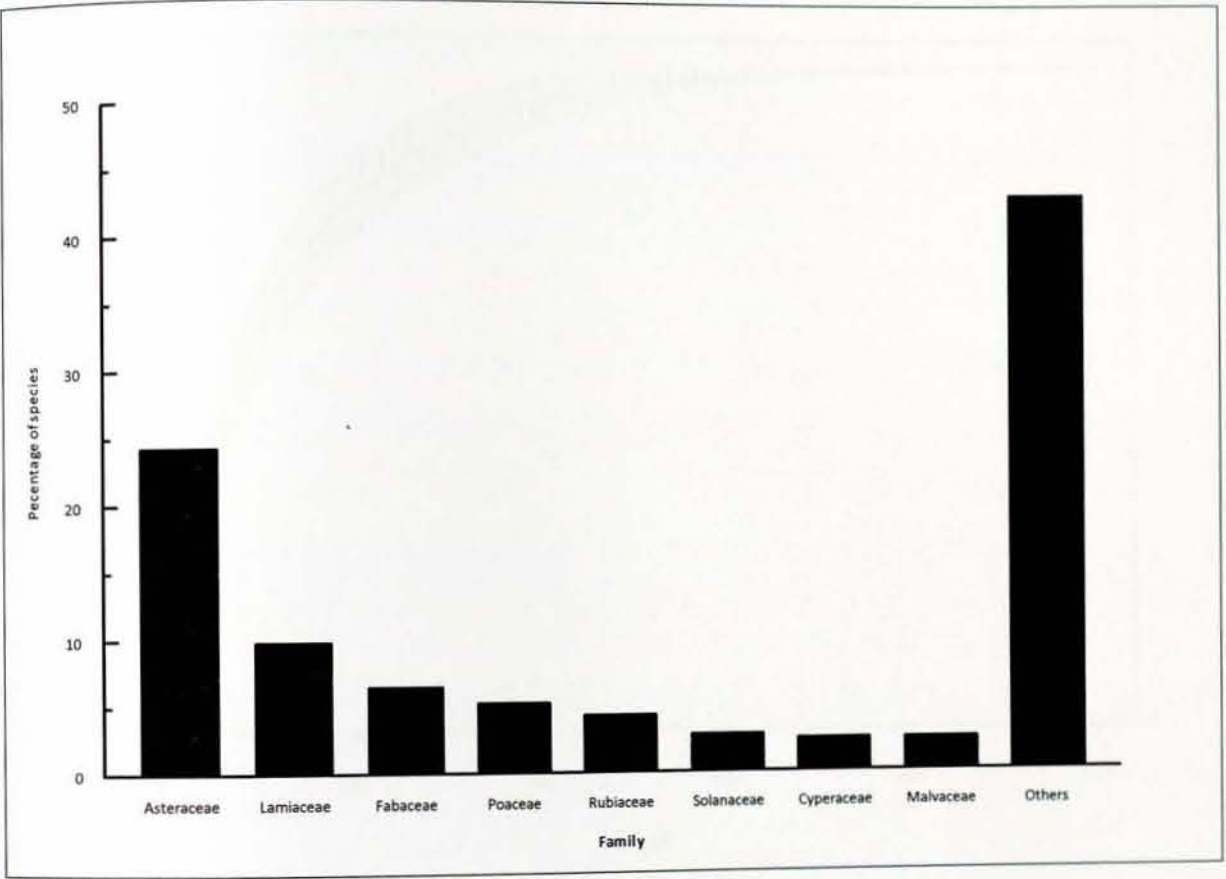


Figure 5: Percentage of species belonging to the different plant families in the study area. Y-axis represents percentage of species belonging to the family in the flora of Gurage Mountains. Many of the species encountered belong to Asteraceae, followed by Lamiaceae.

The number of species reordred as a function of plots studied is shown in species accumulation curve of study area (Figure 6).

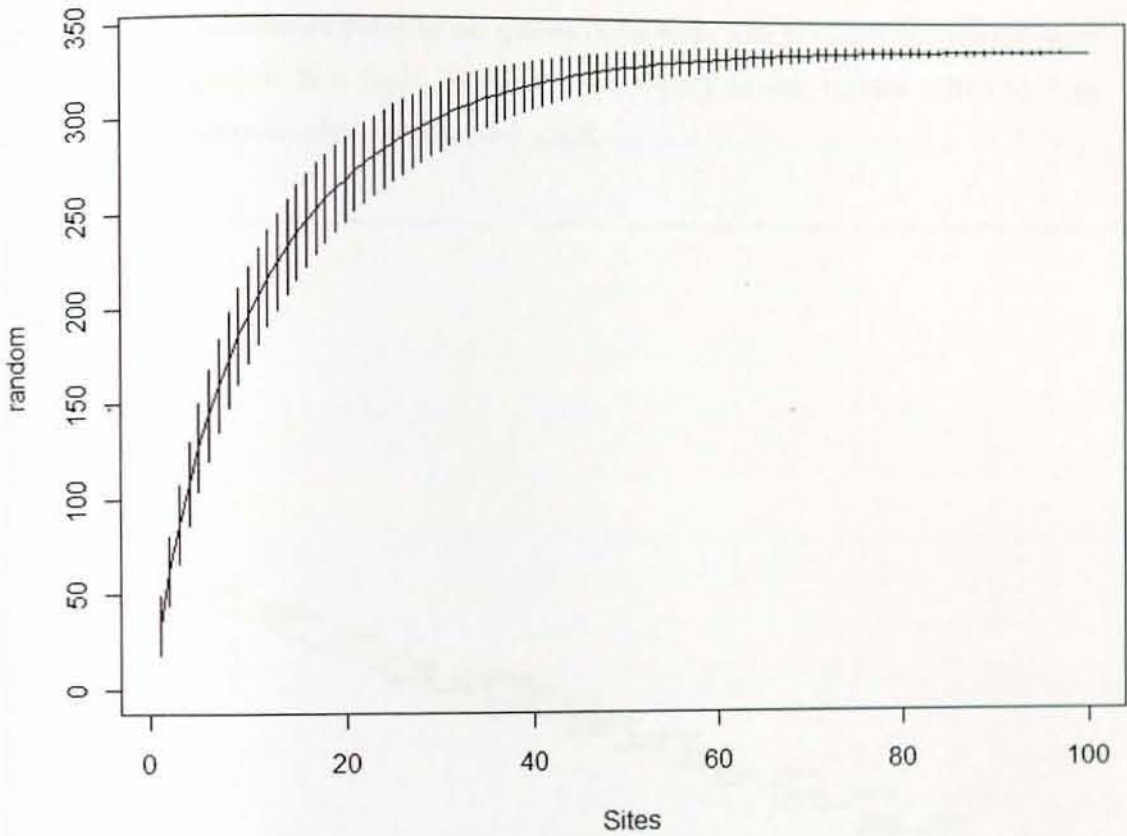


Figure 6: Species accumulation curve of the study area. The x-axis represents number of plots sampled whereas the y-axis represents the number of species encountered.

The species accumulation curve of the study area, Figure 6, leveled off before the total number of observations. The implication is that the study sites were adequately sampled and this inference was made based on Lau (2008); Colwell (2009a). Such curves have been used to estimate the expected number of new species to be detected given a level of additional sampling effort (Mao *et al.*, 2005). For example, it is possible to infer from Figure 6 that about 220 species can be recoded from the study sites after investigating 20 plots; and about 280 species after investigating 40 plots. In the species accumulation curve, the number of species recorded increased radically initially (e.g. from plot 1 to 20) whereas the change in number of species became incremental later on (e.g. from plot 20 to 40) when many of the species in the study area were sampled. Such is a common characteristic of ecological communities (Ugland *et al.*, 2003; Colwell 2009a).

4.1.2 Species abundance and occurrence in the study area

Figure 7 shows the dominance curve of the species in the study area in which the abundances of the species are displayed in a log10 format (on the y-axis) so that species with very high abundances can be accommodated on the same graph.

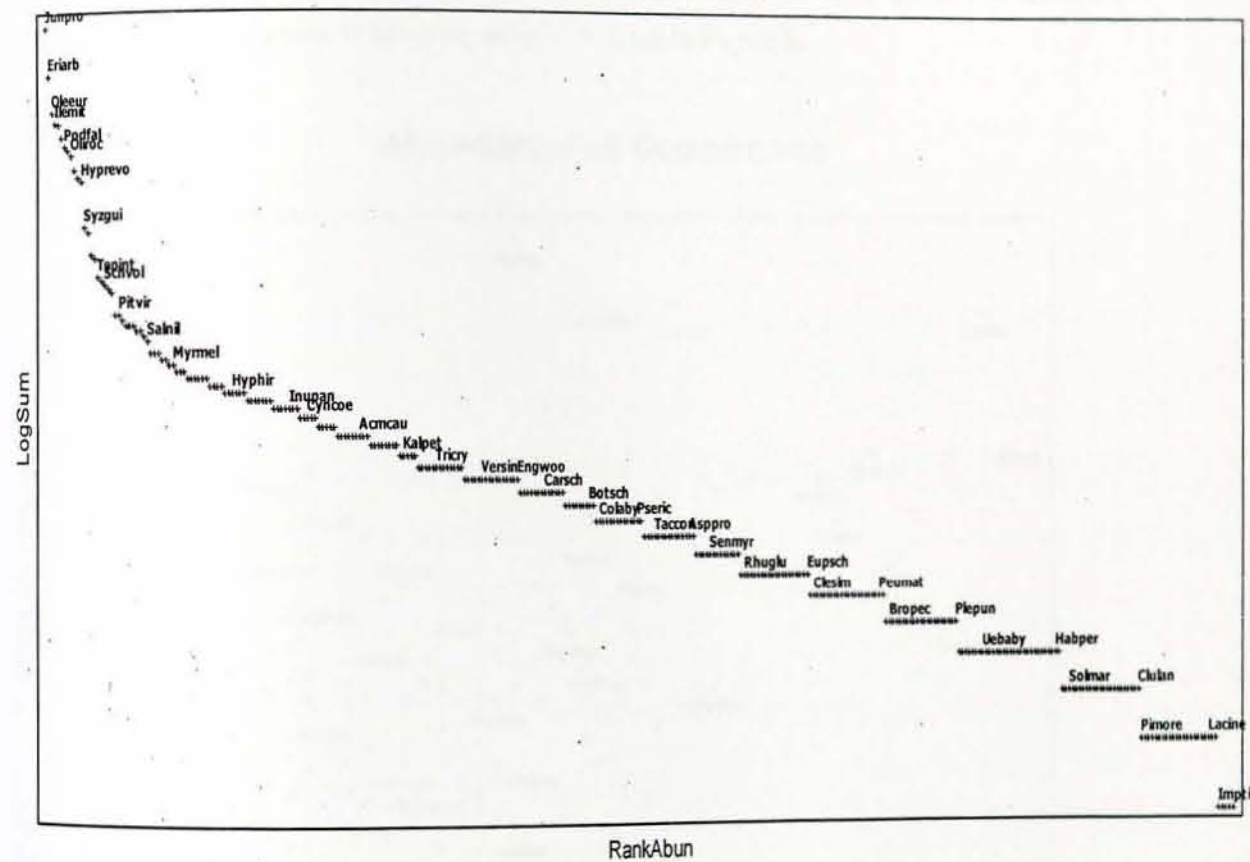


Figure 7: Rank/abundance or dominance curve of the species in the study area. The y-axis in the relative abundance of species (plotted using a log10 scale) while the x-axis ranks each species in order from most to least abundant. The plus signs represent the species. The species are listed by the first three letters of the genus and the specific epithet; see Annex 3 for the full names.

In Figure 7, the species are plotted sequentially from most to least abundant along the horizontal (or x-axis). Given the data from entire study sites, species such as *Juniperus procera*, *Erica arborea*, *Olea europaea* subsp. *cuspidata* and *Podocarpus falcatus* are the most dominant

species. On the other hand, plant species such as *Pimpinella oreophila* and *Lactuca inermis* are least abundant. The low abundance of the latter species may be due to their adaption to limited ecological ranges especially to the highest altitudes in the study area.

In addition to the notable difference in the relative abundance of the species, there was also a clear pattern of variation in the occurrence of the species amongst the study plots. The abundance vs. occurrence of the species in the study area is depicted in Figure 8.

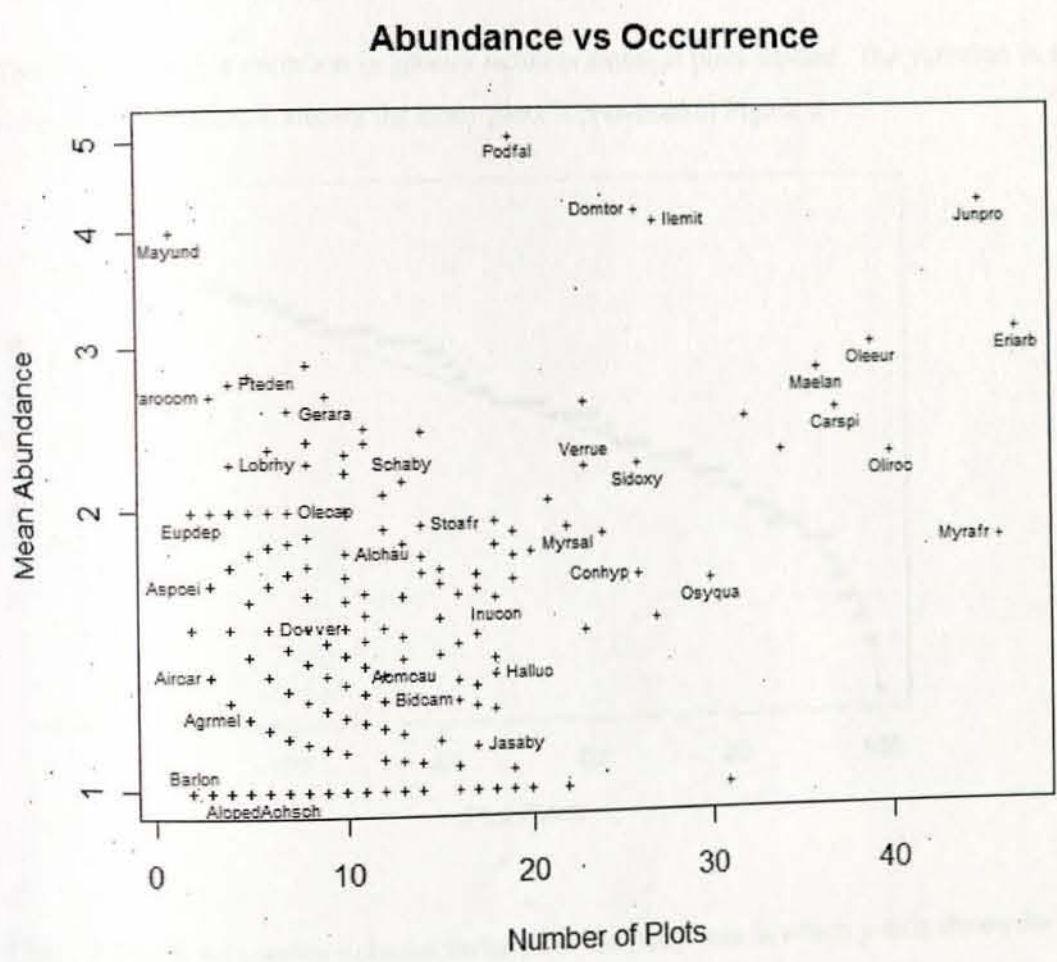


Figure 8: Abundance vs. occurrence of the species in the study area where the x- axis represents the number of plots in which the species occurred whereas y-axis represents the abundance of the species. The plus signs in Figure 8 represent the species. The species are listed by the first three letters of the genus and the specific epithet.

Podocarpus falcatus occurred in 18 plots and in those plots its mean abundance was highest. However, *Juniperus procera* (as shown in Figure 8) had highest average abundance when we consider the entire study area. *Erica arborea*, *Myrsine africana*, *Juniperus procera* and *Olea europaea* subsp. *cuspidata* occurred in more than 40 plots (see Figure 8) and hence were most frequent species in the study area.

4.1.3 Plot level species richness variation in the study area

There was a notable variation in species richness amongst plots studied. The variation in species richness and abundance among the study plots is presented in Figure 9.

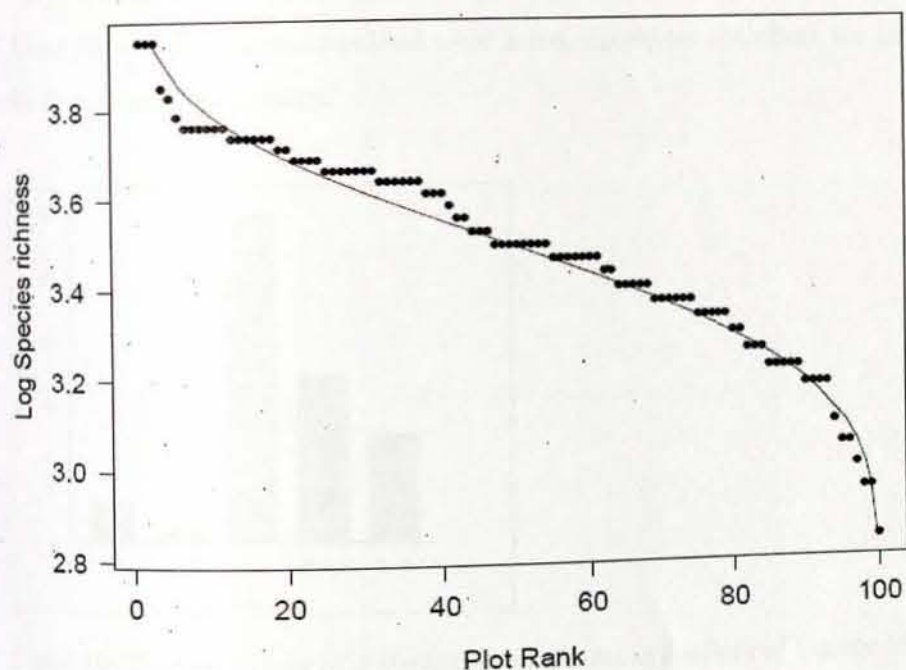


Figure 9: Plot level species richness variation in the study area in which y-axis shows the number of species in the study plots (plotted using a log₁₀ scale) while the x-axis ranks each plot in order from a plot having highest species richness to one with least species richness. The small black circles in the figure represent the plots studied.

The variation in species richness among the plots could be due to local variation in altitude, disturbance as well as other biotic and abiotic factors. Detailed discussion on factors accounting for the variations in species richness of the study sites is presented in section 4.6.

4.1.4 Structural Analysis

The percentage contribution of different plant growth forms as well as DBH and height class distributions were used to get insight into the vegetation structure of the study area.

4.1.4.1 Growth forms

The lion's share of the plants encountered in the study sites were herbs as shown in Figure 10. About 50% of the plants identified were herbs. Epiphytes contribute the smallest proportion to the flora of Gurage Mountains.

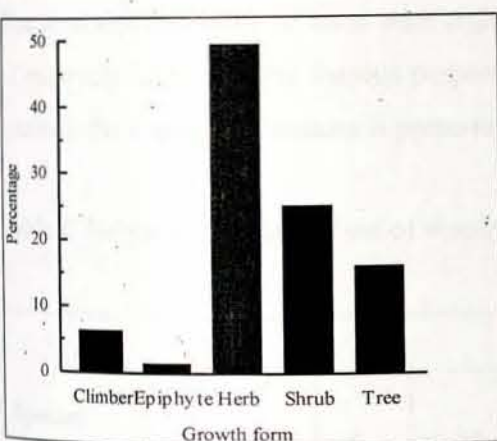


Figure 10: The percentage of different growth forms in the flora of Gurage Mountains.

4.1.4.2 Height class distribution

Most of the woody plants in the study area have height class less than 10 m. Trees with height class greater than 25 m comprised a small proportion of the woody plants investigated as shown in Figure 11.

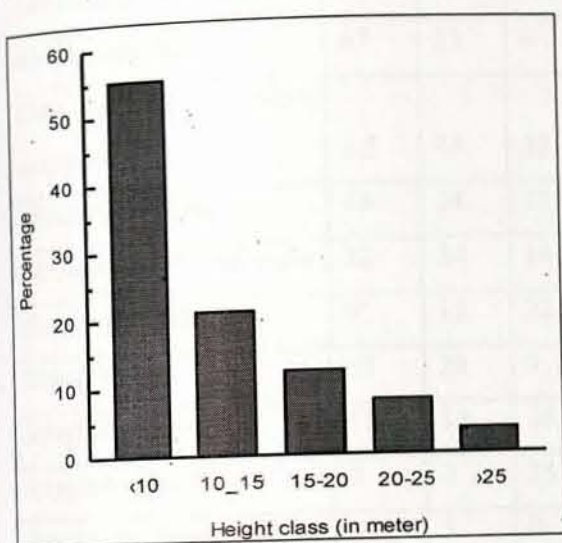


Figure 11: Percentage of plants of various height classes in the study area.

The least representation of trees with higher height classes may also be due to selective logging of relatively large trees for various purposes. The height class distribution of the dominant woody plants in the Gurage Mountains is presented in Table 4.

Table 4: Height class distribution of woody plants in Gurage Mountains (in %)

Species	Height Class							
	<9	9_12	12_15	15_18	18_21	21_24	24_27	>27
<i>Dombeya torrida</i>	13	27	44	12	4	0	0	0
<i>Hagenia abyssinica</i>	0	0	0	27	39	30	4	1
<i>Ilex mitis</i>	5	24	32	20	15	0	0	4
<i>Apodytes dimidiata</i>	49	49	18	0	0	0	0	0
<i>Juniperus procera</i>	9	6	10	45	10	2	3	15
<i>Acacia abyssinica</i>	46	19.4	13.2	14	7.4	0	0	0
<i>Maesa lanceolata</i>	92	8	0	0	0	0	0	0

<i>Maytenus addat</i>	51	21	9	8	6	0	5	0
<i>Myrica salicifolia</i>	67	33	0	0	0	0	0	0
<i>Olea europaea subsp cuspidata</i>	8.5	46	33	13.5	0	0	0	0
<i>Olinia rochetiana</i>	44	24	11	17	4	0	0	0
<i>Pittosporum viridiflorum</i>	22	34	14	13	9	8	0	0
<i>Podocarpus falcatus</i>	9	18	22	26	10	2	3	10
<i>Rhus longipes</i>	67	24	9	0	0	0	0	0
<i>Schefflera volkensii</i>	11	19	28	22	4	8	2	6
<i>Syzygium guineense</i>	3	0	23	20	13	11	10	20
<i>Brucea antidysentrica</i>	95	5	0	0	0	0	0	0
<i>Dovyalis abyssinica</i>	100	0	0	0	0	0	0	0
<i>Nuxia congesta</i>	42	24	14	20	0	0	0	0
<i>Myrsine melanophloeos</i>	60	20	0	15	5	0	0	0
<i>Prunus africana</i>	3	20	44	14	3	5	5	6
<i>Flacourtia indica</i>	94.5	5.5	0	0	0	0	0	0
<i>Croton macrostachyus</i>	31	28	15	3	4	4	11	4

Trees which have high economical and medicinal values such as *Hagenia abyssinica*, *Prunus africana* and *Juniperus procera* were least represented in the lowest height classes which implies that their regeneration status is poor.

In Table 5, the height class distribution of woody plant of the Gurage Mountains is compared with the height class distribution of woody plants of other afro-montane forests of Ethiopia namely Jibat, Chilimo, Menagesha and Wof-Washa forests.

Table 5: Comparison of height class distribution of woody plants in the Gurage Mountains with other afromontane forests of Ethiopia. The data about the height class distribution of woody plants in Jibat, Chilimo, and Menagesha and Wof-Washa forests are based on Tamrat Bekele (1994).

Height Class (%)	Gurage Mountains	Jibat	Chilimo	Menagesha	Wof-Washa
<9	40.6	25.5	42.1	38.5	23.3
9-12	19.3	24	30.8	32	21.3
12-15	14.75	15.2	15.3	10.8	13.7
15-18	12.6	14	7.5	11	13.1
18-21	5.8	7.2	3.4	2.2	6.1
21-24	3.04	3.7	<1	2.2	1.6
24-27	1.9	3.5	0	1	8
>27	2.86	6.8	0	<3	12.8

The population structure of the forest patches of the Gurage Mountains has relatively better resemblance with Menagesha and Chilimo forests in terms the percentage of woody plants having height class less than 9 m.

4.1.4.3 DBH class distribution

DBH class distribution of woody plants in the study area shows a similar trend as that of the height class distribution. Woody plants with DBH class less than 20 cm accounted for most of the plants investigated. Trees with DBH greater than 80 cm were least represented as shown in Figure 12.

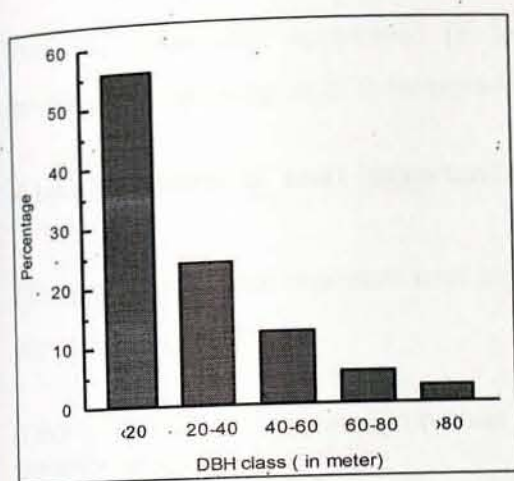


Figure 12: Percentage of woody plants of different DBH class in the study area

As it is the case for the height class frequency distribution, there is a notable similarity in DBH class distribution between the forests of Gurage Mountains and other afromontane forests of Ethiopia as shown in Table 6. The data about the DBH frequency distribution of woody plants in Jibat, Chilimo, and Menagesha and Wof-Washa forests are based on Tamrat Bekele (1994).

Table 6: Comparison of DBH frequency distribution of woody plants in Gurage Mountains with other afromontane forests of Ethiopia. The data about the height class distribution of woody plants in Jibat, Chilimo, and Menagesha and Wof-Washa forests are based on Tamrat Bekele (1994).

DBH Class (%)	Gurage Mountains	Chilimo	Jibat	Menagesha	Wof-Washa
<20	55	60.8	48.9	56.9	32.6
20-50	28.8	36.5	39.5	32.8	31.7
50-80	13	11	9.8	6.5	14.6
80-110	2.2	0	1.4	2.5	11.7
>110	0.9	0	<2	1.1	9.5

In terms of proportion of woody plants with DBH class less than 20 cm, the forest patches of the Gurage Mountains have high similarity with Menagesha forest. Wof-Washa and Mengesha forests also higher resemblance with the forests of the study area in the percentage of trees having DBH class of 20-50 cm. In all of these afromontane forests of Ethiopia, trees with higher

DBH classes were least represented. The low representation of woody plants of higher DBH may be due to selective logging of those trees for various uses.

4.1.4.4 Basal area of most important trees

The basal area of most important trees in each of plant communities identified in the study area is presented in Table 7.

Table 7: Basal area of the most important trees in the each of the plant communities identified in the study area (subsection 4.3)

Community 1	Basal area (m ² /ha)
<i>Podocarpus falcatus</i>	47.4
<i>Schefflera volkensii</i>	6.6
<i>Syzygium guineense</i>	13.7
<i>Olea europea</i>	2.1
<i>Olinia rochetiana</i>	1.4
Community 2	Basal area (m ² /ha)
<i>Acacia abyssinica</i>	6
<i>Dombeya torrida</i>	3.7
<i>Juniperus procera</i>	41.5
<i>Maytenus addat</i>	4.6
<i>Olinia rochetiana</i>	1
Community 3	Basal area (m ² /ha)
<i>Ilex mitis</i>	16.4
<i>Maytenus addat</i>	2.4
<i>Olinia rochetiana</i>	5.8
<i>Pittosporum viridiflorum</i>	2.8
<i>Syzygium guineense</i>	1.3
Community 4	Basal area (m ² /ha)
<i>Apodytes dimidiata</i>	3.7
<i>Hagenia abyssinica</i>	1.14
<i>Maesa lanceolata</i>	4.7
<i>Myrica salicifolia</i>	5.5
<i>Olea europaea subsp cuspidata</i>	11
Community 6	Basal area (m ² /ha)
<i>Dombeya torrida</i>	9.5
<i>Juniperus procera</i>	3.3
<i>Olea europaea</i>	1.6

<i>Olinia rochetiana</i>	2
<i>Schefflera volkensii</i>	2.9

4.1.4.5 Species population structure

The patterns of species population structure for some of most important trees in the study area are presented in Figure 13. Such patterns can be interpreted as an indication of variation in the population dynamics in the forest (Popma *et al.*, 1988 cited in Tamrat Bekele, 1994). Three main patterns of population of structures were identified as shown in Figure 13.

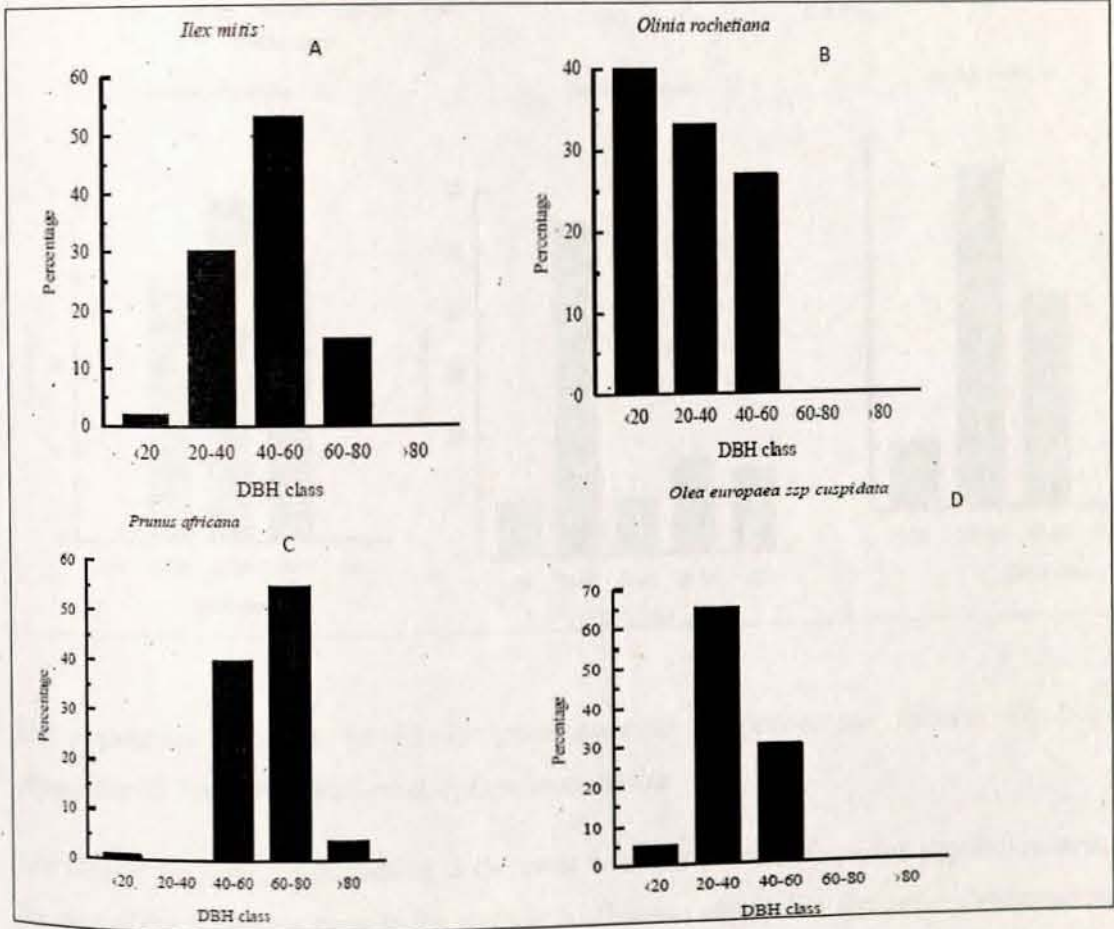
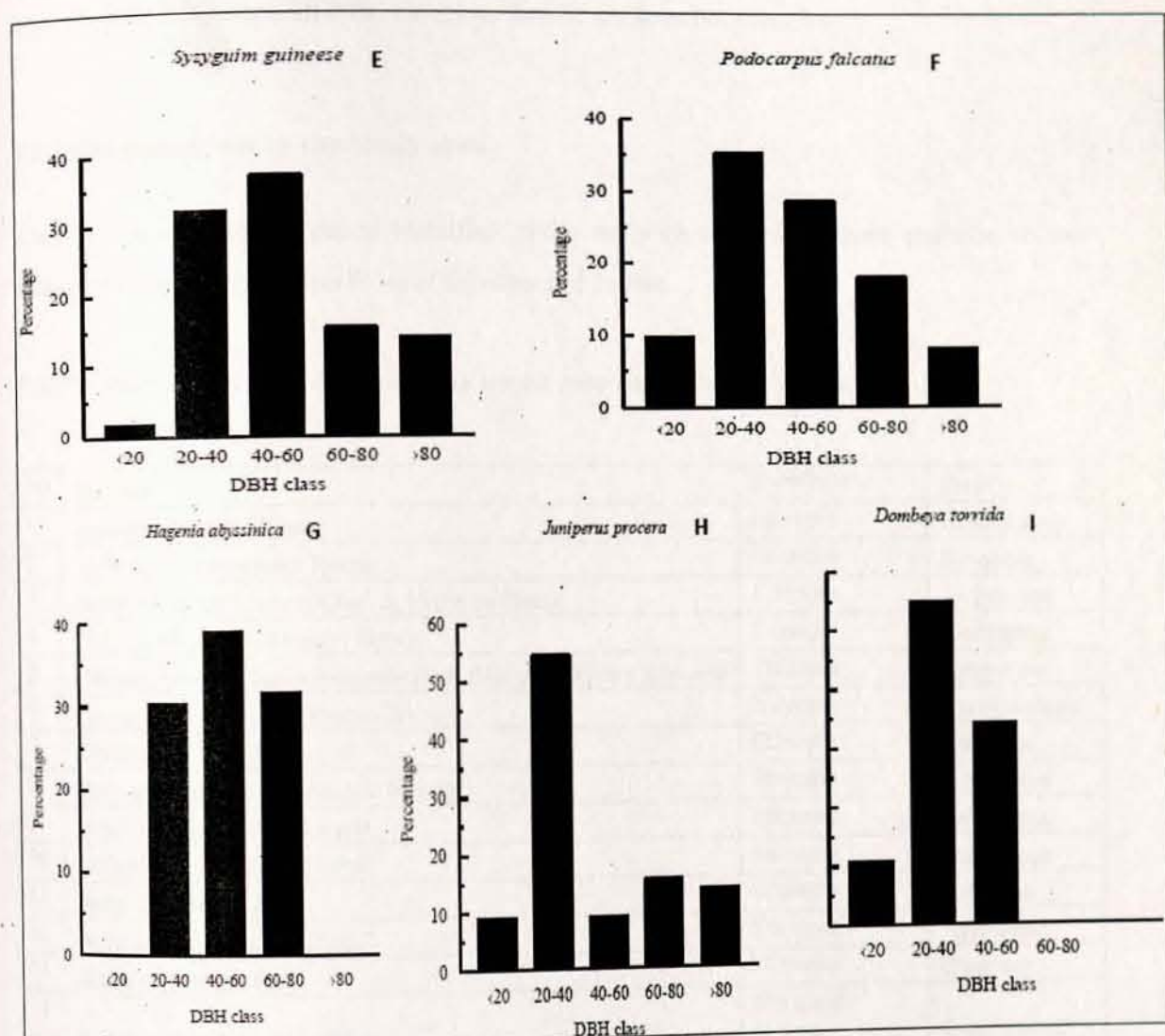


Figure 13: The population structure of the dominant trees in the Gurage Mountains: A) *Ilex mitis* B) *Olinia rochetiana* C) *Prunus africana* & D) *Olea europaea* subsp *cuspidata*

Continued (Figure 13)



The population structure of: E) *Syzygium guineese* F) *Podocarpus falcatus* G) *Hagenia abyssinica* H) *Juniperus procera* & I) *Dombeya torrida*

Bell shaped frequency distribution is the most common pattern of species population structure for most of the dominant trees in the study area. *Hagenia abyssinica*, *Ilex mitis*, *Prunus africana*, *Podocarpus falcatus*, *Olea europaea* subsp *cuspidata* and *Juniperus procera* have bell-shaped frequency distribution (population structure) in which number of individuals in the middle

diameter classes are high and lower in lower and higher diameter classes. For *Hagenia abyssinica*, individuals with DBH class less than 20 cm were not recorded.

4.2 Plant endemism in the study area

About ten percent of the plants identified in the study sites (Table 8) were endemic or near endemic to Ethiopia based on Flora of Ethiopia and Eritrea.

Table 8: Plants endemic to Ethiopia, which were recorded in the study area.

No	Species	Distribution	Family
1	<i>Acanthus sennii</i> Chiov.	Ethiopia	Acanthaceae
2	<i>Alchemilla haumannii</i> Rothm.	Ethiopia	Rosaceae
3	<i>Bothriocline schimperi</i> Oliv. & Hiern ex Benth.	Ethiopia	Asteraceae
4	<i>Chiliocephalum schimperi</i> Benth.	Ethiopia	Asteraceae
5	<i>Crassocephalum macropappum</i> (Sch.Bip. ex A.Rich.) S.Moore	Ethiopia	Asteraceae
6	<i>Cynoglossum densefoliatum</i> Chiov.	Ethiopia	Boraginaceae
7	<i>Erythrina brucei</i> Schweinf.	Ethiopia	Fabaceae
8	<i>Euryops antinorii</i> (Avetta) S. Moore	Ethiopia	Asteraceae
9	<i>Haplocarpha hastata</i> Lewin	Ethiopia	Asteraceae
10	<i>Helichrysum gofense</i> Cufod.	Ethiopia	Asteraceae
11	<i>Indigofera rothii</i> Bak.	Ethiopia	Fabaceae
12	<i>Inula confertiflora</i> A. Rich.	Ethiopia	Asteraceae
13	<i>Jasminum stans</i> Pax	Ethiopia	Oleaceae
14	<i>Kalanchoe petitiiana</i> A. Rich.	Ethiopia & Eritrea	Crassulaceae
15	<i>Kniphofia foliosa</i> Hochst.	Ethiopia	Asphodelaceae
16	<i>Kniphofia isoetifolia</i> Steud ex Hochst.	Ethiopia	Asphodelaceae
17	<i>Laggera tomentosa</i> (Sch.Bip.ex A.Rich.) Oliv. & Hiern	Ethiopia	Asteraceae
18	<i>Lavatera abyssinica</i> Hutch. & Bruce	Ethiopia	Malvaceae
19	<i>Leucas stachydiformis</i> (Hochst ex Benth.) Briq.	Ethiopia	Lamiaceae
20	<i>Lobelia rhynchopetalum</i> Hemsl.	Ethiopia	Lobeliaceae
21	<i>Maytenus addat</i> (Loes.) Sebsebe	Ethiopia	Celastraceae
22	<i>Mikaniopsis clematoides</i> (Sch. Bip.ex A.Rich.) Milne-Redh.	Ethiopia	Asteraceae
23	<i>Milletia ferruginea</i> (Hochst) Bak.	Ethiopia	Fabaceae
24	<i>Ranunculus tembensis</i> Fresen.	Ethiopia	Ranunculaceae
25	<i>Satureja paradoxa</i> (Vatke) Engl. ex Seybold	Ethiopia	Lamiaceae

26	<i>Senecio fresenii</i> Sch.Bip. ex Oliv. & Hiern	Ethiopia	Asteraceae
27	<i>Senecio myriocephalus</i> Sch.Bip. ex A. Rich.	Ethiopia	Asteraceae
28	<i>Senecio ochrocarpus</i> Olivo & Hiern	Ethiopia	Asteraceae
29	<i>Senecio schultzei</i> Hochst. ex A. Rich.	Ethiopia	Asteraceae
30	<i>Senecio unionis</i> Sch.Bip. ex A. Rich.	Ethiopia	Asteraceae
31	<i>Solanecio gigas</i> (Vatke) C. Jeffrey	Ethiopia	Asteraceae
32	<i>Thymus schimperii</i> Ronn.	Ethiopia & Eritrea	Lamiaceae
33	<i>Vernonia filigera</i> Oliv. & Hiern	Ethiopia	Asteraceae

4.3 Classification of the vegetation of the study area

Hierarchical agglomerative clustering with similarity ratio as a resemblance index and Wards group linkage method resulted in a dendrogram with seven distinct communities (Figure 14).

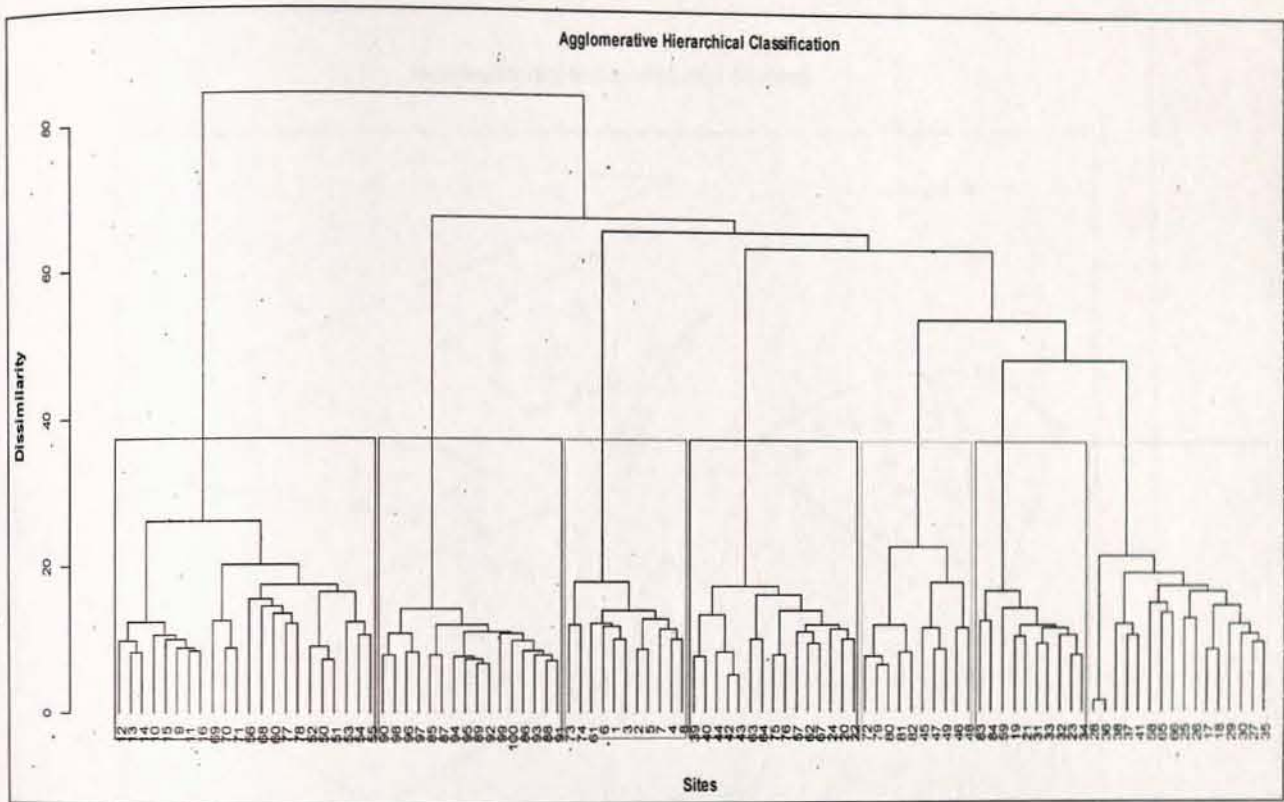


Figure 14: Dendrogram of the Vegetations of Gurage Mountains.

Nonmetric multidimensional scaling (NMDS) resulted in an ordination diagram in which the configuration of the study plots closely matches with the result of the agglomerative hierarchical classification as shown in Figure 15.

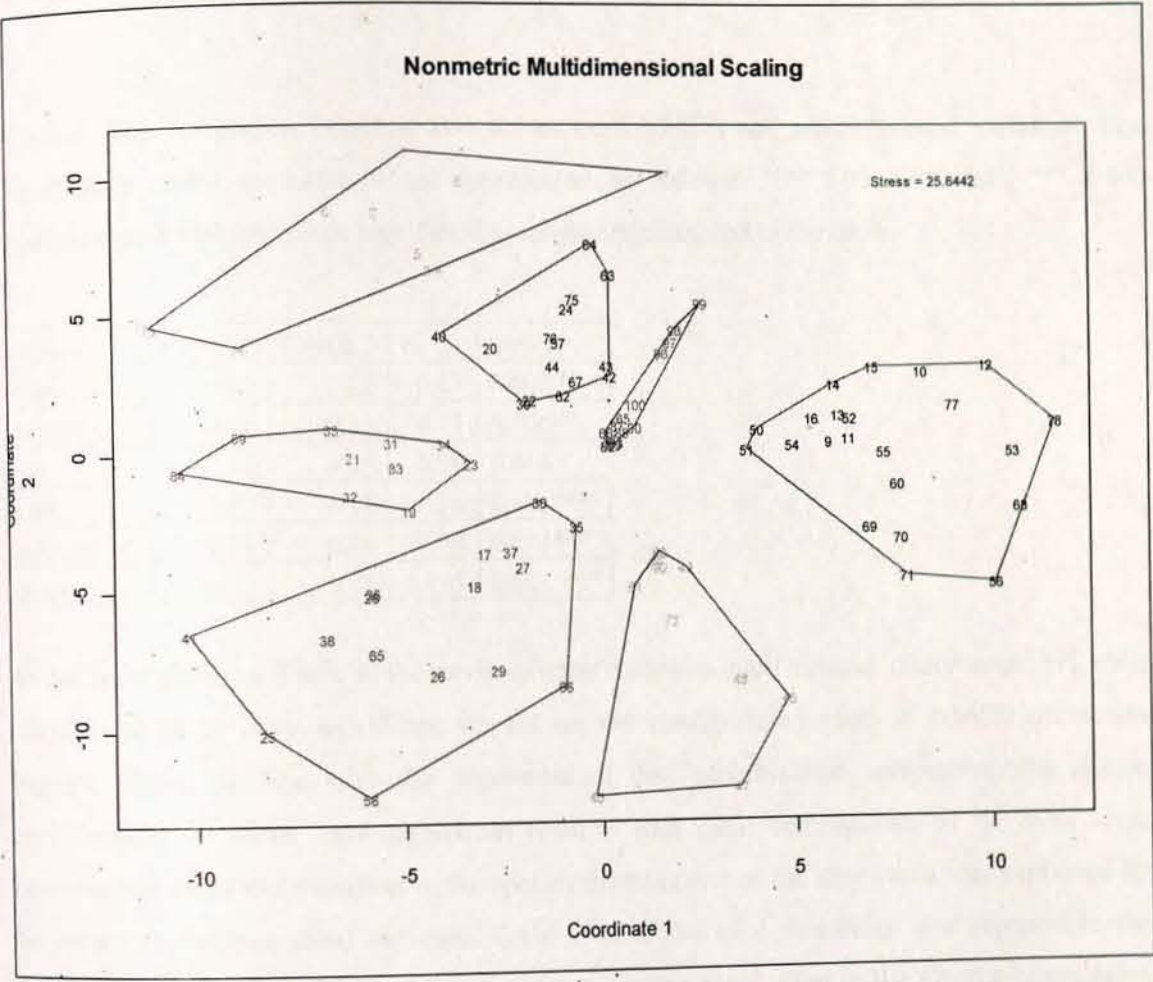


Figure 15: The configuration of the plots in NMDS ordination diagram in which the seven plant communities recognized in the study area distinctively shown. This configuration is based on floristic similarity of the plots.

To investigate how the environmental variables contribute to the configuration plots in NMDS ordination diagram (to relate the plant communities in the study area with the measured environmental variables), the axis scores from NMDS were correlated with each variable and the result is presented in Table 9. Note that the afroalpine community was not included in this part of the analysis as soil was not sampled from the afroalpine plots. See Annex 7 for NMDS ordination diagram into which environmental variables are fitted.

Table 9: The correlation between axis scores from NMDS and environmental variables. The significance codes in Table 9 are represented as follows: '****' 0.001 '**' 0.01 '*' 0.05. Environmental variables with significant p-values are presented in the table.

Variables	Coord.1	Coord.2	r ²	Pr(>r)
Sand	0.97	0.2	0.13	0.005 **
Disturbance	-0.94	-0.33	0.13	0.006**
pH	0.92	0.39	0.09	0.016 *
Clay	0.63	0.78	0.36	0.001***
Altitude	0.33	0.94	0.35	0.001***
Slope	0.663	0.75	0.195	0.001 ***

As can be noted from Table 9, the environmental variables such as sand, disturbance, pH, clay, altitude and slope have significant impact on the configuration plots in NMDS ordination diagram. Hence, in line with the arguments of the individualistic perspective, the abiotic environmental variables have significant relation with plant communities of the study area. However, not all of the variation in the species distributions of the study area was explained by the measured environmental variables. Only 16% of the total variability was captured in the CCA (see section 4.5.1). The implication is that species distribution in the Gurage Mountains could also be affected by a variety of factors in addition to responses to environmental gradients such as species interactions and past history; which is in agreement with the arguments of the organismal perspective. The organismal view of community organization assumes that the ecological limits of distribution of each species coincide with the distribution of the community as a whole i.e. it assumes non-overlapping groups of species response curves along an environmental gradient. Nevertheless, the species identified in the study area were not necessarily restricted to a single community contrary to the assertion of the organismal perspective. Even each of the plant communities has some similarity in species composition with the other communities (see Table 11 for Jaccard index of similarity between the communities) implying that a species's distribution may not unavoidably be restricted to a single community. Hence, the synthesis perspective could better explain the plant community organization in the Gurage

Mountains as species composition along environmental gradients in the study area has more grouping than would be in agreement with the continuum concept, and more variation than would be consistent with the organismal concept.

The seven community types recognized in the study area were:

Community 1: *Podocarpus falcatus*-*Syzygium guineense* community type

Community 2: *Juniperus procera*-*Acacia abyssinica* community type

Community 3: *Ilex mitis*- *Olinia rochetiana* community type

Community 4: *Olea europaea* subsp *cuspidata*-*Maesa lanceolata* community type

Community 5: *Erica arborea*-*Hypericum revolutum* community type

Community 6: *Dombeya torrida*-*Carissa spinarum* community type

Community 7: *Alchemilla haumannii*- *Haplocarpha hastata*- *Lobelia rhynchopetalum* community type

Each of these plant communities is characterized by a group plants which show strong preferential distribution in the respective community. Table 10 presents the list of species with significant indicator values in each community. The probability and indicator values represent Monte Carlo tests and the faithfulness of occurrence of the species in the communities identified, respectively.

Table 10: Species with significant indicator values (in percentage) in each community. Species with highest indicator values are bolded. The indicator values of the species were considered as significant if the respective probability values were less than 0.05 (Dufrêne and Legendre, 1997).

Species	Community	Indicator value	Probability
<i>Podocarpus falcatus</i> (Thunb.) R.B. ex Mirb.	1	85.2	0.001
<i>Syzygium guineense</i> (Willd.) DC.	1	45.4	0.001
<i>Schefflera volkensii</i> (Engl.) Harms	1	37.3	0.001
<i>Blechnum attenuatum</i> (Sw.) Mett.	1	36.8	0.001
<i>Acanthus sennii</i> Chiov.	1	34.7	0.001

<i>Selaginella caffrorum</i> (Milde) Hiern.	1	34	0.004
<i>Plantago africana</i> Verdc.	1	32.9	0.001
<i>Hypoestes triflora</i> (Forssk.) Roem. & Shult.	1	29	0.005
<i>Carduus schimperi</i> Sch.Bip. ex A.Rich.	1	28.8	0.003
<i>Asplenium ceii</i> Pic.-Serm.	1	27.3	0.004
<i>Parochaetus communis</i> D.Don	1	27.3	0.005
<i>Psychotria orophila</i> Petit	1	27.3	0.004
<i>Vernonia hochstetteri</i> Sch.Bip. ex Walp.	1	27.3	0.003
<i>Pentas schimperiana</i> (A.Rich.) Vatke	1	26.8	0.002
<i>Achyrospermum schimperi</i> (Hochst ex Briq.) Perkins	1	25	0.004
<i>Satureja paradoxa</i> (Vatke) Engl. ex Seybold	1	24.6	0.008
<i>Galium aparinoides</i> Forssk.	1	23.8	0.008
<i>Dryopteris lewalleana</i> Pic.Serm.	1	23.6	0.013
<i>Cynoglossum amplifolium</i> Hochst. ex A.DC.	1	22.5	0.004
<i>Colutea abyssinica</i> Kunth & Bouché	1	22.3	0.015
<i>Plectrocephalus varians</i> (A.Rich.) C. Jeff.	1	21.5	0.012
<i>Sanicula elata</i> Buch-Ham. ex D. Don	1	20.8	0.015
<i>Clusia abyssinica</i> Juab. & Spach.	1	19.8	0.031
<i>Hypericum quartinianum</i> A. Rich.	1	19.5	0.04
<i>Polystichum wilsonii</i> H.Christ	1	18.2	0.039
<i>Scadoxus multiflorus</i> (Martyn) Raf.	1	18.2	0.038
<i>Sebaea brachyphylla</i> Griseb.	1	18.2	0.048
<i>Ficus sur</i> Forssk.	1	17.2	0.035
<i>Galium simense</i> Fresen.	1	16.5	0.039
<i>Juniperus procera</i> Hochst. ex Endl.	2	72.7	0.001
<i>Acacia abyssinica</i> Hochst. ex Benth.	2	36.7	0.002
<i>Mikaniopsis clematoides</i> (Sch. Bip. ex A.Rich.) Milne-Redh.	2	35	0.003
<i>Jasminum grandiflorum</i> L.	2	29.45	0.004
<i>Meineckia phyllantoides</i> Baill	2	23	0.017
<i>Pavetta abyssinica</i> Fresen.	2	20	0.013
<i>Chiliocephalum schimperi</i> Benth.	2	20	0.022
<i>Ilex mitis</i> (L.) Radlk.	3	42.4	0.001
<i>Olinia rochetiana</i> A.Juss.	3	40	0.001
<i>Solanecio gigas</i> (Vatke) C. Jeffrey	3	33.9	0.003
<i>Carex spicata-paniculata</i> Bock. ex C.B. Clarke	3	31.8	0.008
<i>Scolopia theifolia</i> Gilg	3	31	0.002
<i>Kohautia platyphylla</i> (K.Schum.) Bremek.	3	29.7	0.001
<i>Cyperus aterrimus</i> Steud.	3	26.2	0.006
<i>Senna septemtrionalis</i> (Viv.) Irwin & Barneby	3	25	0.006
<i>Stomatanthus africanus</i> (Oliv. & Hiern) R.M.King & H.Rob.	3	23.9	0.007

<i>Periploca linearifolia</i> Quart.-Dill. & A.Rich.	3	23.4	0.01
<i>Bidens camporum</i> (Hutch.) Mesfin	3	22.7	0.019
<i>Plectranthus lanuginosus</i> (Hochst ex Benth.) Agnew	3	21.8	0.018
<i>Prunus africana</i> (Hook.f.) Kalkm	3	21.7	0.022
<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	3	18.7	0.031
<i>Clerodendrum alatum</i> Gurke	3	18.6	0.027
<i>Aeschynomene abyssinica</i> (A.Rich.) Vatke	3	13.6	0.035
<i>Olea europaea</i> L. subsp cuspidata (Wall. ex G.Don) Cif	4	48.5	0.001
<i>Maesa lanceolata</i> Forsk.	4	39.3	0.001
<i>Achyranthes aspera</i> L.	4	28.6	0.002
<i>Tephrosia interrupta</i> Hochst. & Steud. ex Engl.	4	28	0.006
<i>Clematis hirsuta</i> Perr. & Guill.	4	27	0.003
<i>Setaria incrassata</i> (Hochst.) Hack.	4	26.9	0.006
<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	4	23.8	0.017
<i>Lippia adoensis</i> Hochst. ex Walp var. <i>adeonsis</i>	4	21.7	0.024
<i>Apodytes dimidiata</i> E.Mey ex Arn.	4	21.5	0.02
<i>Athrixia rosmarinifolia</i> (Sch. Bip. ex Walp.) Oliv & Hiern	4	21.5	0.02
<i>Lagdera crispata</i> (Vahl) Hepper & Wood	4	18.5	0.043
<i>Protea gagedi</i> J.F.Gmel.	4	14.6	0.049
<i>Erica arborea</i> L.	5	63	0.001
<i>Hypericum revolutum</i> Vahl	5	62.7	0.012
<i>Sideroxylon oxyacanthum</i> Baill.	5	29	0.044
<i>Euphorbia petitiiana</i> A. Rich.	5	24.7	0.022
<i>Vernonia bipontini</i> Vatke	5	22.7	0.021
<i>Osyris quadripartita</i> Decn.	5	21.7	0.014
<i>Dombeya torrida</i> (J.F.Gmel.) P. Bamps	6	56.9	0.001
<i>Carissa spinarum</i> L.	6	40.9	0.001
<i>Agrocharis incognita</i> (Norman) Heywood & Jury	6	33.3	0.001
<i>Conyza subcaposa</i> O.Hoffm.	6	32.3	0.001
<i>Rumex nepalensis</i> Spreng.	6	31.8	0.002
<i>Pteris catoptera</i> Kuntze	6	26.3	0.006
<i>Macrotyloma axillare</i> (E.Mey.) Verdc.	6	25.3	0.003
<i>Kniphofia foliosa</i> Hochst.	6	24.8	0.005
<i>Crassocephalum macropappum</i> (Sch.Bip. ex A.Rich.) S.Moore	6	23.3	0.036
<i>Zehneria scabra</i> (Linn.f.) Sond.	6	22.9	0.006
<i>Jasminum dichotomum</i> Vahl	6	21.2	0.029
<i>Datura stramonium</i> L.	6	20.4	0.018
<i>Vernonia urticifolia</i> A. Rich.	6	20	0.027
<i>Rubus steunderi</i> Schweinf.	6	19.7	0.031
<i>Senecio fresenii</i> Sch.Bip. ex Oliv. & Hiern.	6	19.5	0.014

<i>Mellera lobulata</i> S.Moore	6	19.3	0.03
<i>Guizotia scabra</i> (Vis) Chiov.	6	18.7	0.029
<i>Euphorbia abyssinica</i> Gmel.	6	18.7	0.031
<i>Erythrina brucei</i> Schweinf.	6	18.6	0.031
<i>Kalanchoe petitiiana</i> A. Rich.	6	17.7	0.04
<i>Hibiscus macranthus</i> Hochst. ex A. Rich.	6	17.3	0.028
<i>Phyllanthus ovalifolius</i> Forssk.	6	16.9	0.028
<i>Haplocarpha hastata</i> Lewin	7	62	0.001
<i>Alchemilla haumannii</i> Rothm.	7	62	0.001
<i>Lobelia rhynchopetalum</i> Hemsl.	7	56	0.001
<i>Geranium arabicum</i> Forssk.	7	55	0.001
<i>Alchemilla abyssinica</i> Fresen.	7	52	0.001
<i>Trifolium cryptopodium</i> Steud. ex A. Rich.	7	51	0.001
<i>Bidens macroptera</i> (Sch. Bip. ex Chiov.) Mesfin	7	44	0.001
<i>Cerastium octandrum</i> A. Rich.	7	44	0.001
<i>Cynoglossum densefoliatum</i> Chiov.	7	44	0.001
<i>Cyperus elegantulus</i> Steud.	7	44	0.001
<i>Satureja simensis</i> (Benth.) Briq.	7	44	0.001
<i>Swertia lugardae</i> Bullock	7	44	0.001
<i>Carex conferta</i> Hochst. ex A. Rich.	7	38	0.001
<i>Erica temipilosa</i> (Engl. ex Alm & Fries) Cheek	7	38	0.001
<i>Ranunculus tembensis</i> Fresen.	7	38	0.001
<i>Schoenoplectus corymbosus</i> (Roem. & Schult.) Rayn.	7	38	0.001
<i>Kniphofia schimperi</i> Baker	7	33	0.002
<i>Trifolium multinerve</i> A. Rich.	7	33	0.002
<i>Peucedanum mattirolii</i> Chiov.	7	32	0.001
<i>Alepidea peduncularis</i> Steud. ex A. Rich.	7	31	0.003
<i>Anthemis tigreensis</i> J. Gay ex A. Rich.	7	31	0.002
<i>Bromus pectinatus</i> Thunb.	7	31	0.001
<i>Carex erythrorrhiza</i> Bock.	7	31	0.001
<i>Carex simensis</i> Hochst. ex A. Rich.	7	31	0.002
<i>Delphinium dasycaulon</i> Fresen.	7	31	0.002
<i>Epilobium stereophyllum</i> Fresen.	7	31	0.001
<i>Festuca abyssinica</i> Hochst. ex A. Rich.	7	31	0.002
<i>Gladiolus abyssinicus</i> (Brongn. ex Lemaire) Goldblatt & de Vos	7	31	0.002
<i>Scabiosa columbaria</i> L.	7	31	0.002
<i>Senecio ochrocarpus</i> Olivo & Hiern	7	31	0.001
<i>Senecio ragazzii</i> Chiov.	7	31	0.001
<i>Swertia fimbriata</i> (Hochst.) Cufod.	7	31	0.001
<i>Kniphofia isoetifolia</i> Steud ex Hochst.	7	24	0.003

<i>Satureja paradoxa</i> (Vatke) Engl. ex Seybold	7	19	0.021
<i>Sebaea brachyphylla</i> Griseb.	7	19	0.027

The species listed in Table 10 show strong preferential distributions in the communities defined by clustering. The probability value gives the probability of finding higher indicator value in random permutations, and if this probability is low, the species is a significant indicator (Dufrêne and Legendre, 1997; Oksanen, 2012). The indicator values of the species in Table 10 are arranged in descending order. The species with highest indicator values were used for naming the communities. Each community is described below.

Community 1: *Podocarpus falcatus*-*Syzygium guineense* community type

Some of the characteristic plant species in this community were *Podocarpus falcatus*, *Syzygium guineense*, *Schefflera volkensii*, *Acanthus sennii*, *Blechnum attenuatum*, *Selaginella caffrorum*, *Plantago africana*, *Psychotria orophila*, *Vernonia hochstetteri* and *Hypericum quartinianum*. The altitude of this community ranges from 2291 to 2410 m. Average woody plant density per plot and per hectare in this community was 167 and 1043, respectively.

Community 2: *Juniperus procera*-*Acacia abyssinica* community type

Juniperus procera was the most dominant species in this community type. The characteristic species include *Juniperus procera*, *Acacia Abyssinica*, *Mikaniopsis clematoides*, *Jasminum grandiflorum*, *Pavetta abyssinica*, *Conyza megensis* and *Chiliocephalum schimperi*. Its altitude ranged from 2493 to 2897 m. Average woody plant density per plot and per hectare in this community was 199 and 1243, respectively.

Community 3: *Ilex mitis*- *Olinia rochetiana* community type

The characteristic floras of this community were *Ilex mitis*, *Olinia rochetiana*, *Carex spicata-paniculata*, *Solanecio gigas*, *Scolopia theifolia*, *Prunus africana*, *Allophylus abyssinicus* and

Clerodendrum alatum. The altitudinal range of this community was between 2363 and 2885 m. Average woody plant density per plot and per hectare was 181 and 1132, respectively.

Community 4: *Olea europaea* spp *cuspidata*-*Maesa lanceolata* community type

Olea europaea ssp. *cuspidata*, *Maesa lanceolata*, *Achyranthus aspera*, *Tephrosia interrupta*, *Clematis hirsuta*, *Lippia adoensis*, *Apodytes dimidiata*, *Laggera crispata* and *Athrixia rosmarinifolia* were some of the characteristic floras of this community. Average woody plant density per plot and per hectare in this community was 161 and 1011, respectively. The altitude ranged from 2503 to 2766 m.

Community 5: *Erica arborea*-*Hypericum revolutum* community type

Some of the characteristic floras of the community were *Erica arborea*, *Hypericum revolutum*, *Euphorbia petitiiana*, *Osyris quadripartita* and *Sideroxylon oxyacanthum*. Average woody plant density per plot and per hectare in this community was 186 and 1162, respectively.

Community 6: *Dombeya torrida*-*Carissa spinarum* community type

The characteristic floras of this community include *Dombeya torrida*, *Carissa spinarum*, *Agrocharis incognita*, *Conyza subcaposa*, *Rumex nepalensis*, *Pteris catoptera*, *Macaranga capensis*, *Croton macrostachyus*, *Zehneria scabra*, *Jasminum dichotomum* and *Datura stramonium*. Average woody plant density per plot and per hectare was 167 and 1043, respectively. Its altitude ranged from 2312 to 2868 m.

Community-7: *Alchemilla haumannii*- *Haplocarpha hastata*-*Lobelia rhynchopetalum* community type

This community occurs in the heighest altitude of the study area. Some of the characteristic species of this community include *Haplocarpha hastata*, *Alchemilla haumannii*, *Lobelia rhynchopetalum*, *Geranium arabicum*, *Alchemilla abyssinica*, *Trifolium cryptopodium*, *Bidens*

macroptera, *Cerastium octandrum*, *Cynoglossum densefoliatum*, *Cyperus elegantulus*, *Satureja simensis*, *Swertia lugardae*, *Carex conferta* and *Erica tenuipilosa*. The altitude ranges from 2980 to 3588 m. Most of the endemic plants encountered in the area belong to this community.

4.4.1 Similarity between community types in the study area

Jaccard index of similarity between the community types is summarized in Table 11.

Table 11: Jaccard similarity between communities

	Community1	Community2	Community3	Community4	Community5	Community6	Community 7
Community1		0.45	0.39	0.34	0.41	0.37	0.15
Community2		1	0.51	0.44	0.52	0.48	0.15
Community3			1	0.54	0.45	0.4	0.1
Community4				1	0.46	0.41	0.1
Community5					1	0.39	0.19
Community6						1	0.11
Community7							1

Community 7, the afroalpine community, has relatively low floristic similarity with other communities in the study area. This could be due to the unique afroalpine environment that resulted in comparatively distinct flora. However, community 7 has relatively higher resemblance with community 5, the ericaceous community, due to their geographical proximity. Relatively higher similarity was also noted between community 3 and 4 which may be due to the fact that the most of the plots belonging to these communities were investigated from areas that are relatively close to each other that could result in a higher resemblance in their floristic composition and hence a higher index of similarity.

4.4.2 Floristic similarity between the forest patches of Gurage Mountains and other forests in Ethiopia

Floristic resemblance between the forest patches of the Gurage Mountains and other forests in Ethiopia was compared by using the woody species floristic data from other researchers: Menagesha Suba forest (Sebsebe Demessew, 1980; Tamrat Bekele, 1994), Jemjem forest (Hailu

Sharew, 1982), Jibat, Chilimo and Wof-washa forests (Tamrat Bekele, 1994) and Dodola forest (Kitessa Hundera, 2003). Jaccard index of similarity between these forests is summarized in Table 12.

Table 12: Jaccard similarity between the forest patches of the Gurage Mountains and other forests in Ethiopia

	Altitude (m)	Gurage Mountains	Jibat	Chilimo	Menagesha Suba	Wof-washa	Jemjem	Dodola
Gurage Mountains	2290-2940	1	0.42	0.33	0.45	0.36	0.19	0.27
Jibat	2200-2900		1	0.48	0.54	0.36	0.26	0.28
Chilimo	2400-2800			1	0.53	0.51	0.22	0.24
Menagesha	2400-3000				1	0.43	0.25	0.35
Wof-washa	2400-3000					1	0.27	0.31
Jemjem	1570- 1940						1	0.21
Dodola	2400-3300							1

The forest patches in the study area have relatively higher floristic resemblance with Menagesha Suba forest. This can be due to the relative geographic proximity of the Menagesha Suba forests to the forest patches of Gurage Mountains. The forests in the study area have least floristic similarity with Jemjem forest which can be due to their comparatively wide geographic and altitudinal differences. Forest patches of the Gurage Mountains occur at altitude range of 2291-2940 m whereas Jemjem forest occurs, according to Hailu Sharew (1982), at altitude range of 1570- 1940 m.

4.4.4 Expected and estimated species richness of the communities

4.4.4.1 Expected species richness

Sample-based rarefaction was used to compute the expected species richness of each of the communities in the study area. Table 13 shows the expected species richness of each community i.e. the rate at which new species were included vis-à-vis the number of samples.

Table 13: The expected species richness of the plant communities in the study area based on sample-based rarefaction. Sobs represent the the expected species richness whereas LB and UB represent the lower and upper bounds of the expected species richness. N represents number of samples and the communities are represented by C 1-7.

	N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
C1	Sobs	38.7	65.5	85	99.7	111	120	126	132	136	140	143									
	LB	34.3	59.3	78	92.3	103	112	119	124	129	132	135									
	UB	43.1	71.7	92.1	107	118	127	134	139	144	147	151									
C2	Sobs	34.4	61.5	83.8	102	118	131	142	151	159	166	171	176	181	185	188	191	194	196	198	200
	LB	30.9	56.4	77.5	95.3	110	123	134	143	151	158	164	169	173	177	181	184	187	189	191	193
	UB	37.9	66.7	90.1	109	125	139	150	159	167	173	179	184	188	192	195	198	201	203	205	207
C3	Sobs	36.9	64.9	86.8	104	118	129	138	146	152	158	162	166	170	172	175	177				
	LB	33.2	59.2	80.1	96.2	110	121	130	138	145	150	155	158	162	165	167	169				
	UB	40.7	70.6	93.5	111	125	137	146	154	160	166	170	174	177	180	183	185				
C4	Sobs	36.9	63.7	84.1	99.8	112	121	129	134	139	142	145									
	LB	33	58.3	77.9	93.1	105	114	122	127	132	136	138									
	UB	40.8	69.1	90.4	107	119	128	135	141	145	149	152									
C5	Sobs	27.7	49.5	66.7	81.6	94.2	105	114	122	128	134	139	143	147	150	152					
	LB	24.5	44.9	61.2	75.6	87.9	98.5	108	115	122	128	133	137	140	143	146					
	UB	30.9	54.1	72.1	87.6	100	111	120	128	135	141	145	149	153	156	158					
C6	Sobs	42.2	72.9	95.8	113	127	137	145	152	157	161	164									
	LB	38.2	67	89.1	106	120	130	139	145	150	154	157									
	UB	46.2	78.7	102	120	134	144	152	159	164	167	171									
C7	Sobs	25.2	43.3	56.6	66.3	74	80	84.9	88.9	92.3	95.2	97.7	99.9	102	104	105	107				
	LB	21.7	37.8	50	59.1	66.4	72.3	77.1	81	84.4	87.3	89.8	92	94	95.7	97.3	98.8				
	UB	28.8	48.8	63.2	73.5	81.5	87.8	92.8	96.8	100	103	106	108	110	112	114	115				

The expected species richness values were used for plotting the species accumulation curve of each community. Such species accumulation curves have been used for quantitative comparison among species assemblages (Mao *et al.*, 2005; Adane Girma, 2011). Accordingly, sample based rarefaction curves of the communities identified were jointly plotted to facilitate species richness comparison and is presented in Figure 16.

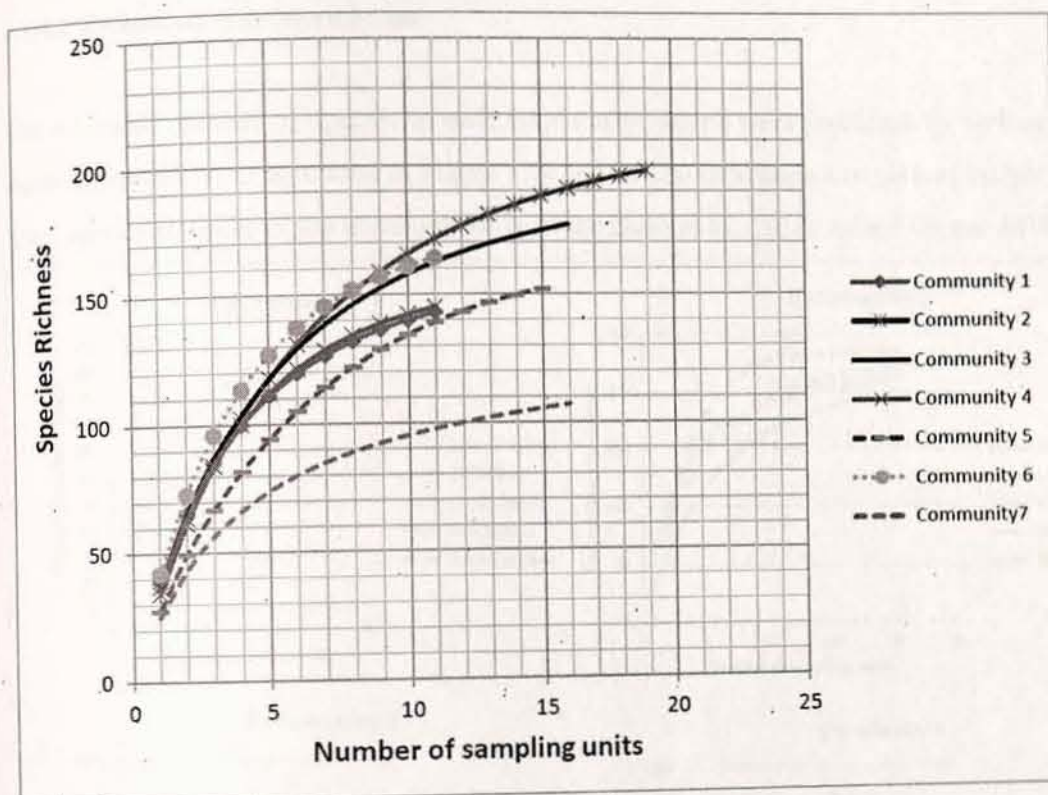


Figure 16: A joint plot of sample-based rarefaction curves of the communities (1-7) showing expected richness as a function of sampling effort. Y-axis represents species richness whereas x-axis represents number of plots studied.

If we compare the species richness of the communities at a point on the rarefaction curve (Figure 16) corresponding to the communities with the lowest number of plots i.e. 11 plots, community 2 had highest species richness (which is about 180 species); whereas community 7 had the lowest species richness (about 100 species). The low species richness of community 7, the afroalpine community, is due to the fact that relatively low numbers of species are capable of coping up the afroalpine environment. Detailed discussion on species species richness controlling variables in the study area is presented in section 4.6.

4.4.4.2 Estimated species richness

The estimated number of species in each community, which were predicted by various species richness estimators, is presented in Figure 17A and B. The estimation can give an insight into the ‘true’ species richness of the communities (e.g. see Duan *et al.*, 2010; Adane Girma, 2011).

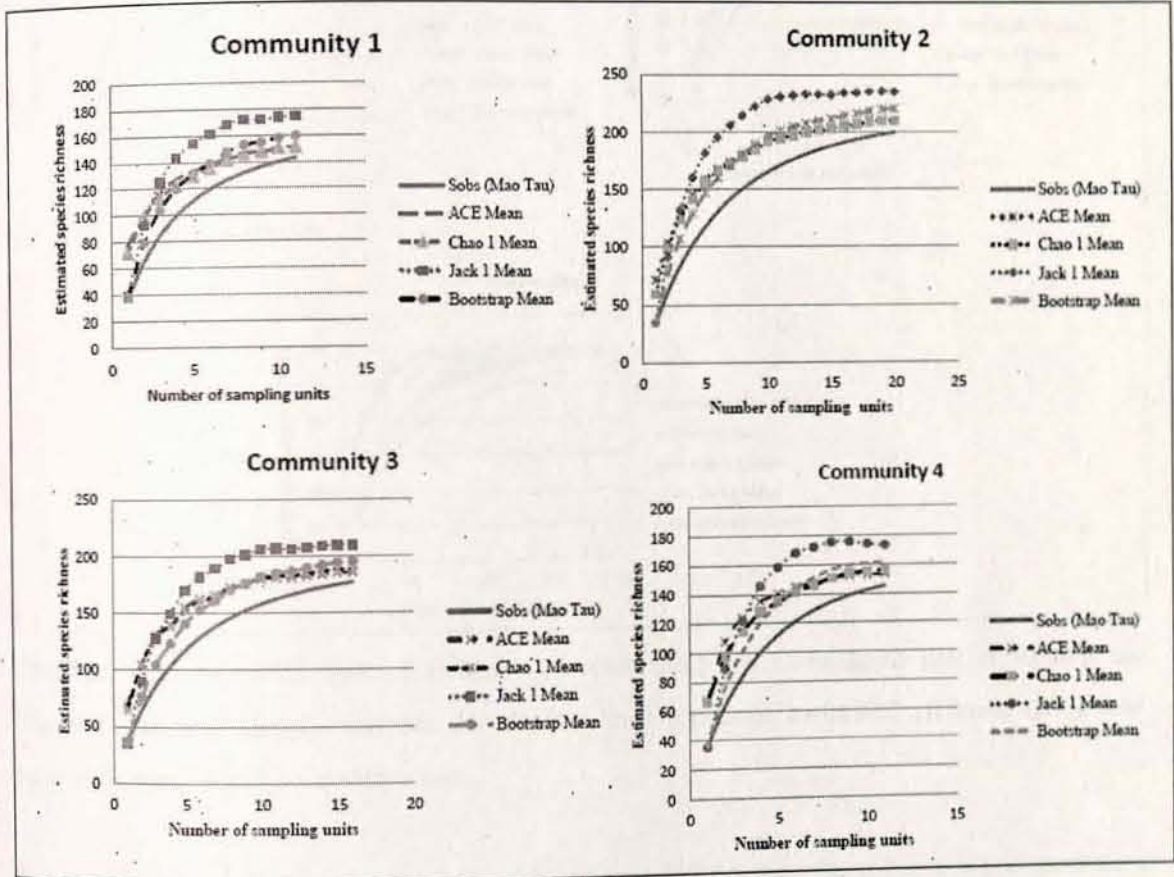
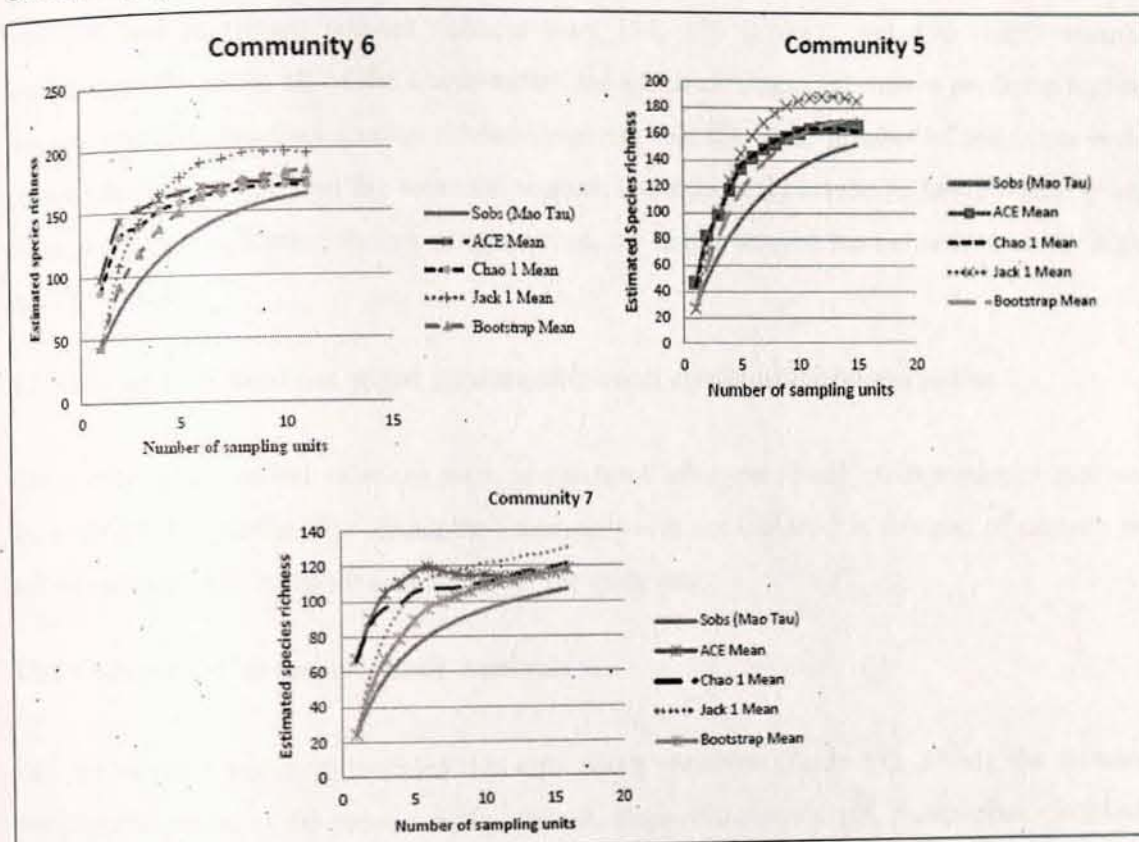


Figure 17: Observed and estimated species richness of community 1-4. The solid line represents the observed richness (Sobs) whereas the dashed lines represent estimated richness using non parametric species richness estimators.

Continued (Figure 17)



Observed and estimated species richness of community 5-7. The solid line represents the observed richness (Sobs) whereas the dashed lines represent estimated richness using non parametric species richness estimators.

In community one, the observed species richness was 143 whereas the minimum and maximum estimated species richness were 151 (ACE mean) and 174 (Jack1 mean), respectively. In community 2, the observed species richness was 200 while the minimum and maximum estimated richness were 210 (ACE mean) and 235 (estimated by Jack1 mean), respectively. The observed species richness, minimum and maximum estimated species richness in community 3 were 177, 186 (ACE mean) and 210 (Jack 1 mean), respectively. In community 4, the observed species richness was 145 whereas the minimum and maximum estimated species richness were 153 (predicted by ACE mean) and 173 (Jack 1 mean), respectively. The observed species richness, minimum and maximum estimated species in community 5 were 152, 162 (predicted by

Chao1 mean) and 285 (Jack1 mean), respectively. In community 6, the observed, the estimated minimum and maximum species richness were 164, 170 (Chao1) and 196 (Jack1 mean), respectively. Hence, in all of the communities, the species richness estimators predicted higher richness than the observed species richness implying that the 'true' number of species in each community was greater than the recorded number. Jackknife predicted the highest richness in all of the communities. Hence, though small patches, the forests studied were characterized by high species richness.

4.5 Relationship between plant communities and environmental variables

Community- environment relations were investigated using canonical correspondence analysis and analysis of variance. The afroalpine community was not included in this part of analysis as soil was not sampled in the afroalpine part of the study area.

4.5.1 Canonical Correspondence Analysis

Stepwise variable selection revealed that only seven variables (Table 14), among the thirteen variables considered in the present study (altitude, slope, disturbance, pH, phosphorus, electrical conductivity, sand, silt, clay, total nitrogen, organic carbon and carbon nitrogen ratio), were significantly related to the vegetation distribution pattern of the study area.

Table 14: Variables having significant relation with plant distribution patterns of the study area (selected through stepwise variable selection procedure). The significance codes in Table 14 are represented as follows: *** 0.01 ** 0.05 .

	Df	AIC	F	Pr(>F)
Altitude	1	394.8	7	0.005 **
Slope	1	397	4.8	0.005 **
Disturbance	1	397	4.6	0.005 **
pH	1	398.9	2.9	0.005**
Clay	1	399.5	2.3	0.005 **
Sand	1	400	1.6	0.032 *
CN(carbon nitrogen ratio)	1	391	1.5	0.038 *

These seven variables were, therefore, used as constraining variables in canonical correspondence analysis. The CCA diagram (Figure 18) shows the relationships between the plant communities in the study area and environmental variables.

CCA Scaling = 1

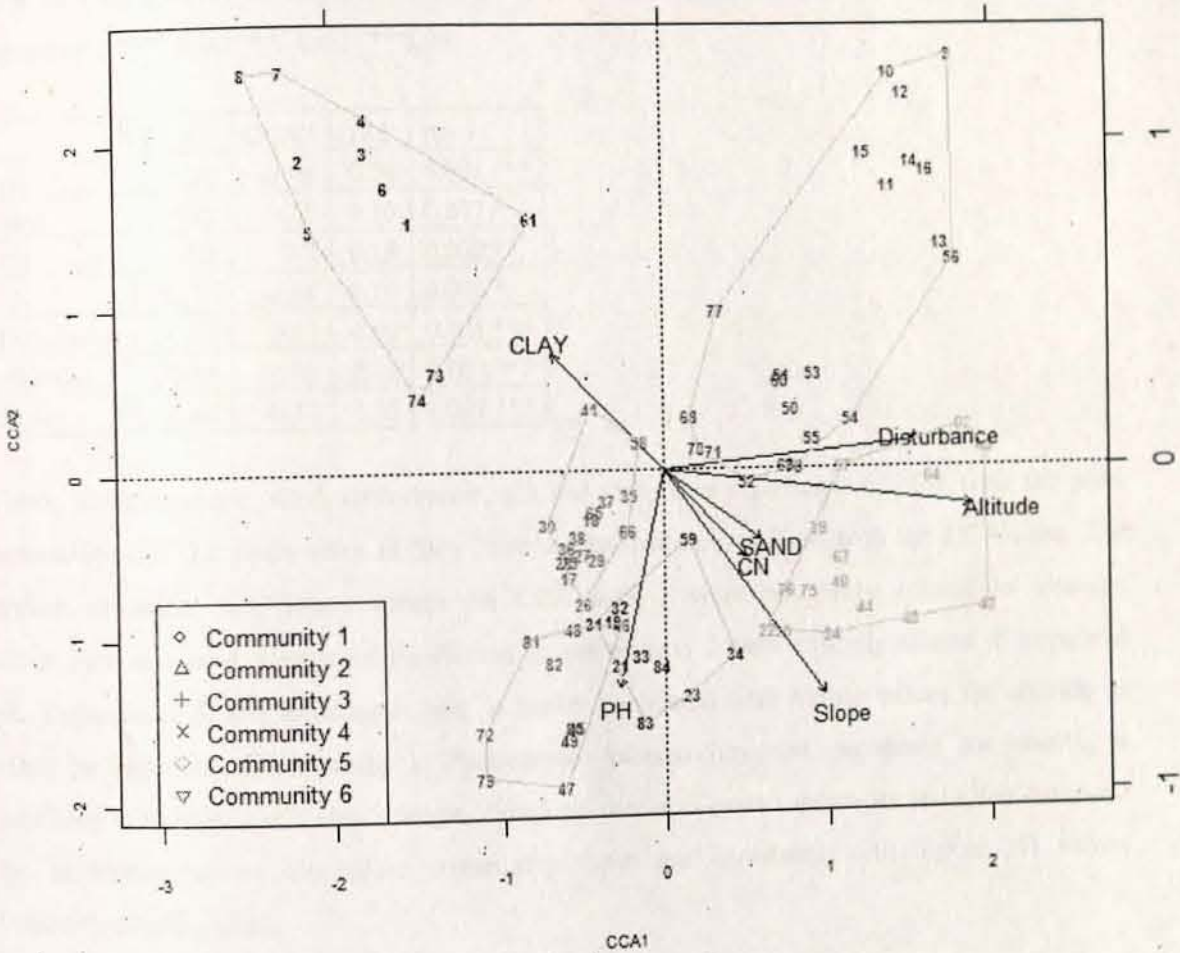


Figure 18: Ordination diagram displaying the first two ordination axes of CCA summarizing direction of influence of environmental variables on the plant communities of the study area. The vectors show direction of influence of the variables.

As can be noted in Figure 18, the configuration of the study plots in the CCA diagram is in agreement with the outputs of the classification. Significant correlation was found between CCA axes and all of the seven environmental variables (altitude, slope, carbon nitrogen ratio, sand,

disturbance, clay and pH) which were selected through stepwise variable selection procedure which is presented in Table 15.

Table 15: Correlation (intraset correlation) between the variables and ordination axes showing how well the species correspond to the measured environmental variables. Significance codes represent: '***' 0.00 '**' 0.01 '*' 0.05 .

	CCA1	CCA2	r ² P	r(>r)
pH	-0.26	-0.96	0.34	0.001 ***
Sand	0.85	-0.5	0.10	0.017 *
Clay	-0.74	0.7	0.18	0.002 **
CN	0.73	-0.68	0.10	0.012 *
Disturbance	0.99	0.11	0.50	0.001 ***
Altitude	0.99	-0.08	0.76	0.001 ***
Slope	0.62	-0.77	0.55	0.001 ***

Hence, altitude, slope, sand, disturbance, pH and clay have significant relation with the plant communities of the study sites as they have a significant correlation with the CCA axes. The highest canonical coefficient scores on CCA axis 1 were positively related to altitude, disturbance and sand. Canonical coefficient scores on axis 2 were strongly related to slope and pH. Community 5, the ericaceous belt, is highly correlated with higher values for altitude as might be expected. Community 1, *Podocarpus falcatus*-*Syzygium guineense* community, is correlated with higher soil clay content. *Dombeya torrida*-*Carissa spinarum* and *Olea europaea* spp *cuspidata*-*Maesa lanceolata* community types are correlated with higher pH values (relatively alkaline soil).

Proportion of Variability Explained by the Constraining Variables

The proportion of variability in the community composition explained the constaining variables in CCA are summarizes as follows:

	Inertia	Rank
Total	7.4	
Constrained	1.0	7

Unconstrained 6.4 76

Eigenvalues for constrained axes:

CCA1	CCA2	CCA3	CCA4	CCA5	CCA6	CCA7
0.27	0.24	0.15	0.12	0.10	0.08	0.07

Partitioning of mean squared contingency coefficient:

	Inertia	Proportion
Total	7.4	1.0
Constrained	1.0	0.16
Unconstrained	6.4	0.84

The CCA output outlined above shows that only 16% of the total variability was captured in the CCA. Since seven environmental variables were used as constraining variables, there were seven constrained eigenvalues. The first CCA axis had an eigenvalue of 0.27 which indicates that about 27 % of the constrained variability explained by this axis which is positively correlated with altitude, disturbance and sand. The second and the third CCA axes accounted for 24% and 15%, respectively of the explained constrained variability. The first two CCA axes accounted for 51% of the constrained variability.

4.5.2 Analysis of Variance

Community-environment relation was also assessed using ANOVA. Boxplots and the concomitant ANOVA tables are presented this section. Note that only environmental variables that have significant difference among community types are presented here. See Annex 4 for ANOVA tables of variables which did not have significant relation with the plant community formations in the study area. The variables that have significant relations with communities in the study area are grouped into three categories: topographic variables, disturbance and edaphic variables.

4.5.2.1 Relation between topographic variables and the plant communities

Figures 19 and 20 show the box plots of altitude and slope, respectively of the six plant communities in the forest patches of the study rea.

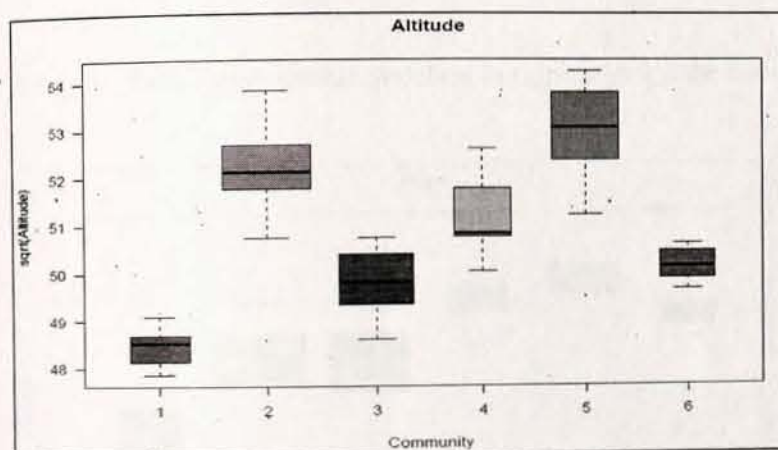


Figure 19: Boxplot of community types vs. altitude. The y-axis represents the square root of the altitude of the plots studied.

Figure 19 shows that there is considerable variation in altitude among the plant communities of the study area. Hence, altitude has considerable relation with plant community formations in the study area. Community 5, the ericaceous community, occurred in relatively higher altitude. Table 16 presents the results of the analysis of variance using altitude as a response.

Table 16: Analysis of variance table (using altitude as response). The significance code '****' represents 0.00.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	1946186	389237	8.785	< 2.2e-16 ***
Residuals	78	385359	4941		

F-value in Table 16 is greater than 1 and p-value is less than 0.05. Hence, the variability between the community means (in altitude) was greater than that we would expect by chance alone. If none of the communities had relation with altitude, then the variation in altitude between plots within a community could be the same as the variation in altitude between plots in different communities and hence F-value could nearly be 1. The implication is that the plant communities in the study area significantly differ in altitude. Pair-wise comparison of mean values of the environmental variables is presented in Annex 5.

Similarly, there was a notable variation in slope amongst the communities (Figure 20).

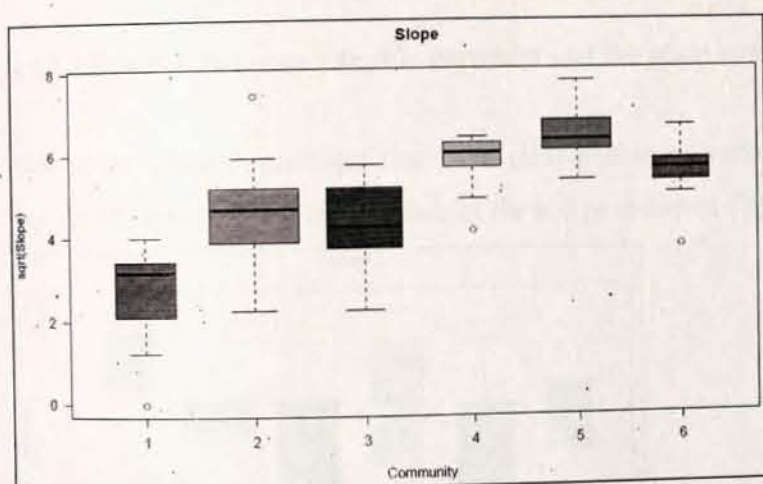


Figure 20: Boxplot of community types vs. steepness slope. The y-axis represents the square root of the slope of the plots studied.

As it is the case for altitude, there is clear pattern of variation in slope among plant communities of the study area implying that slope has a considerable relation with the communities. Community 5, the ericaceous community, occurs in the relatively steep slope of the study area while community 1, *Podocarpus falcatus-Syzygium guineense* community, occurs in relatively gentle slope. The results of analysis of variance using slope as response is presented in Table 17.

Table 17: Analysis of variance table (using slope as a response). The significance code '****' represents 0.00.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	8361	1672.2	2.5	6.6e-14 ***
Residuals	78	5792.3	74.3		

Table 17 shows that F-value is greater than 1 and p-value is less than 0.05 using slope as response. Hence, the variability between the community means (in slope) was greater than the one that might be expected by chance. Hence, the communities were significantly different in slope implying that it has significant relation with plant distribution pattern of the study area.

4.5.2.2 Relation between edaphic variables and the plant communities

One of the edaphic variables that have clear pattern of variation among communities of the Gurage Mountains is the clay content of the soil as shown in Figure 21.

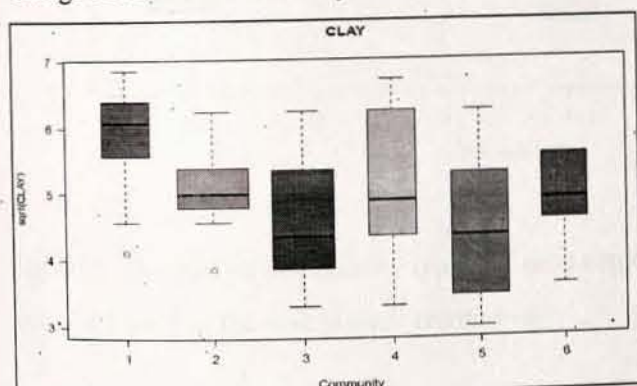


Figure 21: Boxplot of community types vs. clay content of the soil. The y axis represents the square root of the clay content of the soil. The significance of the variation is shown in Table 18.

Table 18: Analysis of variance table using clay as response. The significance code '****' represents 0.00.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	1768	353.6	4.75	0.0007***
Residuals	78	5806	74.4		

Using clay as response, the analysis variance (Table 18) resulted in F-value greater than 1 and p-value less than 0.05. Hence, the variability between the community means (in clay) was greater than that we would expect by chance. The implication is that the clay content of the soil has significant relation with the plant communities of the study area.

The other edaphic variable that has significant difference amongst the communities is the sand content of the soil as shown in Figure 22 and Table 19.

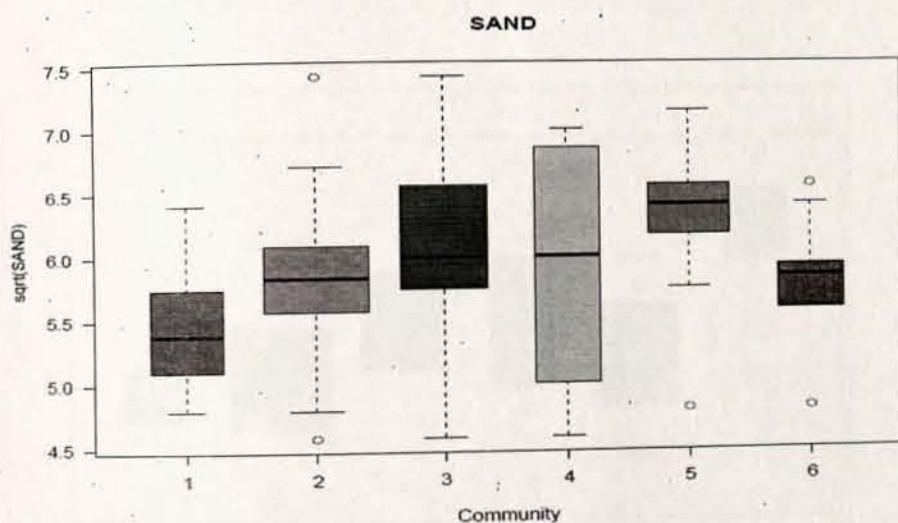


Figure 22: Boxplot of community types vs. sand content of the soil. Y- axis represents the square root of the sand of the soil in each community.

As can be inferred from Figure 22, there is a clear pattern of variation in the sand content of the soil in each community. The significance of the difference is presented in Table 19.

Table 19: Analysis of variance table using sand as response. The significance code '*' represents 0.05.

	Df	Sum Sq	MeanSq	F value	Pr(>F)
as.factor(Community)	5	705	141	2.5	0.04 *
Residuals	78	4394	56.3		

Using sand as response, the analysis variance (Table 19) resulted in F-value greater than 1 and p-value less than 0.05. Hence, the variability between the community means (in sand) was greater than that we would expect by chance. Hence, sand content of the soil has significant relation with plant community formations in the study area.

Clear pattern of variation was also noted in soil pH among the plant communities of the study area as shown in Figure 23.

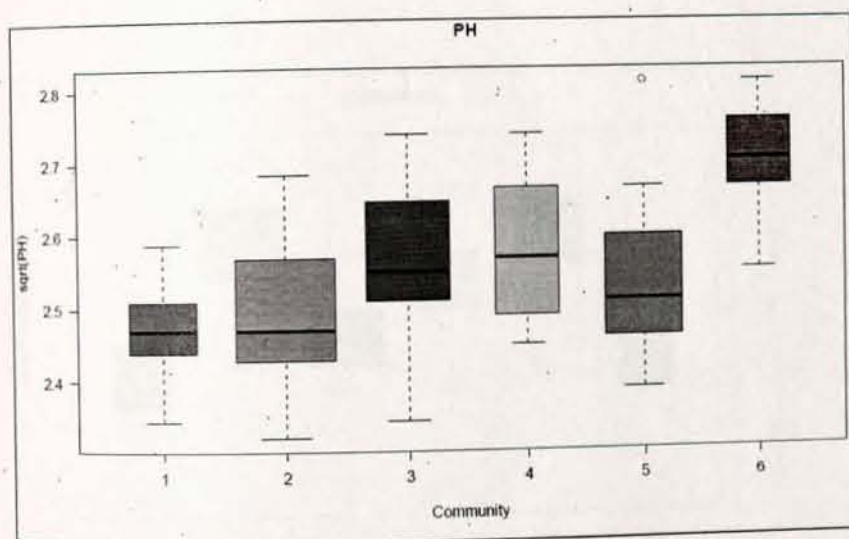


Figure 23: Boxplot of community types vs. pH of the soil. Y- axis represents the square root of the pH of the soil in each community.

The significance of the difference in soil pH between plant communities of the study area is presented in Table 20.

Table 20: Analysis of variance table using soil pH as response. The significance code '****' represents 0.00.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	10.3	2	8.2	2.9e-06 ***
Residuals	78	19.6	0.25		

As can be noted from the ANOVA table (Table 20), there is a significant difference in soil pH between the plant communities of the study area which implies that pH has significant relation with the plant community formations in the Gurage Mountains.

4.5.2.3 Relation between disturbance and the plant communities

As it was the case for edaphic and topographic variables, there was a considerable pattern of variation in disturbance between the plant communities of the Gurage Mountains (Figure 24).

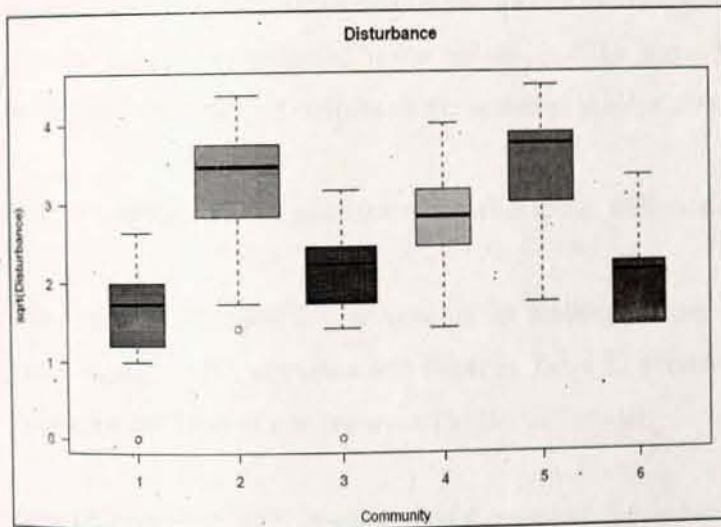


Figure 24: Boxplot of community types vs. disturbance. The y-axis represents the square root of disturbance values.

The significance variation in disturbance between the plant communities of the Gurage Mountains is presented in Table 21.

Table 21: Analysis of variance table using disturbance as response. The significance code '****' represents 0.00

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	1060.7	212	13.6	1.4e-06 ***
Residuals	78	1212.8	15.5		

Using disturbance as response, the analysis variance (Table 21) resulted in F-value greater than 1 and p-value less than 0.05. Hence, the variability between the community means (in disturbance) was greater than that we would expect by chance implying that disturbance has a significant relation with the plant community formations in the Gurage Mountains.

4.6 Relation between environmental variables and species richness

There was considerable variation in species richness across the study sites (see Figure 9). Amongst the predictor variables considered in the present study, a subset of environmental variables with strongest influence on the species richness pattern of the Gurage Mountains were selected through generalized linear modeling. The steps followed in the variable selection process and the resulting outputs of the selection process are discussed below.

Step 1: Addition of one predictor variable to the null model

This step was intended to test how do an addition of one environmental variable to the null model changes AIC, deviance and F-value. Table 22 presents changes in AIC, deviance and F-value upon addition of one parameter to the null model.

Table 22: Change in AIC, Deviance and Corresponding F-values if one variable was added to the null model (**Current model: Species richness ~ +1**). The significance codes in Table 22 are represented as follows: '****' 0.00 '***' 0.05 '.' 0.1 ' ' 1.

Variable added	Df	Deviance	AIC	F value	Pr(F)
Disturbance	1	47.4	503.3	61.7	1.3e-11 ***
Altitude	1	59.8	515.7	31.8	2.3e-07 ***
Slope	1	71.2	527	13.7	0.0004 ***
pH	1	75	531	8.7	0.004 **
Organic carbon	1	80	536	3.2	0.078 .
Carbon nitrogen ratio	1	80.2	536	3	0.085 .
<none>		83	537		
Total nitrogen	1	81	537	1.8	0.17
EC	1	82.6	538.6	0.4	0.51

Phosphorus	1	82.9	538.8	0.14	0.7
Sand	1	83	538.9	0.06	0.8
Clay	1	83.1	538.8	0.02	0.89
Silt	1	83.1	538.8	0.01	0.91

As can be inferred from Table 22, there was significant change in AIC, deviance and corresponding F-values upon addition of some of the environmental variables such as altitude, disturbance, slope and pH to the null model i.e. variables such as altitude, disturbance, slope, and pH had significantly higher F-value at this step.

Smaller AIC shows the better the model. Similarly, smaller deviance indicates a better model. Higher F-value also shows a better model. Given these criteria, addition of disturbance to the null model led to greatest reduction in AIC and deviance as well as a significant increment in F-value. Addition of disturbance parameter resulted in a drop in the AIC from 537 to 503.3, showing that disturbance had strongest influence on the plant species richness of the Gurage Mountains. The significant impact of disturbance on the species richness pattern was also inferred from deviance reduction. The deviance of the null model was 83 whereas the deviance of upon addition of disturbance was 47.4. The fraction of deviance explained by a model with disturbance alone was calculated as follows:

Null deviance = 83

Deviance upon addition of disturbance to the null model = 47.4 = Residual deviance

Fraction of deviance explained by disturbance = $(83-47.4)/83 = 0.43 = 43\%$

This shows 43% of the noted variation in species richness was explained by a model with disturbance i.e. upon addition of disturbance to the null model. This has an important implication for conservation planning. Disturbance minimization should be one of the measures that should be considered for successful vegetation conservation in study area. See section 4.6.1 for further discussion on impact of disturbance on species richness.

As disturbance was the most significant environmental factor influencing the plant species richness of the study area, the selection algorithm was continued with disturbance to identify the second most important variable.

Step 2: Addition of one predictor variable to a model with disturbance

This step was intended to test if there was significant change in AIC, deviance and F values upon addition of one predictor variables to a model with the most significant variable in the preceding step (i.e. disturbance). Changes in AIC, deviance and F-value upon addition of one parameter to a model with disturbance are presented in Table 23.

Table 23: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model with disturbance (**Current Model: Species richness~Disturbance**). The significance codes in Table 23 are represented as follows: '*' 0.01 & ' ' 1.

Variable added	Df	Deviance	AIC	F value	Pr(F)
Altitude	1	44	502	6	0.015 *
<none>		47.4	503.3		
Slope	1	45.9	503.8	2.6	0.1
pH	1	46.5	504.5	1.5	0.22
Organic carbon	1	47	504.59	1.26	0.26
Total nitrogen	1	47	504.74	1	0.32
Carbon nitrogen ratio	1	47	504.82	0.85	0.35
Silt	1	47.2	505.13	0.31	0.57
Electrical conductivity	1	47.3	505.2	0.2	0.65
Phosphorus	1	47.37	505.27	0.08	0.78
Clay	1	47.39	505.29	0.05	0.82
Sand	1	47.4	505.3	0.03	0.85

Table 23 shows a significant change in AIC, deviance and corresponding F-values upon addition of altitude to a model with disturbance i.e. altitude had a significantly higher F-value at this step.

Given AIC and deviance reduction as criteria for measuring goodness of fit, addition altitude to a model with disturbance led to the most optimal model in this step. The addition of altitude resulted in a drop in the AIC from 503.3 to 502, showing a significant relationship between species richness and altitude in addition to disturbance. Deviance reduction also showed the significant impact of altitude on the species richness pattern of the study area. The deviance of the null model is 83 whereas the deviance of upon addition of altitude to a model with disturbance is 44. The fraction of deviance explained by a model comprising both altitude and disturbance was calculated as follows:

Null deviance = 83

Deviance upon addition of altitude to a model with disturbance = 44 = Residual deviance

Fraction of deviance explained by disturbance and altitude = $(83-44)/83 = 0.47 = 47\%$

The main inference from second step was that 47 % of the noted pattern in species richness was explained by a model with disturbance and altitude i.e. upon addition of altitude to a model with disturbance. Hence, altitude was the second most significant environmental factor influencing plant richness in the sites studied. See section 4.6.2 for further discussion on impact of altitude on species richness.

The second step showed that altitude was the second most important variable that had to be added to the optimal model and hence the selection algorithm was continued with disturbance and altitude.

Step 3: Addition of one predictor variable to a model with disturbance and altitude

This step was intended to assess if there was an improvement in AIC, deviance and F values upon addition of one predictor variable to a model with the most significant variables selected in the preceding steps (i.e. disturbance and altitude). Except for pH, Table 24 shows, there was no significant change in AIC, deviance and corresponding F-values upon addition of each of the environmental variables listed in Table 24 to a model with disturbance and altitude.

Table 24: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model with disturbance and altitude (**Model: Species richness~Disturbance+Altitude**). The significance codes in Table 24 are represented as follows: '**' 0.01 & '*' 1.

Variable added	Df	Deviance	AIC	F value	Pr(F)
pH	1	42.2	501.22	4.9	0.02 *
<none>		44	502		
Organic carbon	1	45.8	505.7	1.3	0.25
Slope	1	45.8	505.75	1.2	0.26
Total nitrogen	1	45.9	505.8	1.16	0.28
Carbon nitrogen ratio	1	46.2	506.07	0.68	0.4
Eelectrical conductivity	1	46.4	506.29	0.29	0.58
Silt	1	46.4	506.3	0.28	0.59
Clay	1	46.47	506.37	0.16	0.68
Phosphorus	1	46.54	506.44	0.05	0.81
Sand	1	46.57	506.47	0.004	0.94

Using AIC and deviance reduction as criteria for measuring goodness of fit, addition pH to a model with disturbance and altitude led to a relatively better/optimal model in this step. Addition of pH resulted in a drop in the AIC from 502 to 501.22 and a reduction in deviance from 44 to 42.2 as shown in Table 23. The deviance of the null model was 83 whereas the deviance of upon addition of pH to a model with disturbance and altitude was 42.2. The fraction of deviance explained by a model comprising disturbance, altitude and pH was calculated as follows:

Null deviance = 83

Deviance upon addition of pH to a model with disturbance and altitude = 42.2 = Residual deviance

Fraction of deviance explained by disturbance, altitude and pH = $(83-42.2)/83 = 0.49 = 49\%$

Hence, 49% of the variation in species richness pattern in the Gurage Mountains was explained by a model with disturbance, altitude and pH i.e. upon addition of pH to a model with disturbance and altitude. This step showed that pH was the other variable that had to be added to the model. The selection was continued with disturbance, altitude and pH in the next step.

Step-4: Addition of one predictor variable to a model with disturbance, altitude and pH

In this step, the significance of changes AIC, deviance and F values upon addition of one predictor variable to a model with the most significant variables selected in the preceding steps (disturbance, altitude and pH) was assessed and the output is presented in Table 25.

Table 25: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model with disturbance, altitude and pH (Model: Species.richness~Disturbance+Altitude+pH). The significance codes in Table 25 are represented as follows: '*' 0.05 & ' ' 1.

	Df	Deviance	AIC	F value	Pr(F)
Slope	1	39	500.96	4	0.046 *
<none>		42.2	501.22		
Carbon nitrogen ratio	1	40.8	504.7	0.6	0.43
Clay	1	40.90	504.8	0.39	0.53
Electrical conductivity	1	40.91	504.81	0.38	0.54
Silt	1	40.94	504.84	0.33	0.56
Total nitrogen	1	40.95	504.85	0.31	0.57
Phosphorus	1	41.06	504.96	0.1	0.74
Sand	1	41.09	504.99	0.03	0.84

The addition of slope resulted in a drop in the AIC from 501.22 to 500.96 and a reduction in deviance from 42.2 to 39 as shown in Table 25. The deviance of the null model was 83 whereas the deviance of upon addition of slope to a model with disturbance, altitude and pH was 39. The fraction of deviance explained by a model comprising disturbance, altitude and pH was calculated as follows:

Null deviance = 83

Deviance upon addition of slope to a model with disturbance, altitude and pH = 39 = Residual deviance

Fraction of deviance explained by disturbance, altitude, pH and slope is = $(83-39)/83 = 0.53 = 53\%$. This implies that 53% of the variation in species richness pattern of the Gurage Mountains was explained by a model with disturbance, altitude, pH and slope. Hence, the selection was continued with disturbance, altitude, pH and slope in the next step.

Step-5: Addition of one predictor variable to a model with disturbance, altitude, pH and slope

In this step, the significance of changes AIC, deviance and F values upon addition of one predictor variable to a model with the most significant variables selected in the preceding steps (disturbance, altitude, pH and slope) was assessed and the output is presented in Table 26.

Table 26: Change in AIC, Deviance and Corresponding F-values if one variable was added to a model with disturbance, altitude, pH and slope (**Model: Species.richness~Disturbance+Altitude+pH+Slope**). The significance codes ‘.’ represents 1.

Variable added	Df	Deviance	AIC	F value	Pr(F)
<none>		39	500.96		
Carbon nitrogen ratio	1	38.7	504.64	0.63	0.42
Electrical conductivity	1	38.82	504.72	0.48	0.48
Total nitrogen	1	38.90	504.8	0.32	0.56
Silt	1	38.98	504.88	0.17	0.68
Clay	1	38.98	504.88	0.16	0.69
Sand	1	39.06	504.96	0.007	0.93
Phosphorus	1	39.06	504.96	0.002	0.96

Table 26 shows that the current model, the model with disturbance+altitude+pH+slope (<none>), was the most optimal model as it had lowest AIC. The resulting optimal generalized linear model had only four environmental variables namely disturbance, altitude, pH and slope. Further model specifications, as shown in Table 26, led to an increase in AIC values indicating a reduced fit.

Besides, addition of other environmental variables (listed in Table 26) did not lead to significant improvement in F-values. Hence, the stepping should be stopped at this step i.e. when <none> or the current model was at the top. A predictor variable need not be added to the model if it does not have a statistically significant effect on the response variable. That is, if in the presence of the other variables already in the model, there is no statistically significant relationship between the response variable and the next variable to be added, addition of new predictor variables should be stopped. The selection procedure is stopped when the p-value for the F level is greater than some fixed level; often, the fixed level is taken to be 0.05 (van Belle *et al.*, 2004). Note that all of the variables in Table 26 have p-value greater than 0.05.

It is to be recalled that the steps 1- 5 were intended to select a simple model so that a subset of variables with strong influence on species richness pattern of the study area were recognized. Hence, stopping the stepping at this step yielded a parsimonious model and avoided overparameterization. In other words, the variables listed in Table 26 did not lead to significant reduction in AIC and hence these variables need not be included in the optimal model. Thus, disturbance, altitude, pH and slope were the subset of variables amongst the variables considered in the present study that significantly explained the variation in the species richness pattern of the study sites. This variable reduction is based on *Occam's razor* principle (principle of parsimony) which states that hypotheses need not be multiplied beyond necessity (Brocque and Buckney, 2003; van Belle *et al.*, 2004).

The optimal model, which comprises only four of the measured environmental variables for purpose of this study (disturbance, altitude, pH and slope), explained only 53 % of the deviance (variation) in species richness of the Gurage Mountains. This would not be surprising since there are many factors that can govern species richness other than the variables measured for purpose of the present study. For instance species richness can be governed, among other things, by climatic variables (Pausas and Austin, 2001; Gentry, 1988; O'Brien, 1993) by local biotic interactions such as competition (Brown and Lomolino, 1998; Pausas and Austin, 2001). If such variables were considered, the explained variability could be greater than the amount explained by the optimal model.

4.6.1 Relation between disturbance and plant species richness

Generalized linear modeling revealed that disturbance is one of the most important factors that govern patterns of plant species richness in the Gurage Mountains (Table 22). The scatter diagram of disturbance and species richness is shown in Figure 25.

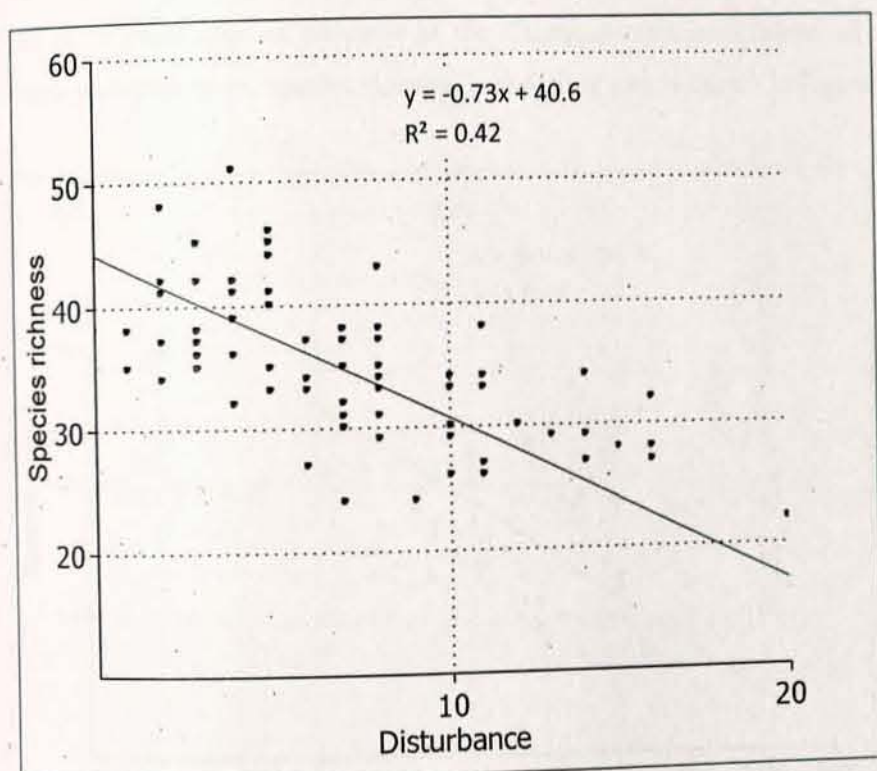


Figure 25: Disturbance vs. species richness pattern in the study area. The direction of the regression line suggests that there is a negative relationship between species richness and disturbance. The small dots represent the plots studied.

Figure 25 shows that there is a steady decrease in species richness with intensification of disturbance in the study sites. This finding has an important implication for vegetation conservation in the study area. Since disturbance was found to be one of the most important factor influencing the pattern of species richness pattern in the Gurage Mountains, conservation

planning in the study area should take disturbance mitigation as main conservation intervention strategy.

4.6.2 Relation between altitude and plant species richness

Generalized modeling showed that altitude is the second most important factor influencing the pattern of plant species richness in the Gurage Mountains (Tables 22 and 23). The scatter diagram of altitude vs. species richness in the study area is shown in Figure 26.

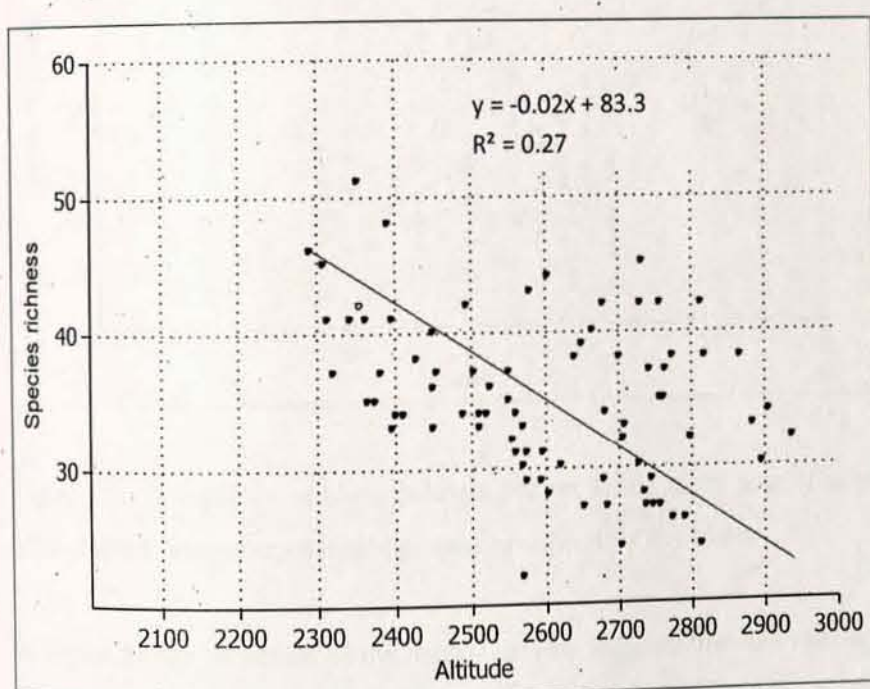


Figure 26: Altitude vs. species richness pattern in the study area. The direction of the regression line suggests there was a negative relationship between richness and altitude. The small dots represent the plots studied.

Figure 26 shows that there is reduction in species richness in the Gurage Mountains with increase in altitude.

4.6.3 Relation between pH and species richness

Generalized linear modeling revealed that soil pH is one of the variables with significant relation to the patterns of variation in species richness in the study sites. Figure 27 shows the relationship between species richness and soil pH in the study area.

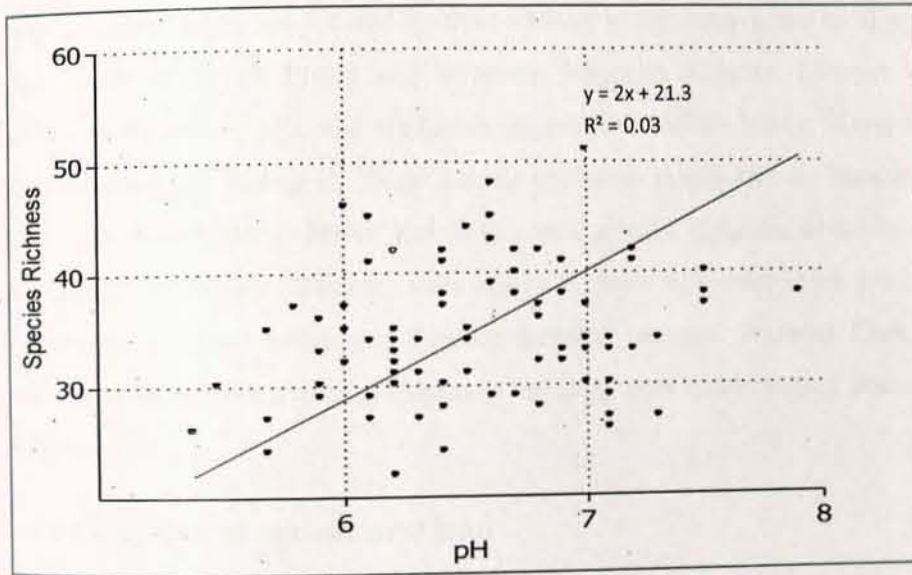


Figure 27: Soil pH vs. species richness pattern in the study area. The small dots represent the plots studied. Y-axis represents the species richness of the plots.

In Figure 27, the direction of the regression line suggests that low species richness was recorded in plots with relatively low soil pH.

4.7 Causes of forest loss and degradation in the study area

From focus group discussions with farmers in the study area, five main causal factors of forest loss and degradation were identified in the study area: expansion of agricultural land, high population growth, wood extraction, grazing and institutional weaknesses. The study also revealed various agents of deforestation and forest degradation in the study area that include farmers whose farms are located in close vicinity to the forests, the local government officials (specifically in Mirab Imbor and Meserete Wegeram Kebeles, Mesqan Wereda), firewood collectors and sellers, charcoal producers (especially in Mirab Imbor, Meserete Wegeram, Dobi, Zemute and Arusi Kebeles), illegal timber producers (especially in Meserete Wegeram, Dega Gogot, Dobi and Mirab Imbor Kebeles), cattle owners (specific to Koter Gedra and Anzire Kebeles) and outsiders (residents from nearby Kebeles who steal forest products as reported by respondents in Mirab Imbor and Yetebon Kebeles, Mesqan Wereda). Each of the factors that account for forest loss and degradation in the study sites is thoroughly discussed in subsections 4.7.1 to 4.7.5.

4.7.1 Expansion of agricultural land

During field observations it was noted that most of the study sites, except for study sites in Mohir and Ezha Weredas, are found in areas that are topographically not conducive for agriculture. However, due to pressing demand for agricultural land, the focus group discussion revealed, there has been gradual encroachment to forest lands and areas which were previously considered as hardly conducive for agriculture. Thus, clearing forest lands or exploitation of forests for agricultural expansion was reported as one of the principal causes of forest loss in the study sites. Data from central statistical agency of Ethiopia (Figure 28) and field observations (Figures 29 and 30) also verified the pressing demand for agricultural land in the study area. Furthermore, deliberate forest fire by farmers to defend crops from wild animals was reported during focus group discussions in Arusi, Zemute, Mirab Imbor, Meserete Wegeram and Dobi which also indicate the impact of subsistence agriculture on the remnant forest patches of the study area. Figure 28A and B shows an increasing demand for agricultural land in the study area while Figures 29 and 30 show expansion of agricultural land into forests.

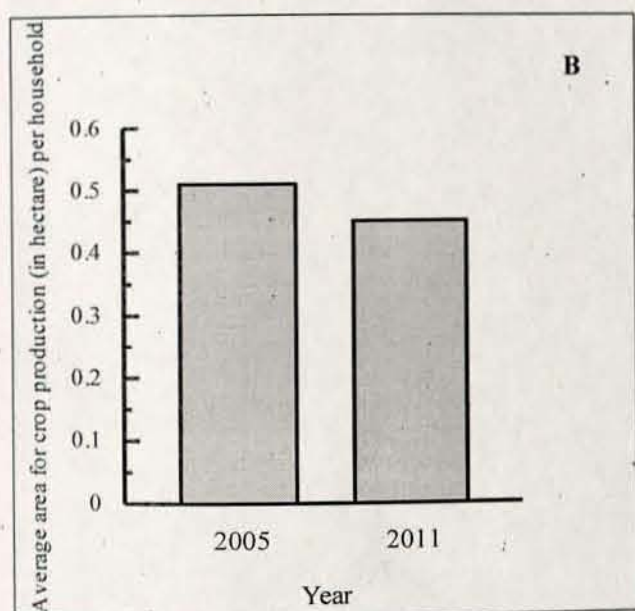
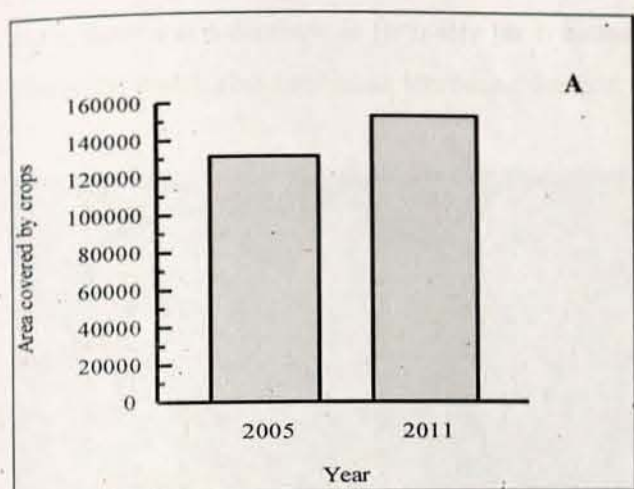


Figure 28: The gradual increase in agricultural land demand in the study area. A) shows gradual increase in the area covered by crops in the Gurage Zone while B) shows gradual decrease in farm size per household from year 2005 to 2011 (Data source: CSA, 2005, 2011a).

Though there was an increase area covered by crops from 2005 to 2011, Figure 28 A and B show, there was a decrease in farm size per household that may be due population pressure (see Figure 29) which also implies an increasing demand for agricultural land in the study area.



Figure 29: Agricultural land expansion into Zemute forest, Sodo Wereda.



Figure 30: Forest in Mirab Imbor (Mesqan Wereda) but now converted to agricultural land (Figure 30 A and B).

The areas shown in Figure 30A and B were given to unemployed youth by the local administrators. This state-led encroachment took place in very steep slope which is highly prone to soil erosion. Obviously, the unemployed deserve attention and the state should facilitate ways that enable them to be economically self sufficient. This, however, should not be done at the expense of biodiversity.

4.8.2 High population pressure

During focus group discussions, the respondents asserted that there has been an increasing demand for agricultural land in the study area as human population number has been increasing. Similarly, data from Central Statistical Agency of Ethiopia (Figure 31) verified that there has been a high population growth in the study area. According to CSA (2007), the rural total fertility rate in Gurage zone was 3.86. With increase in population, demand for agricultural land definitely increases as more food production is needed. Forested lands, the respondents reported, were the prime candidates for encroachment especially by those who have agricultural land in close proximity to the forest land. An important remark by a respondent in one of the study sites, i.e. Mirab Imbor, may sufficiently explain how population growth led to high demand for agricultural land and consequent encroachment into forest land. *"I got nearly a hectare of agricultural land from my father. Now I have seven children of whom five are males. Two of my male children already married and are sharing the land that I got from my father. How can a hectare of land support such an extended family?"* Many of the farmers in the study area may have a similar challenge. Hence, unless the productivity of their agricultural land is improved, the farmers may not stop scrambling for forest land as there is critical demand for increased food production to feed the ever increasing human population.

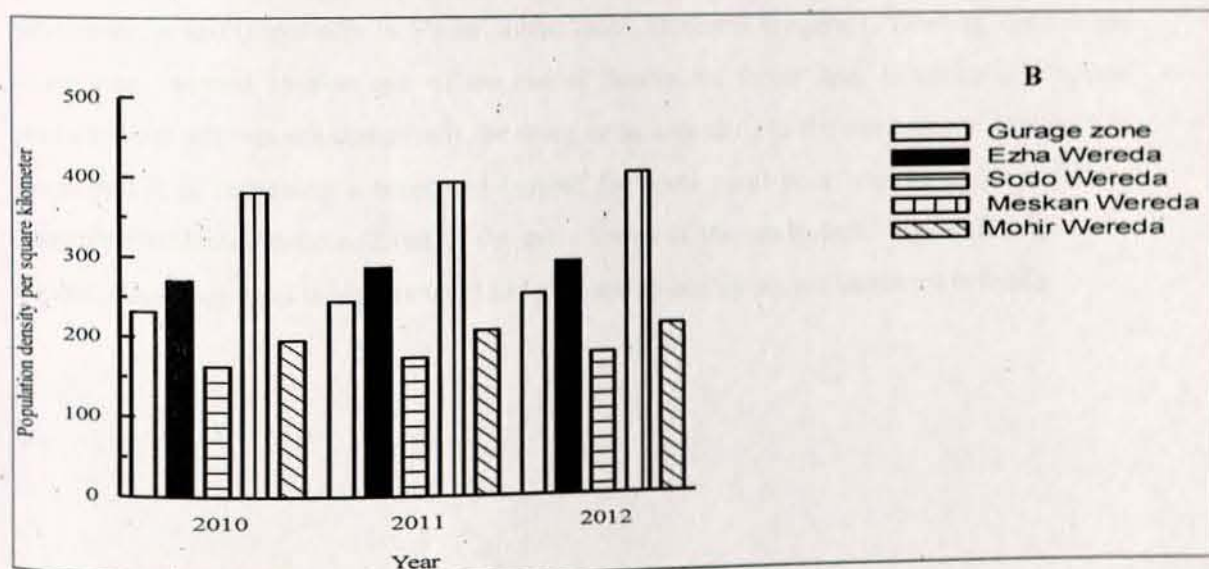
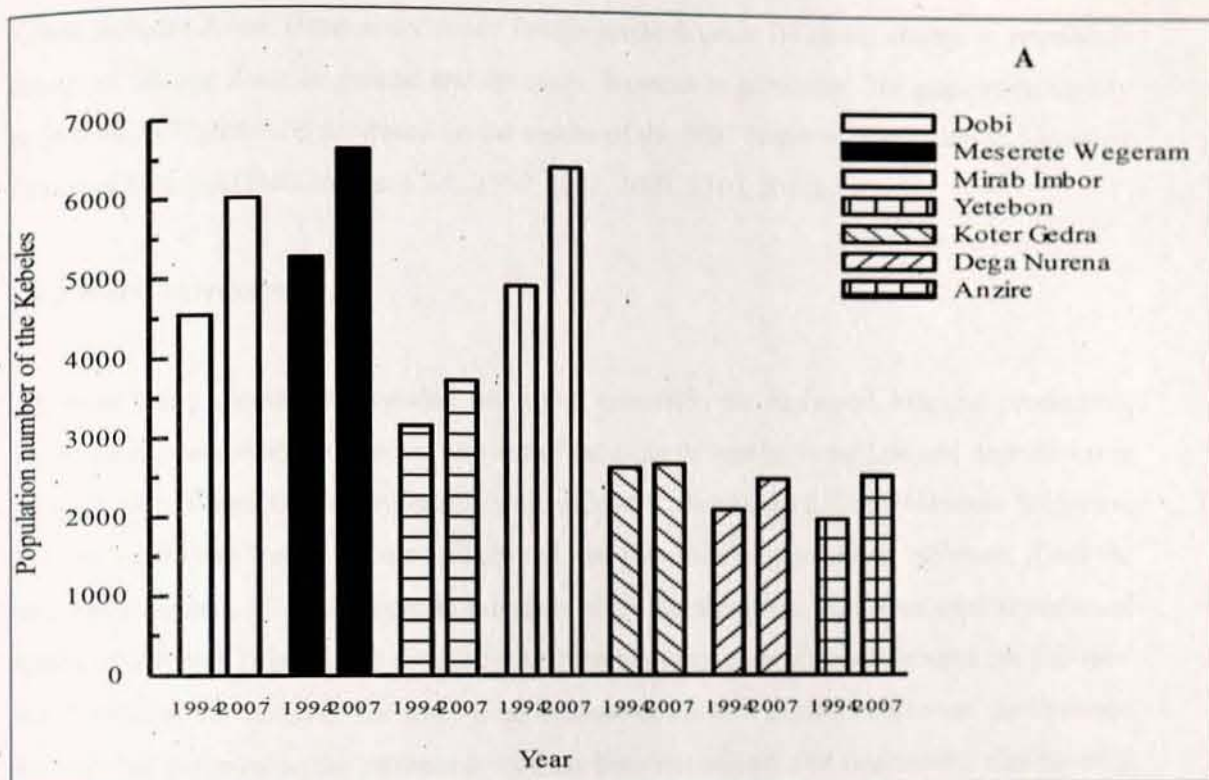


Figure 31: The gradual increase in population number of the study area. A) shows change in population number in some of the Kebeles studied from 1994 to 2007 (Note that Dega Nurena

Kebele includes Arusi, Burat and Zemute forests patches) while B) shows change in population density of Gurage Zone in general and the study Weredas in particular. The population density projections in Figure 32B are based on the results of the 2007 National population and Housing Census of Ethiopia (Data source: CSA, 1996, 2007, 2009, 2010, 2011b).

4.7.3 Wood extraction

The focus group discussion revealed that wood extraction for fuelwood, charcoal production, construction, and timber production was one of the main drivers of forest loss and degradation in the study sites. Illegal timber production was reported in Dega Gogot, Dobi, Meserete Wegeram, Ytebon and Mirab Imbor Kebeles. Fuelwood, the respondents asserted, is the main, if not the sole, energy source for the people in the study sites. Furthermore, data from central statistical agency of Ethiopia (Figure 32) revealed that there has been an increasing demand for firewood and charcoal in the towns of the study area. Because of the ever escalating demand for firewood and charcoal, pressure on the remnant forests has been intensified. The respondents also reported that there is a severe shortage of fuelwood right now as a result of forest destruction. Charcoal production for sell (especially in Mirab Imbor, Dobi, Meserete Wegeram, Ytebon, Zemute and Arusi) was reported as also one of the causal factors for forest loss. Historically, charcoal production for sell was not common in the study areas according to the respondents. However, in recent past it is becoming a source of income for some rural poor who have no or limited alternative livelihood source. Even in the main towns of the study area, Figure 32 shows, the number of housing units using firewood and charcoal as energy source increased radically.

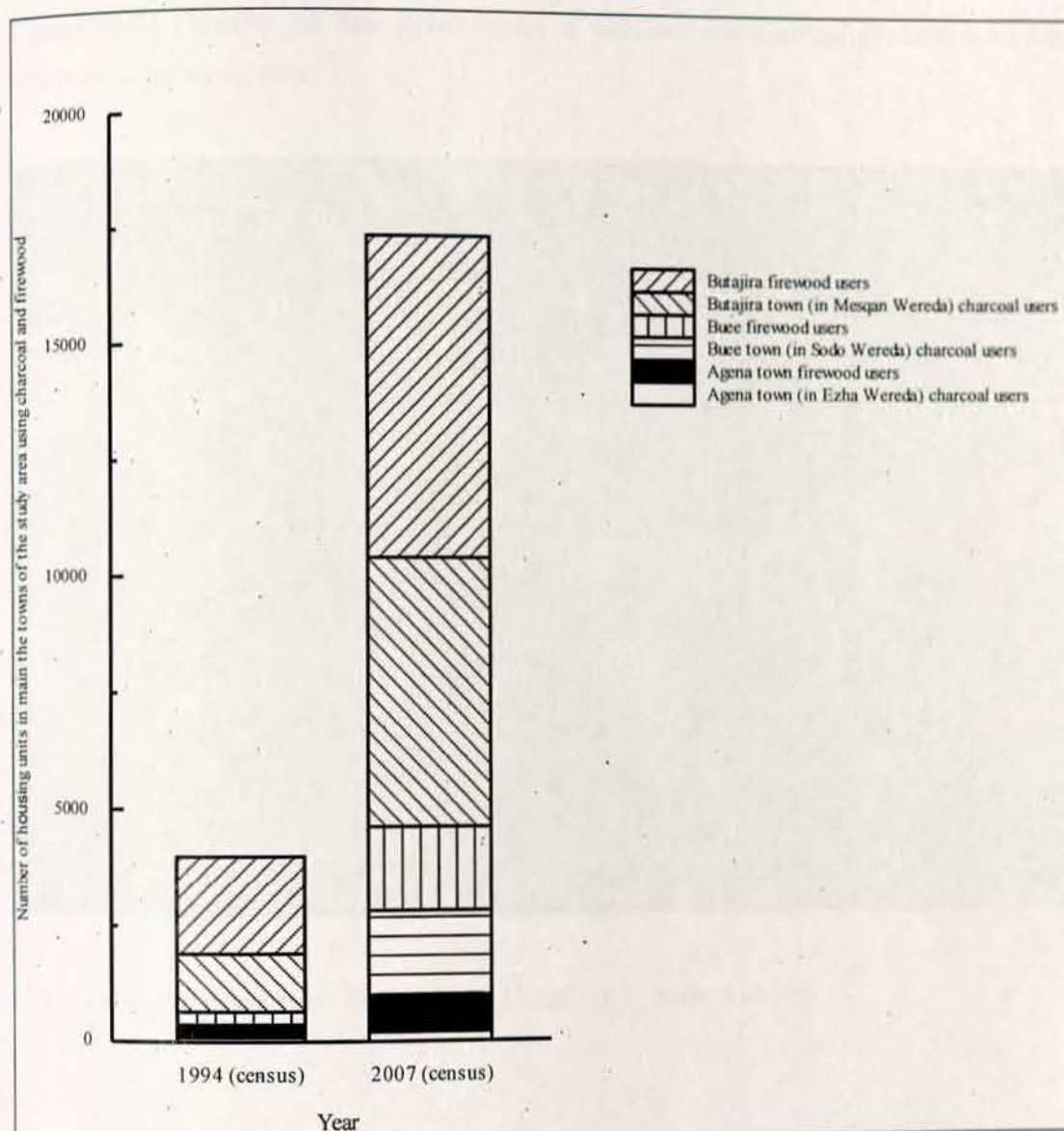


Figure 32: The number housing units in the main towns of the study area and the type of fuels used for cooking (Data source: CSA, 1996, 2007).

Note that CSA (2007) defined a housing unit as a separate and independent place of residence, either intended for habitation or not intended for habitation but occupied as a living quarter by a household at the time of the census and it may at the time of the census be occupied by one or more households.

Figures 33-35 illustrate the destructive impact of fuelwood and charcoal production on forest resources in the study sites.

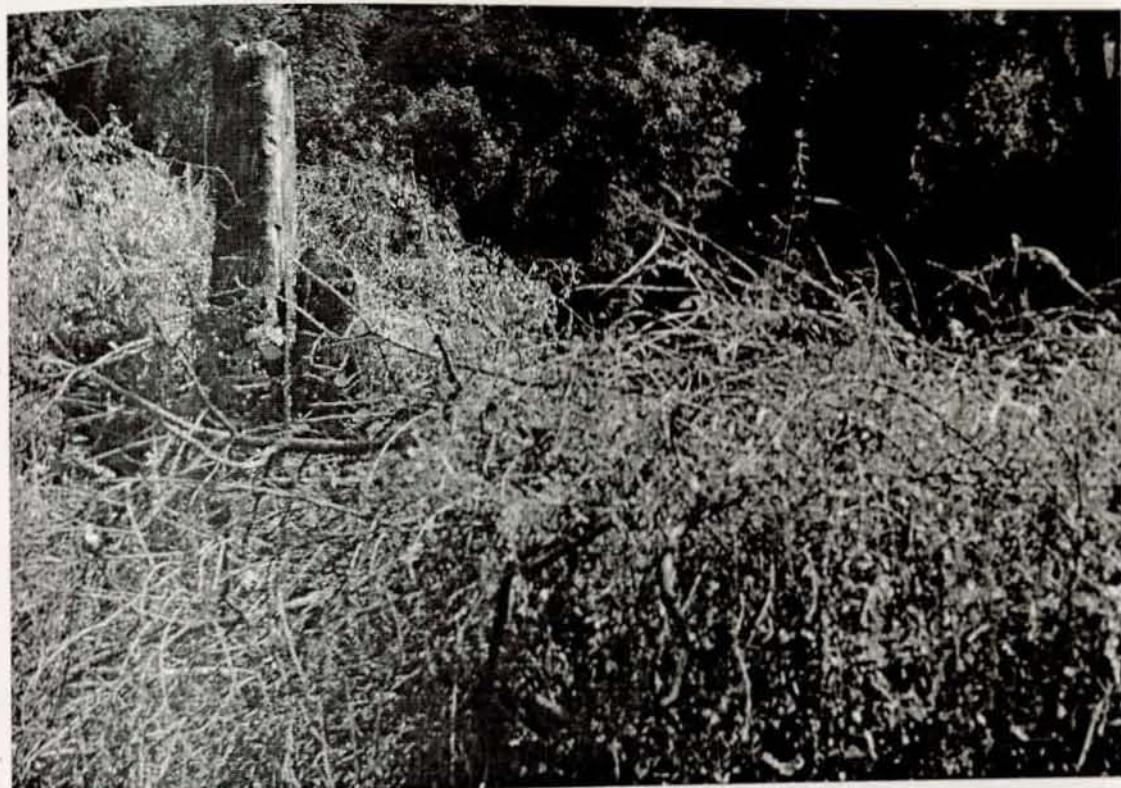


Figure 33: Forest destruction for fuel wood (Arusi forest, Sodo *Wereda*)

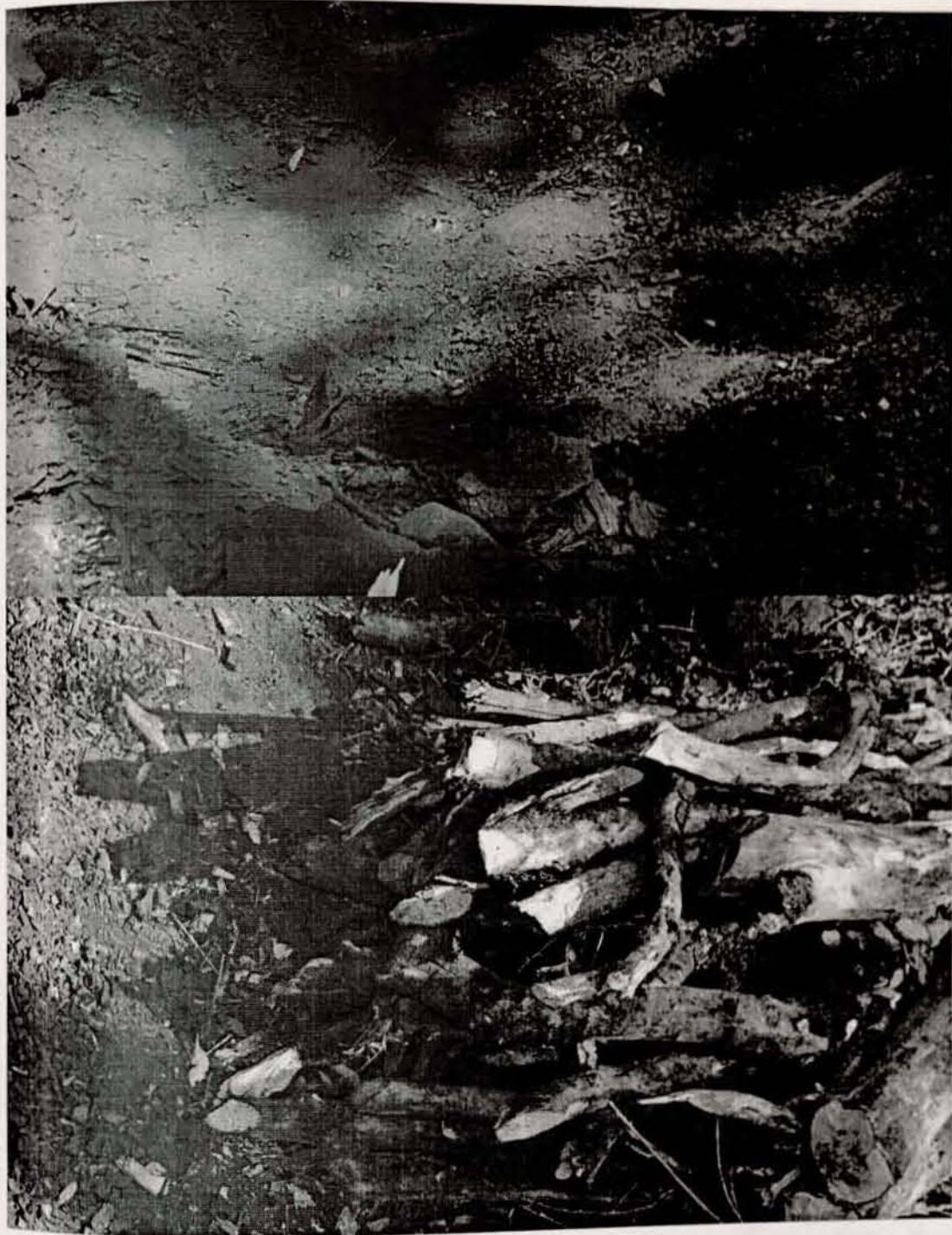


Figure 34: Forest destruction for charcoal production (Zemute forest, Sodo Wereda)



Figure 35: Fuelwood sellers (Mirab Imbor, Mesqan Wereda)

4.7.4 Institutional drivers

Historically, the focus group discussion revealed, local institutions such as 'Shengo'¹, 'Edir'² and tribal /communal leaderships played important roles in determining access to and use of forest resources in the study sites. Forest use, the respondents reported, was mainly based on communal agreement. The traditional institutions regulated access to forest resources for local livelihoods. Relatively better organized customary institutions have been practiced in Koter Gedra, Meserete Wegeram and Dega Gogot whereby tribal/communal leaders used to decide on: Which forest products should be used? What sanctions has to be implemented on those who may defy the customary rules? Who should access the resource? Guided by the customary rules and

¹ Shengo-elected community leaders; especially during the reign of Hailesilasie and the institution was effective in Meserete Wegeram, Dega gogot, Yetebon, Dobi

² Edir-is a social cooperation scheme to mourning families, helpless and members of the community facing any accidental hardship.

regulations, the respondents reported, permissible forest uses include extraction of construction wood for needy and those who may lose their house by accidental fire; for church construction, fuelwood and grazing. Defiance to customary communal agreements /e.g. *yedebo simiminet*/ would lead to curse and ban from social cooperation schemes such as 'Edir'. There was a belief that the curse can lead to bad luck and many other abnormalities in one's personal life. Hence, the traditional institutions in the study area played an important role in sustaining the forest to the present date though their current effectiveness is jeopardized. This is consistent with Gautam and Shivakoti's (2005) argument that resource users may create institutional arrangements that shape interactions among community members and the resource, which helps them to protect their resources.

The Federal proclamation on forest development, conservation and utilization, i.e. Federal Negarit Gazeta of the Federal Democratic Republic of Ethiopia (2007), stipulates two types of forest ownership: state and private forest ownership. Similarly, Debub Negarit Gazeta of the Southern Nations, Nationalities and Peoples' Regional State (2004) proclaims that there are two types of forest ownership in the region: state owned forest and private forest. State owned forest, according to the proclamations, is a forest in a given area that is not private, developed naturally or artificially by the region and described as state-owned forest by the region's official news paper. Private forest means forest developed by any person or group of persons organized under Kebele administration or association. Hence, the natural forests in the region are 'owned' by the state. However, the forest patches in the study sites were not registered /named as state forest though they are naturally developed forests. Besides, the state did not introduce an effective mechanism to halt unsustainable forest use. These imply that the forests studied are akin to open access resources.

There was no clear and consistent understanding among respondents with regard to the ownership of the forest patches in their vicinity. When asked 'who owns the forest?' some of respondents reported that the forest patches are owned by state /*yemengist dibir*/. Others believed that the forests in their environs are communal forests /*yemaber dibir*/. Lack of clear understanding on the ownership of the forests, as we have seen earlier, can have huge impact on

the remnant forest resources as it may foster free rider dilemma. The respondents also reported that in some cases the local administrators (Kebele leaders) believe that they are the sole custodians of the remnant forest patches and fail to appreciate the role of customary institutions for forest conservation.

Ethiopia mainly adopted the command and control system in the past i.e. during the Derge regime (Melaku Bekele, 2003). Nevertheless, in the recent past, efforts have been advanced in formulating biodiversity conservation strategies and action plans in general and in particular forestry action plans aimed at improving local community participation in forest conservation (Mogaka *et al.*, 2001). For example, Federal and Regional proclamations on forest management, development and utilization i.e. Federal Negarit Gazeta of the Federal Democratic Republic of Ethiopia (2007) and Debub Negarit Gazeta of the Southern Nations, Nationalities and Peoples' Regional State (2004) have several provisions in line with collaborative/participatory forest management paradigm:

- Debub Negarit Gazeta of the Southern Nations, Nationalities and Peoples' Regional State (2004) proclaims the need for local participation to realize the sustainable forest management. It states *"the participation of the public is indispensable to equally utilize the income earned from forest resources and preserve the resources for posterity"*. This proclamation also has the following provisions for popular participation: *The local people should directly participate in identifying the problems associated with afforestation as well as in forest conservation and development and the preparation of relevant plans 11 (1). The necessary support shall be rendered to maintain the local inhabitants' awareness (indigenous knowledge) on the forest and environmental conservation 11(2).*
- Similarly, Federal Negarit Gazeta of the Federal Democratic Republic of Ethiopia (2007) stipulates that the sustainable utilization of the country's forest resource is possible through ensuring the participation of and benefit sharing by the concerned communities. *Forest development, conservation and utilization plans shall be formulated to allow the participation of the local communities in the development and conservation and also in sharing of benefits from the development of state forests 9 (3).*

Thus, there are important provisions in the proclamations in conformity with the collaborative forest management paradigm. Nevertheless, the provisions were not enforced. Hence, there should be a genuine endeavor for the implementation of the proclamations in order to ensure sustainable management of the forest resources. The proclamations could be considered as an enabling policy environment for non state development actors such as NGOs and the local people to take part in conservation of the forest patches.

4.8.5 Grazing

Grazing was one of the drivers for vegetation degradation in the study sites. It was found to be destructive in Koter Gedra (Ezha Wereda) and Anzre (Mohir Wereda) where it led to very poor under storey growth and development. The destructive effect of grazing in the study sites can be due to the fact that it has been practiced in uncontrolled way.

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion

The vegetation of Gurage Mountains is characterized by high floristic diversity. Most of the plants encountered in the study were herbs. Epiphytes were least represented in the flora of the Gurage Mountains. Anthropogenic disturbance might have contributed to the least representation of epiphytes. Diversity and abundance of epiphytes are recognized as an indicator of disturbance trends in tropical montane rainforests (Barthlott *et al.*, 2001). The Gurage Mountains comprise considerable number of plants endemic to Ethiopia and most of the endemic plants were recorded in the afroalpine community of the study area. Various reasons are forwarded for high endemism of flora at high mountains. For instance, Hedberg (1970) argued that the afroalpine flora inhabits a number of geographically and ecologically isolated "islands". The afroalpine habitats are considered as islands because the montane forests and the savanna vegetation separate the high mountain enclaves from each other (Hedberg, 1970). Thus, geographical and ecological isolations are considered as the main reasons for the endemism of flora at high mountains (Kruckeberg and Rabinowitz, 1985; Giménez *et al.*, 2004). The isolation of these high mountains provides unique opportunities for studying evolutionary phenomena, that is, speciation relating to geographical isolation and adaptation to extreme environmental conditions (Hedberg, 1975).

There was an increase in the number of species encountered as larger geographic areas were considered in the present study. One of the possible reasons for increase in number of species with an increase in area considered is that larger areas are likely to include a greater number of habitat types or ecoregions, each with its own unique or partially distinct biota (Colwell, 2009a). The species abundance distribution pattern in the study sites is characterized by high dominance of some of the plant species since the rank abundance plot is somewhat steep as shown in Figure 7. The inference is based on Magurran (2004) who proclaimed that steep rank abundance plots indicate assemblages with high dominance while shallower slopes imply higher evenness.

As it is the case for the other afromontane forests of Ethiopia, the woody plants of higher height classes are less represented in the population structure of the forest patches of the Gurage Mountains. Selective exploitation of trees with higher height class may have contributed to the less representation those trees in the afromontane forests of Ethiopia. Such a pattern was also reported in wet afromontane forests of Ethiopia (e.g. Feyera Senbeta, 2006). The selective exploitation of mature seed bearing trees can threaten the sustainability of the forests.

The forest patches of the study sites have considerable resemblance with other afromontane forests of Ethiopia in terms of dominant tree species composition (see Tamrat Bekele, 1994). For instance, *Juniperus procera* is reported to have higher basal area in Wof-Washa and Menagesha forests. Similarly, *Olea europaea subsp cuspidata*, which is a dominant species in community four in the present study, is also a dominant species in Chilimo forest. *Ilex mitis*, a dominant species in Jibat forest, has highest basal area in the community three of this study. *Podocarpus falcatus* has considerably higher basal area compared to the basal area of other most important trees in community 1. It is also the second most dominant species in Chilimo and Wof-Washa forests (Tamrat Bekele, 1994). Such dominant tree species influence and create the main characteristics and structure of the community (Heywood and Iriondo, 2003).

Trees with considerable economic and health importance such as *Hagenia abyssinica* have poor regeneration status. This may be due to the fact that *Hagenia abyssinica* flowers are regularly collected by the inhabitants around the forests for medical purposes which could reduce the seed source for germination and recruitment. The poor regeneration of *Ilex mitis*, *Prunus africana*, *Podocarpus falcatus* and *Juniperus procera* is probably due to selective logging of mature individuals for timber production and construction purposes, which can ultimately have negative impact on seed production and regeneration status of the species. Furthermore, seedling trampling and selective browsing by domestic and wild animals may also have accounted for the poor regeneration status of the dominant trees in the study area.

Dombeya torrida and *Syzygium guineense* have J-shaped frequency distribution (population structure) which is characterized by high number of individuals in higher diameter classes and lower in the lower diameter classes. Feyera Senbeta (2006) reported that *Syzygium guineense* fruits are usually used as food by many animals and humans, which could account for the poor regeneration status of the species. Overharvesting of seed bearing individuals may also have accounted for the poor regeneration of *Dombeya torrida* and *Syzygium guineense*. In addition, uncontrolled grazing might be one of the main causes for the poor regeneration status of these species. *Olinia rochetiana* has an inverted J-shape, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes.

In forests with optimum regeneration status, the patterns of population structure is expected to an inverted J-shaped type, with a high number of individuals in the lower size classes and few individuals in the higher size classes. The reproductive capacity of the forest must be sufficient to sustain the forest, and the population structure of most species must have a reverse J-shaped distribution (seedlings/saplings are over-represented and bigger trees are present in progressively lower numbers). This pattern is an indicator of healthy regeneration of the forest and species, and shows a good reproduction and recruitment capacity (Feyera Senbeta, 2006). Most of the most important tree species of the study area do not have this type of population structure as showed in Figure 13.

The dominant trees in the study area have either J-shaped or bell shaped population structures. The bell-shape population structure indicates a poor reproduction and recruitment of species, which may be associated with the overharvesting of seed bearing individuals. Similarly, the J-shaped pattern indicates poor reproduction and regeneration which may be either because of failure to produce seed due to age of the trees or losses due to predators after reproduction (Feyera Senbeta, 2006). The poor reproduction and regeneration status of the dominant tree species can jeopardize the sustainability of the vegetation in the study area. Hence, proper conservation measures need to be applied so as to improve their regeneration.

Topographic variables, especially altitude and slope, have significant relation with the plant communities of the Gurage Mountains. Several researchers discussed the relation between these topographic variables and the spatial distribution of plant communities (e.g. Day and Monk, 1974; Proctor *et al.*, 1983; Austin *et al.*, 1984; Austin, 1985; Gentry, 1988; Swanson *et al.*, 1988; Austin & Smith, 1989; Harrison *et al.*, 1989; Allen & Peet, 1990; Allen *et al.*, 1991; Busing *et al.*, 1992; Oliveira-Filho *et al.*, 1994; Takyu & Ohsawa, 1997; Clark *et al.*, 1998; Burke, 1999; Clark and Mann, 1999; Titshall *et al.*, 2000; Cannon and Leighton, 2004; Valencia *et al.*, 2004; White & Hood, 2004; Deng *et al.*, 2007; Lorenzo *et al.*, 2007; Solon *et al.*, 2007; Joseph *et al.*, 2008; Bochet *et al.*, 2009). Topographic gradients cause a notable variation in species composition. This is because topographic variations create a mosaic of microhabitat variations (Moody & Meentemeyer, 2001) and hence are considered as principal parameters in ecological specialization (Bazzaz, 1991).

However, these topographic variables indirect factors as they do not have a physiological influence on species, contrary to direct factors such as temperature and soil nutrients (see Austin *et al.*, 1984; Austin, 1985; Austin & Smith, 1989; Kent & Coker, 1995; Ramsay and Oxley, 1997; Pausas and Austin, 2001; Körner, 2000, 2007). For instance, altitudinal species distributions are caused by various factors which change along with altitude such as air pressure, temperature and precipitation that in turn determine the type of vegetation to be supported (Proctor *et al.*, 1983; Swanson, 1988; Harrison *et al.*, 1989; Stohlgren, 1997; Pausas and Austin, 2001; Körner, 2000, 2007). Furthermore, along with altitudinal change other environmental parameters (e.g. soil texture, nutrients, substrate stability, etc.) covary which also affect the structure and composition of the vegetation (see Holland and Steyn, 1975; Ramsay and Oxley, 1997).

Difference in insolation period may occur according to altitude thereby forming a range of microclimates in multifaceted landscape which would in turn affect vegetation types and species composition (Pavon *et al.*, 2000). Similarly, slope determines the microclimate and thus spatial distribution and patterns of vegetation (Day and Monk, 1974; Holland and Steyn, 1975; Allen & Peet, 1990; Allen *et al.*, 1991; Busing *et al.*, 1992; Bale *et al.*, 1998; Burke, 1999; Clark and

Mann, 1999; Titshall *et al.*, 2000; Miller and Franklin, 2002; Sebastia, 2004; Ellu and Obua, 2005; Bennie *et al.*, 2006; Deng *et al.*, 2007; Solon *et al.*, 2007; Joseph *et al.*, 2008; Bochet *et al.*, 2009). Slope causes vegetation changes owing to its effect on soil characteristics (Clark and Mann, 1999; Deng *et al.*, 2007; Solon *et al.*, 2007). For example, Dalling & Tanner (1995) reported that the soils at steep slopes at higher elevations are especially poor in nitrogen and phosphorous which can have impact on type of vegetation to be supported.

Altitude is also one the main factors causing variation in species richness across the study sites. Several studies (e.g. Proctor *et al.*, 1983; Gentry, 1988; Harrison *et al.*, 1989; Pausas and Austin, 2001; Medina, 2007; Joseph *et al.*, 2008) discussed the effect of altitude on species richness. These studies reported that species richness decreases with an increase in altitude. Such a reduction in species richness with altitude happens both in temperate areas (e.g. Harrison *et al.*, 1989) and in tropical mountains (e.g. Proctor *et al.*, 1983). In addition to low temperature, various other factors can account for low species richness at higher altitude. For example, plant nutrient uptake from soil is slow at higher altitude as a result of cooler soil temperatures, decreased rates of nitrogen mineralization and nitrification (Marrs *et al.*, 1988) as well as the increased soil leaching and organic matter content (Tanner *et al.*, 1998). Besides, at higher elevations, the soils are poor in nitrogen and phosphorous (Dalling & Tanner, 1995) which can have an impact on species richness.

Although the present study suggests a decrease in species richness with increase in altitude, there are two perspectives amongst academia regarding the relationship between altitude and species richness: a monotonic decrease in species richness with altitude; or a hump-shaped relationship with a peak in species richness at intermediate elevations (Bhattarai and Vetaas, 2006). Medina (2007) and Gentry (1988) reported a decrease in vascular species diversity with increasing altitude. Similarly, Pausas and Austin (2001) reported a negative relationship between altitude and woody species richness. However, Rahbek (1995), from a review of literature, concluded that humpshaped relationships are most prevalent in both tropical and non-tropical biomes.

Likewise, physical and chemical properties of the soil such as sand and clay content of the soil, carbon nitrogen ratio and soil pH are significantly related with the plant communities of the study area. The impacts of these soil features on the distribution of plants is widely discussed by various authors (e.g. Oliveira Filho *et al.*, 1994; Chen *et al.*, 1997; Clark *et al.*, 1998; Oliveira Filho *et al.*, 1998; Lyon & Sagers, 2000; Cannon and Leighton, 2004; Valencia *et al.*, 2004; Lorenzo *et al.*, 2007; Zare-Chahouki *et al.*, 2012) who underscored that these soil parameters strongly affect patterns of plant distribution. They affect the physiognomy, composition, and productivity of plant communities (Klinger, 1996).

Physical characteristics of the soil influence nutrient retention and availability, organic matter retention, microbial biomass and other soil properties which in turn influence vegetation distribution patterns (Fernandez-Illescas *et al.*, 2001; Scott and Robert, 2006; Hamarashid *et al.*, 2010). Similarly, soil pH influences the growth and distribution of plants as it greatly affects the absorption of inorganic nutrients by plants. For instance, plant growth in acid soils may be limited by the effect of excess H⁺ ion concentration as well as pH-induced toxicities (e.g., Al, Mn) and/or insufficiencies (e.g., Ca, Mg, P, Mo). Excess H⁺ ion concentration causes a decrease in the rate of absorption of cations, probably as a result of competition between the similarly charged ions for binding and carrier sites. High pH has also been considered as detrimental in causing nutrient deficiency and ionic imbalance (Alam *et al.*, 1999). High pH and smaller C/N ratio can increase net N mineralization. Low C/N ratios show N mineralization more than those with wide C/N ratios (Khalila, 2005). Soil pH has a significant impact on the species of the Gurage Mountains. This is because of the fact that it has an effect on plant nutrient and toxic element availability (Alam *et al.*, 1999). For instance, Grime (1973) noted that species richness declines towards both acidic and alkaline soils. He concluded that few species are adapted nutritionally to exploit highly acidic or alkaline soils.

Disturbance plays a significant role in plant community formation in the study area. Disturbance may determine community patterns by (1) directly changing the environment and resource distributions, (2) creating opportunities for the establishment of new species or (3) reducing populations of established species (Motzkin *et al.*, 1999). Anthropogenic disturbance also

influences the soil, nutrient and water conditions as well as microenvironment of the area (Pokhriyal *et al.*, 2012) which in turn determine the type of vegetation to be supported. Disturbance also has significant impact on the species richness of the study area as species richness decreased with increase in disturbance intensity. This is because of the fact that plants do not commonly endure extremes of stress and disturbance (Grime, 1979). For this reason, a significant decrease in species diversity is encountered with increasing frequency in disturbance (Collins *et al.*, 1995). It affects community patterns by changing the environment and resource distributions and by reducing populations of established species (Elliott and Hewitt, 1997; Motzkin *et al.*, 1999). Disturbance also alters the stability and diversity of ecosystems as it reduces invasion resistance while eliminating the buffering effect of high diversity (MacDougall *et al.*, 2013). The most commonly cited mechanism behind this phenomenon is that as species accumulate, competition intensifies and fewer resources remain available for new colonists (Elton, 1958; Case, 1990). Thus, disturbance affects species richness owing to its effect on resource and environmental conditions as well as its effect on invasion resistance.

The intermediate disturbance hypothesis (Grime, 1973; Connell, 1978; Wilkinson, 1999) suggests that species richness is high at intermediate level of disturbance. However, the present study did not support this hypothesis as there was a steady decrease in species richness with intensification of disturbance (Figure 25). Likewise, Hubbell *et al.* (1999) did not get results supporting the intermediate disturbance hypothesis while studying a tropical rainforest.

The forest patches of the study area are under enormous anthropogenic pressure that could jeopardize the sustainable use of the forests. One of the main factors causing the loss of forests is subsistence agriculture. Many studies (e.g. Mayo and Wasserman, 1994; Contreras-Hermosilla, 2000; Roper and Roberts, 2006; Yengoh, 2008; Zak *et al.*, 2008; Slingenberg *et al.*, 2009) discuss that the expansion of subsistence agriculture is one of the most important causes of deforestation in Africa. This is because small-scale agriculture is vital for livelihoods in Africa accounting for 70 % of rural employment and is ranked first on basis of its relative importance for deforestation; accounting for approximately 60% of the total deforestation (Slingenberg *et al.*, 2009). Besides, the effect of subsistence on forests resource is further intensified by the fact

that Africa is the only region in the world where the regional average of food production per person has been declining over the past 40 years which led to an increased demand for new agricultural land (Slingenberg *et al.*, 2009). Hence, unless the productivity of the existing agricultural lands is improved, encroachment into forest land may not be halted.

The second main factor accounting for the loss of forest resources in the study area is high population growth. With increased population, there would be more people in search of agricultural expansion, settlement, grazing land, fuelwood, timber and other forest products. These have certainly been intensifying pressure on forests resources; implying that population growth is one of the primary causal factors leading to conversion of forest land to agricultural land (see also Sunderlin and Resosudarmo, 1996; Roper and Roberts, 2006; MELCA, 2008; Yengoh, 2008; Zak *et al.*, 2008; Slingenberg *et al.*, 2009). Population projections show that the global population will continue to grow throughout the first half of the 21st century (Slingenberg *et al.*, 2009). Unfortunately, most of the population increase is occurring in underdeveloped countries, those nations least equipped to absorb them (Roper and Roberts, 2006). A growing population consequentially implies an increasing demand for food, energy, shelter, water, wood, paper, and all the other goods and services from the forests. This can lead to unsustainable consumption of the resources. Hence, actions to stabilize population pressure are indisputably needed should we try to halt or minimize forest loss and degradation.

Wood extraction for firewood and charcoal production and firewood is the third main driver of deforestation in the study area. Unless alternative livelihood source is arranged for wood and charcoal sellers, it would be hardly possible minimize forest loss in the study areas as human livelihood takes precedence over long term conservation goal'. In other words, given people are hungry, they would not think of retaining the resources at their vicinity at the expense of their lives. Hence, the state and other pertinent development actors should try to look for alternative livelihood for the rural poor who are destroying the forest resources for charcoal production and fuelwood selling. Apparently, fuel wood is a major energy source for the rural and even urban population. Hence, it is unlikely abandon using fuel wood altogether right now. There is an urgent need to develop alternative energy sources and energy saving cookers. Besides, forest

development activities are needed to lessen the pressure on the remnant forest patches of the study area.

Studies on effect of wood extraction for fuel wood and charcoal production on forest resources (e.g. Boahene, 1998; Contreras-Hermosilla, 2000; Roper and Roberts, 2006; Kanninen *et al.*, 2008; Yengoh, 2008; Slingenberg *et al.*, 2009; GFC, 2010) underscored that wood based household energy plays a significant role in deforestation and forest degradation. It is even ranked as the 3rd main proximate drivers of deforestation in Africa as most Africans still use wood and charcoal for cooking as there are no other reasonably priced energy sources available (Slingenberg *et al.*, 2009). Slingenberg *et al.* (2009) also noted that only 7.5 % of the rural population has access to electricity. There has been a steady increase in fuel wood removals in Africa in recent years, a rise from 499 million m³ yearly (in 1990) to 661 million m³ (in 2005) and projections show a 34 % increase in fuel wood consumption from 2000 to 2020 (Slingenberg *et al.*, 2009). For both rural and urban population in developing countries, poverty makes it difficult to substitute commercial fuel for fuelwood (Boahene, 1998; Becek and Odihi, 2008; GFC, 2010).

As stated earlier, with few alternatives available to them; the rural poor in the study sites have been using forests to address their economic problems. Some scholars e.g., Slingenberg *et al.* (2009) reported that the decline in the productivity of African agriculture the consequent decline in income led to increased dependence on off-farm employment, including collection of fuel wood and production of charcoal. Similarly, Boahene (1998); Roper and Roberts (2006); GFC (2010) assert that the extension of subsistence of activities into forestland is the result of poverty, limited alternative employment and inadequate technology. The implication of these all is that successful forest conservation entails considering alternative energy and livelihoods sources to the rural poor.

The fourth main driver of deforestation in the study is destabilization of traditional institutions and lack of appropriate forest governance systems. Historically, the respondents affirmed, the customary institutions in the study sites used to be effective in exercising authority over access to

and use of the forest patches. The destabilization of these institutions started with nationalization of land during the Derg period (1974-1991) when access was controlled by the Kebeles (peasant associations) that constitute the lowest administrative unit in Ethiopia (Dixon and Wood, 2007). With the nationalization of the forests during Derg period, according to Melaku Bekele (2003), private ownership of forests and most rights due to individuals were transferred to the state. Although there were strong warnings against any encroachment during the Derg regime forest depletion continued (Melaku Bekele, 2003). Negligence of the role of traditional institutions is not unique to the study sites. The role of such institutions, according to Kigenyi *et al.* (2002), was usually overlooked and misunderstood by official institutions in Eastern and Southern Africa and often in conflict with official local institutions regarding management of resources. The role of customary (traditional) institutions is built-in the society, with no written rules and laws, they may not be obvious and recognizable, and are therefore largely underrated (Kigenyi *et al.*, 2002).

Various studies revealed that institutional failure is one of main factors for forest loss and degradation. For example, Yengoh (2008) reported that deforestation occurs when institutions are too weak to control it or create an enabling environment for it. Hence, effective institutions are needed for sustainable forest management (Kanninen *et al.*, 2008). This is because the institutions provide the rules and regulations for resources exploitation, defining access and sanctioning poachers (Dixon and Wood, 2007; Hilhorst, 2008) and reduce the arbitrariness of actions by individuals (InfoResources, 2008).

In communal resource management, resource users share the rights and responsibilities towards a resource (Yengoh, 2008). Besides, clear access rules are defined with respect to community membership and property rights could be vested in the local community (Heltberg, 2002). Given this definition, the forest patches in the study sites cannot be considered as communal forests since the forest users do not organize themselves to clearly stipulate their rights (e.g. to use forest rights in the way they choose) and responsibilities towards the forest resources. Hence, the forests in the study sites can be considered as open access resources as neither the resource users nor the state established effective institutions for successful forest use and management. They are akin to open access resources over which nobody or institution exercises ownership and/or

control. MELCA (2008) made a similar conclusion with regard to ownership of the natural forests of Ethiopia. In such a situation, according to Ostrom (1999), destruction of forest resources is most likely to occur since forest users or external authorities, have not established effective governance regime to regulate: who is allowed to appropriate forest products; who are obliged to contribute labor or funds to provide or maintain the forest; how appropriation and obligation activities are to be monitored and enforced. Absence of effective enforcement mechanism, according to Ostrom (1999), has turned many natural resources into open access, with neither traditional nor government authorities exerting control over behavior. In the light of Ostrom's argument and the findings of this study, successful management of the remnant forest patches in the study area entails introduction of appropriate forest governance system.

To this end, there should be a collaborative effort between forest users, non state development actors and state to develop appropriate governance system to sustain and scale up the remnant forest patches in the study sites. Such a collaborative management approach has emerged in response to failure of state centric approaches to ensure sustainable management of forest resources (Kigenyi *et al.*, 2002). Some (e.g. Namarundwe, 2004; Walker and Hurley, 2004) consider the idea of collaboration as the dominant paradigm in natural resource management in the globe nowadays. This paradigm shift in conservation has refocused resource management strategies away from strategies focused on restricting human involvement towards encouraging the involvement of local people (Kellert *et al.*, 2000; Conley and Moote, 2003; Walker and Hurley, 2004). Hence, collaborative approach of forest management need should be promoted in the study area to abate the loss of the remnant forests.

Grazing is one of the main factors causing forest degradation in the study area. Forest grazing could also foster soil erosion, depletion of nutrients, soil compaction, and soil acidification (Belsky and Blumenthal, 1997; Barnes *et al.*, 1998). It also causes tree damage through trampling and browsing (Contreras-Hermosilla, 2000; Palmer *et al.*, 2004; Mayer *et al.*, 2006; Roper and Roberts, 2006; Vandenberghe *et al.*, 2007; Zak *et al.*, 2008; Slingenberg *et al.*, 2009) and loss of species richness and diversity (Fleischner, 1994). However, some researchers assert that forest grazing can be sustainable if grazing intensity is controlled (see Krzic *et al.*, 2001;

Pollock *et al.*, 2005; Mayer and Huovinen, 2007). Controlled grazing can enhance tree growth by reducing the biomass of grasses and sedges that otherwise outcompete tree seedlings (Belsky and Blumenthal, 1997; Gratzner *et al.*, 1999; Darabant *et al.*, 2007). The destructive effect grazing in the study area can be due to the fact that it is practiced in uncontrolled way. Hence, the destructive effect grazing need to be abated in the future conservation endeavors in the study area in order to foster the regeneration of the trees.

5.2. Conclusion and recommendations

Garage Zone does not have large tracts of land that are under forest cover. But there are patches of forests especially in areas that are topographically less accessible to human encroachment. Though small patches, the forests in the study sites comprise species of high diversity and house a good number of endemic plants. All of the richness estimators predict higher richness than the observed which further indicates the high floral diversity of the study sites. The regeneration status of the dominant trees of the study area is found to be poor. Hence, appropriate conservation measures need to be taken so as to improve their regeneration. Plant species richness and distribution in the study sites were influenced by altitude, disturbance, edaphic factors and other environmental variables. The species richness of the study area was strongly influenced by disturbance implying that disturbance mitigation should be one of the main measures in conservation planning in the study sites. Five main drivers of forest loss and degradation were identified: expansion of agricultural land, population growth, institutional weaknesses, wood extraction and grazing. In order to minimize or impede these causal factors, the following actions are recommended:

- i) Curtailing expansion of agricultural land by:
 - improving the yields from the existing agricultural lands by introducing improved crops and use of suitable technologies.
 - stabilizing population growth to minimize the escalating demand for agricultural land and goods from forests. This could involve awareness creation on family planning and provision of contraceptives for free.
- ii) Promoting alternative livelihood and energy sources by:

- growing multipurpose trees with agricultural crops that can minimize the pressure on remnant forest resources of the study area and which could also be a source of income for the rural poor who depend on firewood and charcoal selling.
- introducing solar cookers which would minimize the extraction of firewood and charcoal.
- subsidizing the cost of electricity which may lessen the dependence of the population in the towns in firewood and charcoal as source of energy.
- introducing energy efficient cookers to reduce firewood extraction.
- advocating plantation of indigenous species in areas that have lost their original forest cover to minimize the pressure on the remnant forest patches of the study area and to restore the ecological services. The plantations could also serve as an alternative source of income for the rural poor in the study area who depend on firewood and charcoal selling.
- encouraging and assisting the farmers in the study area to take part in non destructive non-timber forest products (such as honey) production instead of wood extraction.

iii) Addressing institutional weakness through:

- revitalization of traditional institutions that played a pivotal role in governing access to and management of forest resources in the study sites.
 - enforcement of the existing forest related legal documents such as proclamations on forest management, development and utilization so that sustainable forest management could be made a reality.
- iv) Raising awareness of farmers on deleterious consequences of loss of vegetation is recommended to curb the loss of vegetation and consequential ecological and socioeconomic effects as lack of awareness may also have accounted for unsustainable use of the vegetation resources of the study area.
- v) Introduction of participatory/collaborative forest management approach. This should be a joint endeavor between the local community, the state and other development actors for conservation of the remnant forest patches and for abatement of the actual and potential consequences of loss of forest resources.

References

- Adane Girma (2011). Plant Communities, Species Diversity, Seedling Bank and Resprouting in Nandi Forests, Kenya. PhD Thesis. University of Koblenz-Landau, Germany.
- Adomou, A.C. (2005). Vegetation patterns and environmental gradients in Benin: Implications for biogeography and conservation. PhD Thesis Wageningen University, Wageningen.
- Alam, S.M., Naqvi, S.S. and Ansari, R. (1999). Impact of Soil pH on Nutrient Uptake by Crop Plants. pp 51-57.
- Allen, S.E. (1989). Chemical analysis of ecological materials. Blackwell, Oxford.
- Allen, R.B. & Peet, R.K. (1990). Gradient analysis of forest of the Sangre de Cristo Range, Colorado. *Canadian Journal of Botany* **68**: 193-201.
- Allen, R.B., Peet, R.K. & Baker, W.L. (1991). Gradient analysis of latitudinal variation in Southern Rocky Mountain forests. *Journal of Biogeography* **18**: 123-139.
- Anderson, D. J. (1965). Classification and Ordination in Vegetation Science: Controversy over a Non-Existent Problem? *Journal of Ecology* **53** (2):521-526.
- Atalay, I. (2006). The Effects of Mountainous Areas on Biodiversity: A Case Study from the Northern Anatolian Mountains and the Taurus Mountains. Grazer Schriften der Geographie und Raumforschung Band 41 / pp. 17-26.
- Austin, M.P. & Smith, T.M. (1989). A New Model for the Continuum Concept: Progress in Theoretical Vegetation Science. *Vegetatio* **83**: 35-47.
- Austin, M.P. (1985). Continuum Concept, Ordination Methods, and Niche Theory. *Annual Review of Ecology and Systematics* **16**: 39-61.
- Austin, M.P., Cunningham, R.B. & Fleming, P.M. (1984) New approaches to direct gradient analysis using environmental scalars and statistical curve fitting procedures. *Vegetatio* **55**: 11-27.
- Austin, M.P., Pausas, J.G. & Nicholls, A.O. (1996). Patterns of tree species richness in relation to environment in South-eastern New South Wales. *Aust. J. Ecol.* **21**: 154-164.

- Azene Bekele, Birnie, A. and Tenqnas, B. (1993). Useful trees and shrubs for Ethiopia: Identification, Propagation and Management for Agricultural and Pastoral Communities. Technical Handbook No 5. p.5.
- Bale, C.L., Williams, J.B. and Charley, J.L. (1998). The impact of aspect on forest structure and floristics in some eastern Australian sites. *For. Ecol. Manage.* **110**: 363-377.
- Barnes, B.V., Zak, D.R., Denton, S.R. & Spurr, S.H. (1998). Forest Ecology. 4th edition. New York: Wiley.
- Barthlott W., Schmit-Neuerburg V., Nieder J. and Engwald S. 2001. Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rainforest in the Venezuelan Andes. *Plant Ecol.* **152**: 145-156.
- Bazzaz, F.A. (1991). Habitat selection in plants. *Am. Nat.* **137**: 116-130.
- Becek, K. & Odihi, J.O. (2008). Identification and assessment of factors affecting forest depletion in Brunei Darussalam. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B2.
- Belsky, A.J. & Blumenthal, D.M. (1997). Effects of livestock grazing on stand dynamics and soils in upland forests of the interior west. *Conservation Biology* **11**:315-327.
- Bennie, J., Hill, M.O., Baxter, R. and Huntley, B. (2006). Influence of slope and aspect on long-term vegetation change in British chalk grasslands. *Journal of Ecology* **94**: 355-368.
- Bernard, H.R. (1995). Research methods in anthropology: Qualitative and quantitative approaches. 2nd Edition. Altamira Press, Oxford, England.
- Bhattarai, K.R. & Vetaas, O.R. (2006). Can Rapoport's rule explain tree species richness along the Himalayan elevation gradient, Nepal? *Diversity and Distributions, (Diversity Distrib.)* DOI: 10.1111/j.1366-9516.2006.00244.x pp 1-5.
- BirdLife International (2012). Eastern afro-montane biodiversity hotspot. pp 9-106.
- Boahene, K. (1998). The challenge of deforestation in tropical Africa: Reflection on its principal causes, consequences and solutions. *Land degradation and development* **9**: 247-258.
- Bochet, E., García-Fayos, P. and Poesen, J. (2009). Topographic thresholds for plant colonization on semi-arid eroded slopes. Earth Surf. Process. *Landforms* **34**:1758-1771.

- Brocque, A. F. L. & Buckney, R.T. (2003). Species richness–environment relationships within coastal sclerophyll and mesophyll vegetation in Ku-ring-gai Chase National Park, New South Wales, Australia. *Austral Ecology* **28**: 404-412.
- Brown, J. H. & Lomolino, M.V. (1998). Biogeography 2nd edition. Sinauer Associates Inc. p675.
- Brown, R.L., Jacobs, L.A. & Peet, R.K. (2007). Species Richness: Small Scale. Encyclopedia of Life Sciences . John Wiley & Sons, Ltd.
- Burke, I.C. (1999). Spatial variability of soil properties in the short grass steppe: the relative importance of topography, grazing, microsite, and plant species in controlling spatial patterns. *Ecosystems* **2**: 422-438.
- Burns, B.R. (1995). Environmental correlates of species richness at Waipoua Forest Sanctuary, New Zealand. *New Zealand Journal of Ecology* **19** (2): 153-162.
- Busing, R. T., White, P. S., and MacKende, M. D. (1992). Gradient analysis of old spruces fir forest of the Great Smokey Mountains circa 1935. *Canadian Journal of Botany* **71**: 951-958.
- Callaway, R.M. (1997). Positive interactions in plant communities and the individualistic-continuum concept. *Oecologia* **112**:143-149.
- Cannon, C. H. and Leighton, M. (2004). Tree species distributions across five habitats in a Bornean rain forest. *J. Vegetation Sci.* **15**: 257-266.
- Carleton, T. J. (1984). Residual Ordination Analysis: A Method for Exploring Vegetation-Environment. *Ecology* **65** (2): 469-477.
- Chao, A. (2005). Species richness estimation. Institute of Statistics National Tsing Hua University Hsin-Chu, Taiwan.
- Chao, A., Chazdon, R.L., Colwell, R.K. & Shen, T.J. (2005). A new statistical approach for assessing similarity of species composition with incidence and abundance data. *Ecology letters* **8**: 148-159.
- Case, T.J. (1990). Invasion resistance arises in strongly interacting species-rich model competitive systems. *Proceedings of the National Academy of Sciences* **87**: 9610-9614.

- Chen, Z.C.; Hsieh, C.F.; Jiang, F.Y.; Hsieh, T.H. & Sun, I.F. (1997). Relations of soil properties to topography and vegetation in a subtropical rain forest in southern Taiwan. *Plant Ecology* **132**: 229-241.
- Clark, D. B., Clark, D. A. and Read, J. M. (1998). Edaphic variation and the mesoscale distribution of tree species in a Neotropical rain forest. *J. Ecol.* **86**: 101-112.
- Clark, D.B. and Mann, V.I. (1999). Edaphic factors and the landscape-scale distribution of Tropical rainforest trees. *J. Ecol.* **80** (8): 2662-2675.
- Clements, F.E. (1916). *Plant Succession: An Analysis of the Development of Vegetation*. Carnegie Institute Publication no 242. Washington, DC: Carnegie Institute.
- Collins, S.L. Glenn, S. M. and Roberts, D.W. (1993). The Hierarchical Continuum Concept. *Journal of Vegetation Science* **4**(2): 149-156.
- Collins, S.L., Glenn, S.M. & Gibson, D.J. (1995). Experimental analysis of intermediate disturbance and initial floristic composition: decoupling cause and effect. *Ecology* **76**: 486-492.
- Colwell, R.K. & Coddington, J.A. (1994). Estimating terrestrial biodiversity through extrapolation. *Phil.Trans.R.Soc.Lond.B* **435**: 101-118.
- Colwell, R.K. (2006). EstimateS: Statistical estimation of species richness and shared species from samples. Version 8. Persistent URL<purl.oclc.org/estimates>.
- Colwell, R. K. (2009a). Biodiversity: concepts, patterns, and measurement. Pages 257-263 in S. A. Levin Editor. *The Princeton Guide to Ecology*.
- Colwell, R.K. (2009b). EstimateS 8.2 *User's Guide*. Department of Ecology & Evolutionary Biology, University of Connecticut, Storrs, CT 06869-3043, USA.
- Colwell, R.K., Mao, C.X. & Chang, J. (2004). Interpolating, Extrapolating, and comparing incidence-based species accumulation curves. *Ecology* **85** (10): 2717-2727.
- Conley, A. & Moote, M.A. (2003). Evaluating Collaborative Natural Resource Management. *Society and Natural Resources*. **16**:371-386.
- Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. *Science* **199**: 1302-1310.
- Contreras-Hermosilla, A. (2000). The Underlying Causes of Forest Decline. *Occasional Paper* **30**: 1-22. Center for International Forestry Research.

- CSA (1996). The 1994 population and housing census of Ethiopia results for Southern Nations, Nationalities and Peoples' Region statistical report on population size and characteristics. Part I and IV. pp 277-285.
- CSA (2005). Agricultural Sample Survey Report on Land Utilization (Private peasant holdings, Meher season). *Statistical Bulletin*. Volume IV: p37.
- CSA (2007). The 2007 Population and Housing Census of Ethiopia: Statistical Report for Southern Nations, Nationalities and Peoples' Region; Part I and IV. pp375-380.
- CSA (2009). Statistical abstract section-B: Population Size by Sex, Area and Density by Region, Zone and Wereda.
- CSA (2011a). Agricultural Sample Survey Report on Land Utilization (Private peasant holdings, Meher season). *Statistical Bulletin*. Volume VII: p37.
- CSA (2010). Statistical abstract section-B: Population Size by Sex, Area and Density by Region, Zone and Wereda.
- CSA (2011b). Statistical abstract section-B: Population Size by Sex, Area and Density by Region, Zone and Wereda.
- Curtis, J. T. & McIntosh, R. P. (1951). An upland forest continuum in the prairie-forest border region of Wisconsin. *Ecology* **32**: 476-496.
- Curtis, J.T. (1959). The vegetation of Wisconsin. University of Wisconsin Press, Madison.
- Dalling, J.W. and Tanner, E.V.J. (1995). An experimental study on regeneration on landslides in montane rain forest in Jamaica. *J. Ecol.* **83**: 55-64.
- Darabant A., Rai, P.B., Kenzin, K., Roder, W. & Gratzner, G. (2007). Cattle grazing facilitates tree regeneration in a conifer forest with palatable bamboo understory. *Forest Ecology and Management* **252**:73-83.
- Daubenmire, R. (1966). Vegetation: Identification of Typical Communities. *Science, New Series* **151** (3708): 291-298.
- Day, F. P. and Monk, C. D. (1974). Vegetation patterns on a Southern Appalachian watershed. *Ecology* **55**: 1064-1074.
- Debub Negarit Gazeta of the Southern Nations, Nationalities and Peoples' Regional State (2004). Southern Nations, Nationalities and Peoples' Regional State, Forest Management, Development and Utilization Proclamation. Proclamation no 77/2004.

- Demel Teketay (2001). " Deforestation, Wood Famine and Environmental Degradation in Highlands Ecosystems of Ethiopia: Urgent Need for Actions" paper contributed to Managing Natural Resources for Sustainable Agriculture in African Highland Ecosystems Workshop, August 16-18,2001, Western Michigan University, Kalamazoo.
- Deng, Y., Chen, X., Chuvieco, E., Warner, T. and Wilson, J.P. (2007). Multi-scale linkages between topographic attributes and vegetation indices in a mountainous landscape. *Remote Sensing of Environment J.* **3** (1): 122-134.
- Dixon, A.B. & Wood, A.P. (2007). Local Institutions for Wetland Management in Ethiopia: Sustainability and State Intervention. CAB International. Community-based Water Law and Water Resource Management Reform in Developing Countries (eds B. van Koppen, M. Giordano and J. Butterworth) pp130-144.
- Duan, J., Ma, L., Jia, L., Chen, Z., Jia, Z. & Che, W. (2010). Tree Richness and Climatic Dominance in Different Districts of Beijing City, China. *Not. Bot. Hort. Agrobot. Cluj.* **38** (1): 262-265.
- Dufrêne M. and Legendre P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Mono.* **67**:345-366.
- Edvardsen, A. & Økland, R.H. (2007). Introduction to R. Department of Botany, Natural History museum, University of Oslo. pp 16-33.
- Edwards S., Demissew S. and Hedberg I. (Eds). (1997). Flora of Ethiopia. Vol. 6. *Hydrocharitaceae to Arecaceae*. Addis Ababa University and Uppsala University.
- Edwards S., Tadesse M. and Hedberg I. (Eds.) (1995). Flora of Ethiopia and Eritrea. Vol 2, Part 2. *Canellaceae to Euphorbiaceae*. Addis Ababa University and Uppsala University.
- Edwards S., Tadesse M., Demissew S. and Hedberg I. (Eds.) (2000). Flora of Ethiopia and Eritrea. Vol 2, Part 1. *Magnoliaceae to Flacourtiaceae*. Addis Ababa University and Uppsala University.
- Elliott, K.J. & Hewitt, D. (1997). Forest Species Diversity in Upper Elevation Hardwood Forests in the Southern Appalachian Mountain. *Castanea* **62** (1): 32-42.
- Ellu, G. and Obuga, J. (2005). Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable forest national park, southern Uganda. *Tropical Ecology* **46** (1): 99-111.

- Elouard, C. & Krishnan, R.M. (1999). Assessment of forest biological diversity. Case study in India. *Pondy Papers in Ecology*. A FAO training course.
- Elton, C. S. (1958). The ecology of invasions by animals and plants. Methuen, London, UK.
- EMA (1988). National Atlas of Ethiopia, Addis Ababa.
- Enright, N.J. (1982). Recognition Pathways in Forest Communities Using Site Class Ordination. *Vegetatio* **48**: 133-140.
- Eymann, J., Degreef, J., Häuser, C., Monje, J.C., Samyn, Y. & Vandenspiegel, D. (2010). Manual on field recording techniques and protocols for All Taxa Biodiversity Inventories and Monitoring. Volume 8, part 2.
- Federal Negarit Gazeta of the Federal Democratic Republic of Ethiopia (2007). Forest Development, Conservation and Utilization Proclamation. Proclamation no 542/2007.
- Fernandez-Illescas, C.P., Porporato, A., Laio, F. & Rodriguez-Iturb, I. (2001). The ecohydrological role of soil texture in a water-limited ecosystem. *Water resources research*. **37**(12): 2863-2872.
- Feyera Senbeta (2006). Biodiversity and ecology of Afromontane rainforests with wild *Coffea Arabica* L. populations in Ethiopia. *Ecology and Development Series* **38**: 60-63.
- Fleischner, T.L. (1994). Ecological costs of livestock grazing in western North America. *Conservation Biology* **8**:629-644.
- FoB (Facts on Biodiversity) (2005). A Summary of the Millennium Ecosystem Assessment Biodiversity Synthesis by the Millennium Ecosystem Assessment (MA): Ecosystems and Human Well-being: Biodiversity Synthesis.
- Friis, I. (1986a). The forest vegetation of Ethiopia. *Symb. Bot. Ups.* **26** (2):31-47.
- Friis, I. (1992). Forests and forest trees of North East Tropical Africa. *Kew Bull. Add. Ser.*
- Friis, I. and Sebsebe Demissew (2001). Vegetation maps of Ethiopia and Eritrea. A review of existing maps and the need for a new map for the flora of Ethiopia and Eritrea. *Biol. Skr.* **54**: 399-439.
- Friis, I., Sebsebe Demissew & van Breugel, P. (2011). Atlas of the Potential Vegetation of Ethiopia. Addis Ababa University Press and Shama Books.
- Gbetnkom, D. (2008). Forest Depletion and Food Security of Poor Rural Populations in Africa: Evidence from Cameroon. *Journal of African Economies*. Pp 1-26.

- Gentry, A. H. (1988). Changes in Plant Community Diversity and Floristic Composition on Environmental and Geographical Gradients. *Annals of the Missouri Botanical Garden* **75** (1): 1-34.
- GFC (Global Forest Coalition) (2010). Getting to the Roots. Underlying Causes of Deforestation and Forest Degradation, and Drivers of Forest Restoration. pp 6-33.
- Giménez, E., Melendo, M., Valle, F., Gómez-Mercado, F. and Cano, E. (2004). Endemic flora biodiversity in the south of the Iberian Peninsula: altitudinal distribution, life forms and dispersal modes. *Biodiversity Conserv.* **13**: 2641-2660.
- Gleason, H. A. (1939). The Individualistic Concept of the Plant Association. *American Midland Naturalist* **21** (1): 92-110.
- Gotelli, N.J. & Colwell, R.K. (2001). Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* **4**: 379-391.
- Gough, L. Grace, J.B. & Taylor, K.L. (1994). The Relationship between Species Richness and Community Biomass: The Importance of Environmental Variables. *Oikos* **70** (2):271-279.
- Gratzer, G., Rai, P.B. & Glatzel, G. (1999). The influence of the bamboo *Yushania microphylla* on regeneration of *Abies densa* in central Bhutan. *Canadian Journal of Forest Research* **29**:1518-1527.
- GreenFacts (2007). Scientific Facts on Biodiversity: A Global Outlook. pp 3-16.
- Grime, J.P. (1973). Competitive exclusion in herbaceous vegetation. *Nature* **242**: 344-347.
- Grime, J. P. (1979). Plant Strategies and Vegetation Processes. Wiley-Interscience, John Wiley & Sons, Inc., Somerset, N. J. 222 pp.
- Grossman, D. H., Faber-Langendoen, D., Weakley, A. S., Anderson, M., Bourgeron, P., Crawford, R., Goodin, K., Landaal, S., Metzler, K., Patterson, K. D. Pyne, M., Reid, M. & Sneddon, L. (1998). International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. The Nature Conservancy, Arlington, Virginia, USA.

- Grubb, P.J. (1987). Global trends species-richness in terrestrial vegetation: a view from the northern hemisphere. In: Gee, J.M.R. & Giller, P.S. (eds.) *Organization of communities, past and present, Symp. Brit. Ecol. Soc.* **27**: 99-118.
- Guatam, A.P. & Shivakoti, G.P. (2005). Conditions for Successful Local Collective Action in Forestry: Some Evidence from the Hills of Nepal. *Society and Natural Resources* **18**:153-171.
- Guisan, A., Weiss, S.B. & Weiss, A.D. (1999). GLM versus CCA spatial modeling of plant species distribution. *Plant Ecology* **143**: 107-122.
- Guisan, A., Edwards, T. C., & Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modeling* **157**: 89-100.
- GZFECD (Gurage Zone Finance and Economic Development Coordination Office) (2008). Growth poles and Development corridors. Pp 12-32.
- Hailu Sharew (1982). An Ecological Study of a Forest in Jemjem Sidamo M Sc. Thesis. A.A.U.
- Hamarashid, N.H., Othman, M.A. & Hussain, M.A.H. (2010). Effects of soil texture on chemical compositions, microbial populations and carbon mineralization in soil. *Egypt. J. Exp. Biol. (Bot.)*. **6**(1): 59-64.
- Hamilton, A.J. (2005). Species diversity or biodiversity? *Journal of Environmental Management* **75**: 89-92.
- Harrison, E.A., McIntyre, B.M. & Dueser, R.D. (1989). Community dynamics and topographic controls on forest pattern in Shenandoah National Park, Virginia. *Bulletin of Torrey Botanical Club* **116**:1-14.
- Hedberg I. and Edwards S. (Eds.) (1989). *Flora of Ethiopia*. Vol. 3. *Pittosporaceae to Araliaceae*. Addis Ababa University and Uppsala University.
- Hedberg I., Edwards S. and Nemomissa S. (Eds.) (2003). *Flora of Ethiopia and Eritrea*. Vol 4, Part 1. *Apiaceae to Dipsaceae*. Addis Ababa University and Uppsala University.
- Hedberg, I., and Edwards, S. (Eds.) (1995). *Flora of Ethiopia and Eritrea*, Vol. 7. *Poaceae (Graminae)*. Addis Ababa University & Uppsala University.
- Hedberg, I., Friis, I. and Edwards, S. (Eds.) (2004). *Flora of Ethiopia and Eritrea* Vol 4, Part 2. *Asteraceae (Compositae)*. Addis Ababa University and Uppsala University.

- Hedberg, I., Ensermu Kelbessa, Edwards, S., Sebsebe Demissew & Persson, E. (2006). Flora of Ethiopia and Eritrea Vol.5. *Gentianaceae to Cyclocheilaceae*. Addis Ababa University and Uppsala University.
- Hedberg, O. (1970). Evolution in the Afroalpine. *Biotropica* **2**: 16-23.
- Hedberg, O. (1975). Studies of adaptation and speciation in the afroalpine flora of Ethiopia. *Boissiera* **24**: 71-74.
- Heltberg, R. (2002). Property Rights and Natural Resource Management in Developing Countries. *Journal of Economic Surveys* **16** (2): 189-214.
- Hersperger, A. M. & Wohlgemuth, T. (2004). Rarefaction method for assessing plant species diversity on a regional scale. *Ecography* **27**: 532-544.
- Heywood, V.H. & Iriondo, J.M., (2003). Plant conservation: old problems, new perspectives. *Biological Conservation* **113** (3): 321-335.
- Hilhorst, T. (2008) Local governance institutions for natural resource management in Mali, Burkina Faso and Niger. KIT Working Papers Series G1. Amsterdam: KIT. pp 1-21.
- Holland, P.G. and Steyn D.G. (1975). Vegetational responses to latitudinal variations in slope angle and aspect. *Journal of Biogeography* **2**: 179-183.
- Hubbell, S.P., Foster, R.B., O'Brien, S.T., Harms, K.E., Condit, R., Wechsler, B., Wright, S.J. & Loo de Lao, S. (1999). Light-gap disturbance, recruitment limitation, and tree diversity in a Neotropical forest. *Science* **283**: 554-557.
- InfoResources (2008). Shaping Institutions for Natural Resource Management. *InfoResources Focus*. No 3/08 pp1-16.
- Jansen, H., Hengsdijk, H., Dagnachew, L., Tenalem, A., Hellegers, P., and Spliethoff, P. (2007). Land and water resources assessment in the Ethiopian Central Rift Valley. Altera Rapport-158.
- Joseph, S., Reddy, C. S., Pattanaik, C. and Sudhakar, S. (2008). Distribution of plant communities along climatic and topographic gradients in Mudumalai Wildlife Sanctuary (southern India). *Biological Lett.* **45**: 29-41.
- Kamrani, A., Naqinezhad, A., Jalili, A., & Attar, F. (2010). Environmental Gradients across wetland vegetation groups in the arid slopes of western Alborz Mountains, N. Iran. *Acta Societatis Botanicorum* **79** (4): 295-304.

- Kanninen, M., Murdiyarso, D., Seymour, F., Angelsen, A., Wunder, S. & German, L. (2008). Do Trees Grow on Money? The implications of deforestation research for policies to promote REDD. *CIFOR infobriefs*.
- Kellert, S.R., Mehta, J.N., Ebbinand, S.A. & Lichtenfeld, L.L. (2000). Community Natural Resource Management: Promise, Rhetoric, and Reality. *Society and Natural Resources*. **13**:705-715.
- Kenkel, N.C. (2006). On selecting an appropriate multivariate analysis. *Can. J. Plant Sci.* **86**: 663-676.
- Kent, M. & Ballard, J. (1988). Trends and Problems in the Application of Classification and Ordination Methods in Plant Ecology. *Vegetatio* **78** (3): 109-124.
- Kent, M. & Coker, P. (1995). Vegetation description and analyses: a practical approach. London, John Wiley & Sons.
- Kigenyi, F., Gondo, P., & Mugabe, J. (2002). Practice Before Policy: An Analysis of Policy and Institutional Changes Enabling Community Involvement in Forest Management in Eastern and Southern Africa, xiii + 54pp.
- Kimmins, J. P. (1997). Forest ecology: a foundation for sustainable management. Second edition. Prentice Hall, Upper Saddle River, New Jersey, USA.
- Kitessa Hundera (2003). Florestic Composition and Structure of the Dodola Forest, Bale Zone, Oromiya Reginal State. M. Sc Thesis.
- Klinger, L.F. (1996). Coupling of Soils and Vegetation in Peatland Succession. *Arctic and Alpine Research* **28** (3): 380.
- Knollová, I., Chytrý, M., Tichý, L. & Hájek, O. (2005). Stratified resampling of phytosociological databases: some strategies for obtaining more representative data sets for classification studies. *Journal of Vegetation Science* **16**: 479-486.
- Körner, C. (2000). Why are there global gradients in species richness? Mountains might hold the answer. *Trends in Ecology and Evolution* **15**:513-514.
- Körner, C. (2007). The use of 'altitude' in ecological research. *Trends in Ecology and Evolution* **22**:569-574.
- Kruckeberg, A. R. and Rabinowitz, D. (1985). Biological aspects of endemism in higher plants. *Annu. Rev. Ecol. Syst.* **16**: 447-479.

- Krzić, M., Broersma, K., Newman, R.F., Ballard, T.M. & Bomke, A.A. (2001). Soil quality of harvested and grazed forest cutblocks in southern British Columbia. *Journal of Soil and Water Conservation* **56**:192-197.
- Lau, M. (2008). Introduction to Ecological Analysis in R. pp1-6.
http://perceval.bio.nau.edu/downloads/igert/IntroR-Course_Notes/R-Course_Day3.pdf.
- LeCompte, M.D., Preissle, J. & Renata, T. (1993). Ethnography and qualitative design in educational research. San Diego, Academic Press.
- Legendre, L. & Legendre, P. (1998). Numerical Ecology. 2nd English Edition. Elsevier Science B.V. Amsterdam.
- Lepš, J. & Šmilauer, P. (1999). Multivariate Analysis of Ecological Data. Faculty of Biological Sciences, University of South Bohemia, České Budejovice. pp7-101.
- Logan, W. E. M. (1946). An introduction to the forests of central and southern Ethiopia. *Imp. For. Inst. Paper* **24**: 1-58.
- Lorenzo, M., Michele, S., Sebastian, K., Johannes, I. and Angelo, P. (2007). Effects of local factors on plant species richness and composition of Alpine meadows. *Agriculture, Ecosystems and Environment* **119**: 281-288.
- Ludwig, J.A. & Reynolds, J.F. (1988). Statistical Ecology. A primer on methods and computing. A Wiley Interscience Publication. John Wiley and Sons.
- Lyon, J. & Sagers, C.L. (2003). Correspondence analysis of functional groups in a riparian landscape. *Plant Ecology* **164**: 171-183.
- Khalila, M.I., Hossaina, M.B. and Schmidhalter, U. (2005). Carbon and nitrogen mineralization in different upland soils of the subtropics treated with organic materials. *Soil Biology & Biochemistry* **37**: 1507-1518.
- MacDougall, A.S., MacCann, K.S., Gellner, G. & Turkington, R. (2013). Diversity loss with persistent human disturbance increases vulnerability to ecosystem collapse. *Nature* **494**: 86-89.
- Mack, N., Woodson, C., Macqueen, M.M, Guest, G. and Namey, E. (2005). Qualitative Research Methods: A data collector's field guide.
- Magurran, A.E. (2004). Measuring Biological Diversity. Blackwell Science Ltd.

- Mao, C.X., Colwell, R.K. & Chang, J. (2005). Estimating the Species Accumulation Curve Using Mixtures. *Biometrics* **61**: 433-441.
- Marrs, R.H., Proctor, J., Heaney, A. and Mountford M.D. (1988). Changes in soil nitrogen-mineralization and nitrification along an altitudinal transect in tropical rain forest in Costa Rica. *J. Ecol.* **76**:466-482.
- Mayer, A.C. & Huovinen, C. (2007). Silvopastoralism in the Alps: Native plant species selection under different grazing pressure. *Ecological Engineering* **29**:372-381.
- Mayer, A.C., Stockli, V., Konold, W. & Kreuzer, M. (2006). Influence of cattle stocking rate on browsing of Norway spruce in subalpine wood pastures. *Agroforestry Systems* **66**:143-149.
- Mayo, M. & Wasserman, C. (1994). Deforestation technical support package. In workshops on the Principles of Environmental Enforcement launched at the Third International Conference on Environmental Enforcement held in Oaxaca, Mexico, April 25-28.
- McCune, B. & Grace, J.B. (2002). Analysis of Ecological Communities. MjM Software Design. USA.
- McIntosh, R.P. (1966). The continuum concept of vegetation. *Botanical Review* **33**:130-167.
- Mckee, J. (2007). Ethiopia-Country Environmental Profile. pp 16-33.
- Medina, E. (2007). Tropical Forests: Diversity and Function of Dominant Life-Forms. In Functional plant ecology 2nd ed. Edited by Francisco Pugnaire and Fernando Valladares. Taylor & Francis Group, LLC.
- Melaku Bekele (2003). Forest property rights, the role of the state and institutional exigency. Doctoral dissertation, Department of Rural Development studies, Acta Universitatis Agriculturae Sueciae.
- MELCA (2008). Communal Forest Ownership: An Option to Address the Underlying Causes of Deforestation and Forest Degradation in Ethiopia? Proceeding of a workshop held at Chilimo Forest and Ghion Hotel November 25-27. *Publication No.7*.
- Michaelsen, J., Schimel, D.S., Friedl, M.A., Davis, F.W., Dubayah, R.C. (1994). Regression Tree Analysis of Satellite and Terrain Data to Guide Vegetation Sampling and Surveys. *Journal of Vegetation Science* **5** (5): 673-686.

- Miller, J. and Franklin, J. (2002). Modeling the distribution of four vegetation alliances using generalized linear models and classification trees with spatial dependence. *Ecol. Model.* **157**: 227-247.
- Mittermeier, R.A., Robles Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J. & Fonseca, G.A.B. da. (2004). Hotspots: Revisited. Mexico: CEMEX.
- Mittermeier, R.A., Turner, W.R., Larsen, F.W. Brooks, T.M. and Gascon, C. (2011). Global Biodiversity Conservation: The Critical Role of Hotspots. *Biodiversity Hotspots*. pp 3-6.
- MoA (Ministry of Agriculture) (2000). Agroecological Zonations of Ethiopia. Addis Ababa, Ethiopia.
- MoARD (Ministry of Agriculture and Rural Development) (2005). Major Agro-ecological Zones of Ethiopia. Forestry, Land Use and Soil Conservation Department. Addis Ababa, Ethiopia.
- Mogaka, H., Simons, G., Turpie, J. Emerton, L. & Karanja, F. (2001). Economic Aspects of Community Involvement in Sustainable Forest Management in Eastern and Southern Africa, iv + 151pp.
- Moody, M. & Meentemeyer, R.K. (2001). Environmental factors influencing spatial patterns of shrub diversity in chaparral, Santa Ynez Mountains, California. *J. Veg. Sci.* **12**: 41-52.
- Motzkin, G., Wilson, P., Foster, D.R. & Allen, A. (1999). Vegetation patterns in heterogeneous landscapes: The importance of history and environment. *Journal of Vegetation Science* **10**: 903-920.
- Mucina, L. (1997). Classification of Vegetation: Past, Present and Future. *Journal of Vegetation Science* **8** (6):751-760.
- Myers, N. (1988). Threatened biotas: "Hot spots" in tropical forests. *The Environmentalist* **8**: 1-20.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B.da & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-857.
- Naeem, S., Chair, F.S., Costanza, R., Ehrlich, P.R., Golley, F.B., Hooper, D.U., Lawton, J.H., O'Neil, R.V., Mooney, H.A., Sala, O.E., Symstad, A.J. & Tilman, D. (1999). Biodiversity and Ecosystem Functioning: Maintaining Natural Life Support Processes. *Issues in Ecology* **4**: 1-12.

- Nelder, J. A. and Wedderburn, R.W.M (1972). Generalized Linear Models. *Journal of the Royal Statistical Society*. **135** (3): 370-384.
- Nemarundwe, N. (2004). Social Charters and Organization for Access to Woodlands: Institutional Implications for Devolving Responsibilities for Resource Management to the Local Level in Chivi District, Zimbabwe. *Society and Natural Resources*. **17**:279-291.
- Noy-Meir, I. & van der Maarel, E. (1987). Relations between Community Theory and Community Analysis in Vegetation Science: Some Historical Perspectives. *Vegetatio* **69**: 5-15.
- O'Brien, E.M. (1993). Climatic gradients in woody plant species richness: towards an explanation based on an analysis of southern Africa's woody flora. *J. Biogeogr.* **20**: 181-198.
- Økland, R.H., Rydgren, K. & Økland, T. (2008). Species richness in boreal swamp forests of SE Norway: The role of surface microtopography. *Journal of Vegetation Science* **19**: 67-74.
- Oksanen, J. (2004). Multivariate Analysis in Ecology. Department of Biology, University of Oulu. pp 6-116.
- Oksanen, J. (2007). Multivariate Analysis of Ecological Communities in R: vegan Tutorial. pp 2-37. <http://cc.oulu.fi/~jarioksa/opetus/metodi/session3.pdf>
- Oksanen, J., Kindt, R., Legendre, P., and O'Hara, B. (2007). Package 'vegan' documentation. <http://cc.oulu.fi/~jarioksa/>.
- Oksanen, J. (2012). Cluster Analysis: Tutorial with R. pp 1-8. <http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf>
- Oliveira-Filho, A.T., Curi, N., Vilela, E.A. & Carvalho, D.A. (1998). Effects of canopy gaps, topography, and soils on the distribution of woody species in a Central Brazilian Deciduous Dry Forest. *Biotropica* **30**: 362-375.
- Oliveira-Filho, A.T., Vilela, E.A., Carvalho, D.A. & Gavilanes, M.L. (1994). Effects of soils and topography on the distribution of tree species in a tropical riverine forest in a south-eastern Brazil. *Journal of Tropical Ecology* **10**: 483-508.
- Ostrom, E. (1999). Self-Governance and Forest Resources. *CIFOR occasional paper no. 20*
- Palmer, M. W. & Dixon, P.M. (1990). Small-scale environmental heterogeneity and the analysis of species distributions along gradients. *Journal of Vegetation Science* **1**: 57-65.

- Palmer, S.C.F., Mitchell, R.J., Truscott, A.M. and Welch, D. (2004). Regeneration failure in Atlantic Oakwoods: The roles of ungulate grazing and invertebrates. *Forest Ecology and Management* **192**:251-265.
- Panwar, P., & Bhardwaj, S.D. (2005). Handbook of practical forestry. Agrobios. India.
- Pausas, J.G. & Austin, M.P. (2001). Patterns of Plant Species Richness in Relation to Different Environments: *An Appraisal. Journal of Vegetation Science* **12** (2):153-166.
- Pausas, J.G. & Carreras, J. (1995). The effect of bedrock type, temperature and moisture on species richness of Pyrenean Scot pine forests. *Vegetatio* **116**: 85-92.
- Pavon, N.P., Hernandez-Trejo, H. and Rico-Gray, V. (2000). Distribution of plant life forms along an altitudinal gradient in the semi arid valley of Zapotitlan, Mexico. *Journal of vegetation science* **11**: 39-42.
- Pellerin, S., Lagneau, L.A., Lavoie, M. & Larocque, M. (2009) Environmental factors explaining the vegetation patterns in a temperate peatland, C. R. *Biologies*, doi:10.1016/j.crv.04.003.
- Pignatti, S. (1996). Some Notes on Complexity in Vegetation. *Journal of Vegetation Science* **7** (1): 7-12.
- Pokhriyal, P., Chauhan, D. S. & Todaria, N. P. (2012). Effect of altitude and disturbance on structure and species diversity of forest vegetation in a watershed of central Himalaya. *Tropical Ecology* **53** (3): 307-315.
- Pollock, M.L., Milner, J.M., Waterhouse, A., Holland, J.P. and Legg, C.J. (2005). Impacts of livestock in regenerating upland birch woodlands in Scotland. *Biological Conservation* **123**(4):443-452.
- Popma, J.; Bongers, F. & Meave del Castillo, J. (1988). Patterns in the vertical structure of the lowland rain forest Los Tuxlas, Mexico. *Vegetatio* **74**:81-91.
- Proctor, J.; Anderson, J.M. & Fogden, S.C.L. (1983). Ecological studies in four contrasting lowland rain forest in Gunung Mulu National Park. Sarawak. *Journal of Ecology* **71**: 237-260.
- Quinn, G.P. & Keough, M.J. (2002). Experimental Design and Data Analysis for Biologists. Cambridge University Press.
- R Development Core Team (2009). R version 2.10.1 (2009-12-14) The R Foundation for Statistical Computing. URL <http://www.R-project.org>. ISBN 3-900051-07-0.

- Rahbek, C. (1995). The elevational gradient of species richness, a uniform pattern? *Ecography* **18**: 200-205.
- Ramsay, P.M. and Oxley E.R.B. (1997). The growth composition of plant communities in the Ecuadorian paramos. *Plant Ecology* **131**: 173-192.
- Reddy, C. S., Pattanaik, C., Mohapatra, A. & Biswal, A.K. (2007). Phytosociological Observations on Tree Diversity of Tropical Forest of Similipal Biosphere Reserve, Orissa, India. *Taiwania* **52** (4): 352-359.
- Richard, J.V., Cottam, G., & McIntosh, R.P. (1966). Vegetational Continuum. *Science, New Series* **152** (3721): 546-547.
- Roberts, D.W. (2012). Package 'labdsv': Ordination and Multivariate Analysis for Ecology. Version 1.5-0. <http://ecology.msu.montana.edu/labdsv/R>.
- Roper, J. & Roberts, R.W. (2006). Forestry issues. Deforestation: Tropical Forests in Decline. CIDA forestry advisers network. pp 3-35.
- Schulz, B.K., Bechtold, W.A. & Zarnoch, S.J. (2009). Sampling and estimation procedures for the vegetation diversity and structure indicator. *Gen. Tech. Rep. PNW-GTR-781*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 53 p.
- Scott, J and Robert, J. (2006). Soil texture and nitrogen mineralization potential across a riparian toposequence in a semi-arid savanna. *Soil Boil. Biochem.* **38**(6): 1325-1333.
- Scott, D. (1995). Vegetation: A mosaic of discrete communities, or a continuum? *New Zealand Journal of Ecology* **19** (1): 47-52.
- Sebastia, M. T. (2004). Role of topography and soils in grassland structuring at the landscape and community scales. *Basic Appl. Ecol.* **5**: 331-346.
- Sebsebe Demissew (1980). A Study on the Structure of a Montane Forest. The Menagesha State Forest. M Sc. Thesis. A.A.U.
- Sebsebe Demissew et al. (1996). Forest resources of Ethiopia. In: EWNHS (ed), Important Bird Areas of Ethiopia. Ethiopian Wildlife and Natural History Society, Addis Ababa, pp. 10-25.
- Shipley, B. & Keddy, P.A. (1987). The individualistic and community-unit concepts as falsifiable hypotheses. *Vegetatio* **69**: 47-55.

- Slik, J.W.F, Poulsen, A.D., Ashton, P.S., Cannon, C.H., Eichhorn, K.A.O, Kartawinata, K., Lanniari, I. & Nagamasu, H. (2003). A floristic analysis of the lowland dipterocarp forests of Borneo. *Journal of Biogeography* **30**: 1517-1531.
- Slingenberg A., Braat, L., van der Windt, H., Rademaekers, K., Eichler, L. & Turner, K. (2009). Study on understanding the causes of biodiversity loss and the policy assessment framework. pp 14-60.
- Solon, J., Degórski, M. and Roozieliska, E. (2007). Vegetation response to a topographical-soil gradient. *Catena J.* **71** (2): 309-320.
- Steinmann, K., Linder, H.P. & Zimmermann, N.E. (2009). Modeling plant species richness using functional groups. *Ecological Modeling* **220**: 962-967.
- Stohlgren, T.J., Bachand, R.R., Onami, Y. & Binkley, D. (1997). Species environment relationships and vegetation patterns: effects of spatial scale and tree life stage. *Plant Ecology* **135**: 215-228.
- Stoll-Kleemann, S. & O'riordan, T. (2002). From Participation to Partnership in Biodiversity Protection: Experience from Germany and South Africa. *Society and Natural Resources* **15**: 161-177.
- Sunderlin, W.D. & Resosudarmo, I.A.P. (1996). Rate and causes of deforestation in Indonesia: Towards a resolution of the ambiguities. CIFOR *Occasional Paper No.* 9.
- Sutherland, W.J. (1998). *Ecological Census Techniques: A Hand Book*. Cambridge University Press.
- Swanson, F. J., Kratz, T. K., Caine, N., Woodmansee, R. G. (1988). Landform Effects on Ecosystem Patterns and Processes. *BioScience* **38** (2): 92-98.
- Tadesse Woldermariam (2003). Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for in situ conservation of wild *Coffea arabica* L. populations. Doctoral Dissertation, Center for Development Research, University of Bonn.
- Takyu, M. & Ohsawa, M. (1997). Distribution and regeneration strategies of major canopy dominants in species-rich subtropical/warm temperate rainforests in south-western Japan. *Ecol. Res.* **12**: 139-151.
- Tamartash, R., Yousefian, M., Tatian, M.R. & Ehsani, M. (2010). Vegetation Analysis in Rangelands of Lasem, Iran. *American-Eurasian J. Agric. & Environ. Sci.* **7** (4): 397-401.

- Tamrat Bekele (1994). Phytosociology and Ecology of a Humid Afromontane Forest on the Central Plateau of Ethiopia. *Journal of Vegetation Science* 5 (1): 87-98.
- Tanner, E.V.J., Vitousek, P.M. & Cuevas, E. (1998). Experimental investigation of nutrient limitation of forest growth on wet tropical mountains. *Ecology* 79: 10-22.
- ter Braak, C.J.F. & Prentice, I.C. (2004). A Theory of Gradient Analysis. *Advances in Ecological Research* 34:236-269.
- ter Braak, C.J.F. (1986). Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis. *Ecology* 67 (5):1167-1179.
- Teshome Soromessa, Demel Teketay & Sebsebe Demissew (2004). Ecological study of the vegetation in Gamo Gofa zone, Southern Ethiopia. *Tropical Ecology* 45 (2): 209-221.
- Titshall, L.W., O'Connor, T.G., and Morris, C.D. (2000). Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. *African Journal of Range and Forage Science* 17: 70-80.
- Ugland, K.I., Gray, J.S. & Ellingsen, K.E. (2003). The Species-Accumulation Curve and Estimation of Species Richness. *The Journal of Animal Ecology* 72 (5): 888-897.
- Valencia, R., Foster, R.B.G., Villa, R., Condit, J. C., Svenning, C., Hernandez, K., Romoleroux, E., Losos, E., Magard, A. and Balslev, H. (2004). Tree species distributions and local habitat variation in the Amazon: large forest plot in eastern Ecuador. *J. Ecol.* 92: 214-229.
- van Belle, G., Fisher, L.D., Heagerty, P.J. & Lumley, T. (2004). Biostatistics: A Methodology for the Health Sciences. Second Edition. John Wiley & Sons, Inc.
- Vandenbergh, C., Francois, F., Moravie, M.A., Gadallah, F. and Buttler, A. (2007). Short-term effects of cattle browsing on tree sapling growth in mountain wooded pastures. *Plant Ecology* 188:253-264.
- van der Maarel, E. (1979). Transformation of Cover-Abundance Values in Phytosociology and Its Effects on Community Similarity. *Vegetatio* 39 (2): 97-114.
- van der Maarel, E. (2005). Vegetation ecology - an overview. Blackwell Publishing Company.
- von Breitenbach, F. (1961). Forests and woodlands of Ethiopia: a geobotanical contribution to the knowledge of the principal plant communities of Ethiopia, with special regard to forestry. *Ethiopian Forestry Review* 1:5-10.

- Walker, P.A. & Hurley, P.T. (2004). Collaboration Derailed: The Politics of Community- Based Resource Management in Nevada County. *Society and Natural Resources* **17**:735-75.
- White, D.A. & Hood, C.S. (2004). Vegetation patterns and environmental gradients in tropical dry forests of the northern Yucatan Peninsula. *Journal of Vegetation Science* **15**: 151-160.
- Whittaker, R.H. (1951). A criticism of the plant association and climatic climax concepts. *Northwest Sci* **25**:17-31.
- Whittaker, R.H. (1956) Vegetation of the Great Smoky Mountains. *Ecol Monogr* **26**:1-80.
- Whittaker, R.H. (1972). Evolution and measurement of species diversity. *Taxon* **21**: 213-251.
- Wilkinson, D.M. (1999). The disturbing history of intermediate disturbance. *Oikos* **84**: 145-147.
- Williams, S., Pol, V., Spawls, S., Anteneh Shimelis & Ensermu Kelbessa (2004). Ethiopian Highlands: Biodiversity, Flagship Species Threats, Conservation. Agrupación Sierra Madre, S.C.
- Yengoh, G.T. (2008). Explaining the Causes of Deforestation with the Hyde Model (A Conceptual Framework). Interim Report. International Institute for Applied Systems Analysis Schlossplatz. A-2361 Laxenburg, Austria. pp 10-32.
- Zak, M. R., Cabido, M., Caceres, D. & Diaz, S. (2008). What Drives Accelerated Land Cover Change in Central Argentina? Synergistic Consequences of Climatic, Socioeconomic and Technological Factors. *Environmental Management* **42**:181-189.
- Zare-Chahouki, M.A., Khojasteh, F. and Tavili, A. (2012). Distribution of Vegetation type according to Edaphic properties and topography in Iran. *Pol.J.Environ.Stud.* **21** (4): 1071-1077.
- Zerihun Woldu & Backeus, I. (1991). The shrub land vegetation in Western Shewa, Ethiopia and its possible recovery. *Journal of Vegetation Science* **2**:173-180.
- Zerihun Woldu, Feoli, E. & Lissanework Nigatu (1989). Partitioning an elevation gradient of vegetation from south-eastern Ethiopia by probabilistic methods. *Vegetatio* **81**: 189-198.
- Zuur, A.K., Ieno, E.N. & Smith, G.M. (2007). Analyzing Ecological Data. Springer Science Business Media, LLC. New York.

Annexes

Annex 1: Data sheet used for collection of vegetation and environmental variables

Place-name _____ Vegetation type _____
Altitude _____ Slope _____ Aspect _____
Plot no _____

No	Local name/ specimen code no	Habit	DBH (if applicable)	Height (if applicable)	Other features	Abundance/number of individuals per plot	Cover/abundance

Annex 2: Data sheet used for estimation of disturbance intensity

Place name _____		Plot number _____
No	Disturbance indicator	Number/intensity of cases observed
1	Grazing/browsing (to be recorded based on the following scales: 0 = nil; 1 = slight; 2 = moderate; 3 = heavily and 4 = destructive)	
2	Number of foot trails	
3	Number of trees and shrubs cut	
5	Number of seedlings trampled	
	Total	

Annex 3: List of plant species identified in the study sites

SPECIES	ABBR	FAMILY
<i>Acacia abyssinica</i> Hochst. ex Benth.	Acaaby	Fabaceae
<i>Acalpha psilostachya</i> Hochst.	Acalpsi	Euphorbiaceae
<i>Acanthus sennii</i> Chiov.	Acaemi	Acanthaceae
<i>Achyranthes aspera</i> L.	Achasp	Amaranthaceae
<i>Achyropermum schimperi</i> (Hochst ex Briq.) Perkins	Achsch	Lamiaceae
<i>Acmella caulirhiza</i> Del.	Acmcau	Asteraceae
<i>Adiantum poiretii</i> Wikstr.	Adipoi	Adiantaceae
<i>Aeschynomene abyssinica</i> (A.Rich.) Vatke	Aesaby	Fabaceae
<i>Agarista salicifolia</i> (Comm. ex Lam.) Don	Agasal	Ericaceae
<i>Agrocharis incognita</i> (Norman) Heywood & Jury	Agrinc	Apiaceae
<i>Agrocharis melanantha</i> Hochst.	Agrmel	Apiaceae
<i>Aira caryophylla</i> L.	Aircar	Poaceae
<i>Ajuga integrifolia</i> Buch.-Ham. ex D. Don	Ajuint	Lamiaceae
<i>Alchemilla abyssinica</i> Fresen.	Alcaby	Rosaceae
<i>Alchemilla haumannii</i> Rothm.	Alchau	Rosaceae
<i>Alchemilla pedata</i> A. Rich.	Alcped	Rosaceae
<i>Alepidea peduncularis</i> Steud. ex A. Rich.	Aleped	Apiaceae
<i>Allophylus abyssinicus</i> (Hochst.) Radlk.	Allaby	Sapindaceae
<i>Anchusa affinis</i> R.Br.	Ancaff	Boraginaceae
<i>Andropogon amethystinus</i> Steud.	Andame	Poaceae
<i>Anisopappus buchwaldii</i> (Hook.f.) Ortiz & Paiva	Anibuc	Asteraceae
<i>Anthemis tigrensensis</i> J.Gay ex A.Rich.	Anttig	Asteraceae
<i>Anthospermum herbaceum</i> L.f.	Anther	Rubiaceae
<i>Apodytes dimidiata</i> E.Mey ex Arn.	Apodim	Icacinaceae
<i>Arundinaria alpina</i> K. Schum.	Arualp	Poaceae
<i>Asparagus africanus</i> Lam.	Aspafr	Asparagaceae
<i>Asplenium protensum</i> Schrad	Asppro	Aspleniaceae
<i>Asplenium abyssinicum</i> Fee	Aspaby	Aspleniaceae
<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Aspaet	Aspleniaceae
<i>Asplenium ceii</i> Pic.-Serm.	Aspcei	Aspleniaceae
<i>Asplenium elliottii</i> C.H. Wright	Aspell	Aspleniaceae
<i>Asplenium monanthes</i> L.	Aspmon	Aspleniaceae
<i>Athrixia rosmarinifolia</i> (Sch. Bip. ex Walp.) Oliv. & Hiern	Athros	Asteraceae
<i>Avena sativa</i> L.	Avesat	Poaceae
<i>Bartsia decurva</i> Hochst. ex Benth.	Bardec	Scrophulariaceae
<i>Bartsia longiflora</i> Hochst.ex Benth.	Barlon	Scrophulariaceae
<i>Bersama abyssinica</i> Fresen.	Beraby	Melanthaceae
<i>Bidens camporum</i> (Hutch.) Mesfin	Bidcam	Asteraceae
<i>Bidens macroptera</i> (Sch. Bip. ex Chiov.) Mesfin	Bidmac	Asteraceae

Annex 3 : continued

Blechnum attenuatum (Sw.) Mett.
Bothriocline schimperi Oliv. & Hiern ex Benth.
Bromus pectinatus Thunb.
Brucea antidysentrica J.F. Mill.
Buddleja polystachya Fresen.
Caesalpinia decapetala (Roth) Alston
Calpurnia aurea (Ait.) Benth.
Canthium oligocarpum Hiern
Carduus leptacanthus Fresen.
Carduus schimperi Sch. Bip. ex A. Rich.
Carex conferta Hochst. ex A. Rich.
Carex erythrorrhiza Bock.
Carex simensis Hochst. ex A. Rich.
Carex spicato-paniculata Bock. ex C.B. Clarke
Carex steudneri Bock.
Carissa spinarum L.
Cassipourea malosana (Baker) Alston
Celtis africana Burm.f.
Cerastium octandrum A. Rich.
Cerastium octandrum A. Rich.
Cheilanthes farinosa (Forssk.) Kulf.
Chiliocephalum schimperi Benth.
Cineraria deltoidea Sond.
Clausena anisata (Willd.) Benth.
Clematis hirsuta Perr. & Guill.
Clematis simensis Fresen.
Clerodendrum alatum Gurke
Clitoria ternatea L.
Clutia abyssinica Jaub. & Spach.
Clutia lanceolata Forssk.
Colutea abyssinica Kunth & Bounche
Commelina imberbis Ehrenb. ex Hassk.
Convolvulus kilimandschari Engl.
Conyza abyssinica Sch. Bip. ex A. Rich.
Conyza bonarensis (L.) Cronq.
Conyza hypoleuca A. Rich.
Conyza megensis F.G. Davies
Conyza newii Oliv. & Hiern
Conyza pyrrhopappa Sch. Bip. ex A. Rich.
Conyza schimperi Sch. Bip. ex A. Rich.
Conyza stricta Willd.

Bleatt	Blechnaceae
Botsch	Asteraceae
Bropec	Poaceae
Bruant	Simaroubaceae
Budpol	Loganiaceae
Caedec	Fabaceae
Calaur	Fabaceae
Canoli	Rubiaceae
Carlep	Asteraceae
Carsch	Asteraceae
Carcon	Cyperaceae
Carery	Cyperaceae
Carsim	Cyperaceae
Carespi	Cyperaceae
Carste	Cyperaceae
Carspi	Apocynaceae
Casmal	Rhizophoraceae
Celafr	Ulmaceae
Ceroct	Caryophyllaceae
Ceroct	Caryophyllaceae
Chefar	Sinopteridaceae
Chisch	Asteraceae
Cindel	Asteraceae
Claani	Rutaceae
Clehir	Ranunculaceae
Clesim	Ranunculaceae
Cleala	Lamiaceae
Cliter	Fabaceae
Cluaby	Euphorbiaceae
Clulan	Euphorbiaceae
Colaby	Fabaceae
Comimb	Commelinaceae
Convkil	Convolvulaceae
Conaby	Asteraceae
Conbon	Asteraceae
Conhyp	Asteraceae
Conmeg	Asteraceae
Connew	Asteraceae
Conpyr	Asteraceae
Consch	Asteraceae
Constr	Asteraceae

Annex 3 : continued

Conyza subcaposa O.Hoffm.
Crassocephalum macropappum (Sch.Bip. ex A.Rich.) S.Moore
Crassula alba Forssk.
Crotalaria agatiflora Schweinf.
Croton macrostachyus Del.
Cyanotis barbata D. Don
Cynoglossum amplifolium Hochst. ex A.DC.
Cynoglossum coeruleum Hochst. ex A.DC.
Cynoglossum densefoliatum Chiov.
Cyperus alternifolius L.
Cyperus denudatus Lf
Cyperus elegantulus Steud.
Cyperus flavescens L.
Cyphostemma cyphopetalum (Fresen.) Desc. ex Wild & Drum.
Datura stramonium L.
Delphinium dasycaulon Fresen.
Desmodium repandum (Vahl) DC.
Dicrocephala chrysanthemifolia (Bl.) DC.
Dicrocephala integrifolia (L.f.) Kuntze
Dipsacus pinnatifidus Steud. ex A.Rich.
Discopodium penninnervium Hochst.
Dodonea angustifolia L.f.
Dombeya torrida (J.F.Gmel.) P. Bamps
Dovyalis abyssinica (A.Rich.) Warb.
Dovyalis verrucosa (Hochst.) Warb.
Dracaena afromontana Mildbr.
Dregea schimperi (Decne) Bullok
Droguetia iners (Forssk.) Schweinf.
Dryopteris kilimensis (Kuhn) Kuntze
Dryopteris lewalleana Pic.Serm.
Dumasia villosa DC.
Echinops amplexicaulis Oliv.
Ehrharta erecta Lam.
Ekebergia capensis Sparrm.
Embelia schimperi Vatke
Englerina woodfordioides (Schweinf.) M. Gilbert
Epilobium hirsutum L.
Epilobium stereophyllum Fresen.
Erica arborea L.
Erica tenuipilosa (Engl.ex Alm & Fries) Cheek
Erythrina brucei Schweinf.

Consub	Asteraceae
Crosmac	Asteraceae
Craal	Crassulaceae
Croaga	Fabaceae
Cromac	Euphorbiaceae
Cyabar	Commelinaceae
Cynamp	Boraginaceae
Cyncoe	Boraginaceae
Cynden	Boraginaceae
Cypalt	Cyperaceae
Cypden	Cyperaceae
Cypele	Cyperaceae
Cypflav	Cyperaceae
Cypcyp	Vitaceae
Datstr	Solanaceae
Deldas	Ranunculaceae
Desrep	Fabaceae
Dicchr	Asteraceae
Dicint	Asteraceae
Dippin	Dipsacaceae
Dispen	Solanaceae
Dodang	Sapindaceae
Domtor	Sterculariaceae
Dovaby	Flacourtiaceae
Dovver	Flacourtiaceae
Draafr	Dracaenaceae
Dresch	Asclepiadaceae
Droine	Urticaceae
Drykil	Dryopteridaceae
Drylew	Dryopteridaceae
Dumvil	Fabaceae
Echamp	Asteraceae
Ehrere	Poaceae
Ekecap	Meliaceae
Embsch	Myrsinaceae
Engwoo	Loranthaceae
Epihir	Onagraceae
Episte	Onagraceae
Eriarb	Ericaceae
Eriten	Ericaceae
Erybru	Fabaceae

Annex 3 : continued

Eugenia bukobensis Engl.
Euphorbia abyssinica Gmel.
Euphorbia depauperata A. Rich.
Euphorbia petitiiana A. Rich.
Euphorbia schimperiana Scheele
Euryops antinorii (Avetta) S. Moore
Festuca abyssinica Hochst. ex A. Rich.
Ficus sur Forssk.
Flacourtia indica (Burm.f.) Merr.
Galiniera saxifraga (Hochst.) Bridson
Galium aparinoides Forssk.
Galium simense Fresen.
Geranium aculeolatum Oliv.
Geranium arabicum Forssk.
Gerbera piloselloides (L.) Cass.
Gladiolus abyssinicus (Brongn. ex Lemaire) Goldblatt & de Vos
Glycine wightii (Wightii & Arn.) Verdc.
Gnidia glauca (Fresen.) Gilg.
Guizotia scabra (Vis) Chiov.
Habenaria peristylodes A. Rich.
Hagenia abyssinica (Brace) J.F. Gmel.
Halleria lucida L.
Haplocarpha hastata Lewin
Haplocarpha reupellii (Sch.Bip) Beauv.
Haplocarpha schimperi (Sch.Bip) Beauv.
Hebenstretia angolensis Rolfe
Helichrysum formosissimum Sch.Bip.ex A. Rich
Helichrysum forsskahlii (J.F. Gmel.) Hilliard & Burt
Helichrysum gofense Cufod.
Helichrysum schimperi (Sch. Bip.ex A. Rich.) Moeser
Helichrysum stenopterum DC.
Helichrysum traversii Chiov.
Heracleum abyssinicum (Boiss.) Norman
Heteromorpha trifoliata (Wendel.) Eckl. & Zeyh.
Hibiscus berberidifolius A.Rich.
Hibiscus calyphyllus Cavan.
Hibiscus diversifolius Jacq.
Hibiscus ludwigii Eckl. & Zeyh.
Hibiscus macranthus Hochst. ex A. Rich.
Hyparrhenia anthistiriodes (A. Rich.) Stapf
Hyparrhenia hirta (L.) Stapf

Eugbuk	Myrtaceae
Eupaby	Euphorbiaceae
Eupdep	Euphorbiaceae
Euppel	Euphorbiaceae
Eupsch	Euphorbiaceae
Eurant	Asteraceae
Fesaby	Poaceae
Ficbur	Moraceae
Flaind	Flacourtiaceae
Galsax	Rubiaceae
Galapa	Rubiaceae
Galsim	Rubiaceae
Geracu	Geraniaceae
Gerara	Geraniaceae
Gerpil	Asteraceae
Glaaby	Iridaceae
Glywig	Fabaceae
Gnigla	Thymelaceae
Guisca	Asteraceae
Habper	Orchidaceae
Hagaby	Rosaceae
Halluc	Scrophulariaceae
Haphas	Asteraceae
Hapreu	Asteraceae
Hapsch	Asteraceae
Hebang	Scrophulariaceae
Helfor	Asteraceae
Helfors	Asteraceae
Helgof	Asteraceae
Helsch	Asteraceae
Helste	Asteraceae
Heltra	Asteraceae
Heraby	Apiaceae
Hettri	Apiaceae
Hibber	Malvaceae
Hibcal	Malvaceae
Hibdiv	Malvaceae
Hiblud	Malvaceae
Hibmac	Malvaceae
Hypant	Poaceae
Hyphir	Poaceae

Annex 3 : continued

Hypericum quartinianum A. Rich.
Hypericum revolutum Vahl
Hypoestes forskoolii (Vahl) R. Br.
Hypoestes triflora (Forssk.) Roem. & Shult.
Ilex mitis (L.) Radlk.
Impatiens hochstetteri Warb.
Impatiens tinctoria A. Rich.
Indigofera rothii Bak.
Inula confertiflora A. Rich.
Inula paniculata (Klatt) Burt-Davy
Jasminum stans Pax
Jasminum abyssinicum Hochst. ex DC.
Jasminum dichotomum Vahl
Jasminum grandiflorum L.
Juniperus procera Hochst. ex Endl.
Kalanchoe petitiiana A. Rich.
Kniphofia foliosa Hochst.
Kniphofia isoetifolia Steud. ex Hochst.
Kniphofia schimperi Baker
Koeleria capensis (Steud.) Nees
Kohautia platyphylla (K.Schum.) Bremek.
Lactuca inermis Forssk.
Lagenaria abyssinica (Hook.f.) C. Jeffrey
Laggera alata (D.Don) Sch.Bip.ex Oliv.
Laggera crispata (Vahl) Hepper & Wood
Laggera tomentosa (Sch.Bip.ex A.Rich.) Oliv. & Hiern
Lannea fruticosa (A.Rich.) Engl.
Lavatera abyssinica Hutch. & Bruce
Leonotis ocyimifolia (Bunn. f.) Iwarsson var. *raineriana* (Vis.) Iwarsson
Leucas stachydiformis (Hochst ex Benth.) Briq.
Lippia adoensis Hochst. ex Walp. var. *adoensis*
Lobelia giberroa Hemsl.
Lobelia rhynchopetalum Hemsl.
Macaranga capensis (Baill.) Sim
Macrotyloma axillare (E.Mey.) Verdc.
Maesa lanceolata Forrsk.
Maytenus addat (Loes.) Sebsebe
Maytenus arbutifolia (A.Rich.) Wilczek
Maytenus gracilipes (Welw. ex Oliv.) Exell subsp. *arguta* (Loes.) Sebsebe
Maytenus heterophylla (Eckl. & Zeyh.) Robson

Hypqua Hypericaceae
Hyprevo Hypericaceae
Hypfor Acanthaceae
Hyptri Acanthaceae
Ilemit Aquifoliaceae
Imphoc Balsaminaceae
Imptin Balsaminaceae
Indrot Fabaceae
Inucon Asteraceae
Inupan Asteraceae
Jasaby Oleaceae
Jasdic Oleaceae
Jasgra Oleaceae
Jassta Oleaceae
Junpro Cuppressaceae
Kalpet Crassulaceae
Knifol Asphodelaceae
Kniiso Asphodelaceae
Knisch Asphodelaceae
Koecap Poaceae
Kohpla Rubiaceae
Lacine Asteraceae
Lagaby Cucurbitaceae
Lagala Asteraceae
Lagcri Asteraceae
Lagtom Asteraceae
Lanfru Anacardiaceae
Lavaby Malvaceae
Leoocy Lamiaceae
Leusta Lamiaceae
Lipado Verbenaceae
Lobgib Lobeliaceae
Lobrhy Lobeliaceae
Maccap Euphorbiaceae
Macaxi Fabaceae
Maelan Myrsinaceae
Mayadd Celastraceae
Mayarb Celastraceae
Maygra Celastraceae
Mayhet Celastraceae

Annex 3 : continued

<i>Maytenus undata</i> (Thunb.) Blakelock	Mayund	Celastraceae
<i>Meineckia phyllantoides</i> Baill	Meiphy	Euphorbiaceae
<i>Mellera lobulata</i> S.Moore	Mellob	Acanthaceae
<i>Mikania capensis</i> DC.	Mikcap	Asteraceae
<i>Mikaniopsis clematoides</i> (Sch. Bip.ex A.Rich.) Milne-Redh.	Mikcle	Asteraceae
<i>Milletia ferruginea</i> (Hochst) Bak.	Milfer	Fabaceae
<i>Mimulopsis solmii</i> Schweinf.	Mimsol	Acanthaceae
<i>Momordica pterocarpa</i> Hochst. ex A. Rich.	Mompte	Cucurbitaceae
<i>Moraea stricta</i> Baker	Morstr	Iridaceae
<i>Myrica salicifolia</i> A. Rich.	Myrsal	Myricaceae
<i>Myrsine africana</i> L.	Myrafr	Myrsinaceae
<i>Myrsine melanophloeos</i> (L.) R. Br.	Myrmel	Myrsinaceae
<i>Nepeta azurea</i> R.Br. ex Benth.	Nepazu	Lamiaceae
<i>Nuxia congesta</i> R.Br.Fresen.	Nuxcon	Loganiaceae
<i>Ocimum lamiifolium</i> Hochst ex. Benth.	Ocilam	Lamiaceae
<i>Oenanthe palustris</i> (Choiv.) Norman	Oenpal	Apiaceae
<i>Olea capensis</i> L. subsp. <i>macrocarpa</i> (c. H. Wright) Verdc.	Olecap	Oleaceae
<i>Olea europaea</i> L. subsp. <i>cuspidata</i> (Wall. ex G.Don) Cif.	Oleeur	Oleaceae
<i>Olinia rochetiana</i> A.Juss.	Oliroc	Oliniaceae
<i>Oncoba spinosa</i> Forssk.	Oncspi	Flacourtiaceae
<i>Orobanche minor</i> Smit	Oromin	Orobanchaceae
<i>Osyris quadripartita</i> Decn.	Osyqua	Santalaceae
<i>Oxanthus speciosus</i> DC.	Oxaspe	Rubiaceae
<i>Parochaetus communis</i> D.Don	Parocom	Fabaceae
<i>Pavetta abyssinica</i> Fresen.	Pavaby	Rubiaceae
<i>Pellaea quadripinnata</i> (Forssk.) Prantl	Pelqua	Sinopteridaceae
<i>Pennisetum sphacelatum</i> (Nees) Th. Dur. & Schinz	Pensph	Poaceae
<i>Pentas schimperiana</i> (A.Rich.) Vatke	Pensch	Rubiaceae
<i>Periploca linearifolia</i> Quart.-Dill. & A.Rich.	Perlin	Asclepiaceae
<i>Periscaria senegalensis</i> (Meisn.) Sojak	Persen	Polygonaiceae
<i>Peucedanum mattirolii</i> Chiov.	Peumat	Apiaceae
<i>Phagnalon abyssinicum</i> Sch. Bip. ex A.Rich.	Phaaby	Asteraceae
<i>Phragmanthera sarertaensis</i> (Hutch. & E.A. Bruce) M.Gilbert	Phrsar	Loranthaceae
<i>Phyllanthus ovalifolius</i> Forssk.	Phyova	Euphorbiaceae
<i>Physalis peruviana</i> L.	Phyper	Solanaceae
<i>Phytolacca dodecandra</i> L.'Herit.	Phydod	Phytolaccaceae
<i>Pimpinella oreophila</i> Hook.f.	Pimore	Apiaceae
<i>Pittosporum viridiflorum</i> Sims	Pitvir	Pittosporaceae
<i>Plantago africana</i> Verdc.	Plaaftr	Plantaginaceae
<i>Plectranthus alpinus</i> (Vatke) Ryding	Plealp	Lamiaceae
<i>Plectranthus lanuginosus</i> (Hochst ex Benth.) Agnew	Plelan	Lamiaceae

Annex 3 : continued

Plectranthus punctatus (L.f.) L'Her.
Plectrocephalus varians (A.Rich.) C. Jeff.
Podocarpus falcatus (Thunb.) R.B. ex Mirb.
Polystichum magnificum F.Bellard
Polystichum wilsonii H.Christ
Premna schimperi Engl.
Protea gaguedi J.F.Gmel.
Prunus africana (Hook.f.) Kalkm
Pseudognaphalium luteoalbum Hilliard & Burtt
Pseudognaphalium richardianum (Cufod.) Hilliard & Burtt
Psychotria orophila Petit
Pteridium aquilinum (L.) Kuntze
Pteris catoptera Kuntze
Pteris cretica L.
Pteris dentata Forssk.
Pycnostachys abyssinica Fresen.
Pycnostachys eminii Gurke
Pycnostachys meyeri Gurke
Ranunculus aberdaricus Ulbr.
Ranunculus multifidus Forssk.
Ranunculus oreophytus Del.
Ranunculus tembensis Fresen.
Rhabdotosperma scrophulariifolia (Hochst. ex A. Rich.) Hartl
Rhamnus prinoides L'Herit
Rhamnus staddo A.Rich.
Rhus longipes Engl.
Rhus glutinosa A.Rich.
Rhus retinorrhoea Oliv.
Rosa abyssinica Lindley
Rubia cardifolia L.
Rubus apetalus Poir.
Rubus steunderi Schweinf.
Rumex abyssinicus Jacq.
Rumex nepalensis Spreng.
Rumex nervosus Vahl
Salix subserrata Willd.
Salvia nilotica Jacq.
Sanicula elata Buch-Ham. ex D. Don
Satureja abyssinica (Benth.) Briq.
Satureja imbricata (Forssk.) Briq.
Satureja paradoxa (Vatke) Engl. ex Seybold

Plepun	Lamiaceae
Plevar	Asteraceae
Podfal	Podocarpaceae
Polmag	Dryopteridaceae
Polwil	Dryopteridaceae
Presch	Lamiaceae
Progag	Proteaceae
Pruafr	Rosaceae
Pselut	Asteraceae
Pseric	Asteraceae
Psyoro	Rubiaceae
Pteaqu	Hypolepidaceae
Ptecat	Pteridaceae
Ptecre	Pteridaceae
Pteden	Pteridaceae
Pycaby	Lamiaceae
Pycemi	Lamiaceae
Pycmey	Lamiaceae
Ranabe	Ranunculaceae
Ranmul	Ranunculaceae
Ranore	Ranunculaceae
Rantem	Ranunculaceae
Rhascr	Scrophulariaceae
Rhapri	Rhamnaceae
Rhasta	Rhamnaceae
Rhulon	Anacardiaceae
Rhuglu	Anacardiaceae
Rhuret	Anacardiaceae
Rosaby	Rosaceae
Rubcar	Rubiaceae
Rubape	Rosaceae
Rubste	Rosaceae
Rumaby	Polygonaceae
Rumnep	Polygonaceae
Rumnern	Polygonaceae
Salsub	Salicaceae
Salnil	Lamiaceae
Sanela	Apiaceae
Sataby	Lamiaceae
Satimb	Lamiaceae
Satpar	Lamiaceae

Annex 3 : continued

Satureja punctata (Benth.) Briq.
Satureja simensis (Benth.) Briq.
Scabiosa columbaria L.
Scadoxus multiflorus (Martyn) Raf.
Schefflera abyssinica (Hochst. ex A.Rich.) Harms
Schefflera volkensii (Engl.) Harms
Schoenoplectus corymbosus (Roem. & Schult.) Rayn.
Schrebera alata (Hochst.) Welw.
Scolopia theifolia Gilg
Sebaea branchyphylla Griseb.
Selaginella caffrorum (Milde) Hiern.
Senecio fresenii Sch.Bip. ex Oliv. & Hiern.
Senecio myriocephalus Sch.Bip. ex A. Rich.
Senecio ochrocarpus Olivo & Hiern
Senecio ragazzii Chiov.
Senecio schimperii Sch.Bip. ex A.Rich.
Senecio schultzii Hochst. ex A. Rich.
Senecio unionis Sch.Bip. ex A.Rich.
Senna septemtrionalis (Viv.) Irwin & Barneby
Setaria incrassata (Hochst.) Hack.
Sida tenuicarpa Vollesen
Sideroxylon oxyacanthum Baill.
Smilax aspera L.
Solanecio gigas (Vatke) C. Jeffrey
Solanum incanum L.
Solanum dasyphyllum Schumach.
Solanum marginatum L.f.
Solanum nigrum L.
Solanum vilosum Mill.
Sonchus bipontini Asch.
Stachys aculeolata Hook. f.
Stephania abyssinica (Dill. & A. Rich.) Walp.
Stomatanthes africanus (Oliv. & Hiern) R.M.King & H.Rob.
Streblochaete longiarista (A. Rich.) Pilger
Swertia abyssinica Hochst.
Swertia fimbriata (Hochst.) Cufod.
Swertia kilimandscharica Engl.
Swertia lugardae Bullock
Syzygium guineense (Willd.) DC.
Tacazzea conferta N.E.Br.

Satpun	Lamiaceae
Satsim	Lamiaceae
Scacol	Dipsacaceae
Scamul	Amoryllidaceae
Schaby	Araliaceae
Schvol	Araliaceae
Schcor	Cyperaceae
Schala	Oleaceae
Scothe	Flacourtiaceae
Sebbra	Gentianeae
Selcaf	Selaginellaceae
Senfre	Asteraceae
Senmyr	Asteraceae
Senorch	Asteraceae
Senrag	Asteraceae
Sensch	asteraceae
Sensch	Asteraceae
Senuni	Asteraceae
Sensep	Fabaceae
Setinc	Poaceae
Sidten	Malvaceae
Sidoxo	Sapotaceae
Smiasp	Smilacaceae
Solgig	Asteraceae
Solinc	Solanaceae
Soldas	Solanaceae
Solmar	Solanaceae
Solnig	Solanaceae
Solvil	Solanaceae
Sonbip	Asteraceae
Staacu	Lamiaceae
Steaby	Menispermaceae
Stoaf	Asteraceae
Strlon	Poaceae
Sweaby	Gentianeae
Swefim	Gentianeae
Swekil	Gentianeae
Swelug	Gentianeae
Syzgui	Myrtaceae
Taccon	Asclepiaceae

Annex 3 : continued

Tagetes minuta L.

Tephrosia interrupta Hochst. & Steud. ex Engl.

Thalictrum rhynchocarpum Dill. & A.Rich.

Thymus schimperi Ronn.

Toddalia asiatica (L.) Lam.

Trichocladus ellipticus Eckl. & Zeyh.

Trifolium cryptopodium Steud. ex A. Rich.

Trifolium multinerve A. Rich.

Triumfetta annua L.

Uebelina abyssinica Hochst.

Urera hypselodendron (A.Rich.) Wedd.

Verbascum sinaiticum Benth.

Vernonia amygdalina Del.

Vernonia auriculifera Hiern

Vernonia bipontini Vatke

Vernonia filigera Oliv. & Hiern

Vernonia hochstetteri Sch.Bip. ex Walp.

Vernonia myriantha Hook.f.

Vernonia rueppellii Sch.Bip. ex Walp.

Vernonia schimperi DC.

Vernonia urticifolia A. Rich.

Vicia sativa L.

Zehneria scabra (Linn.f.) Sond.

Tagmin	Asteraceae
Tepint	Fabaceae
Tharhy	Ranunculaceae
Thysch	Lamiaceae
Todasi	Rutaceae
Triell	Hamamelidaceae
Tricry	Fabaceae
Trimul	Fabaceae
Truann	Tiliaceae
Uebaby	Caryophyllaceae
Urehyp	Urticaceae
Versin	Scrophulariaceae
Veramy	Asteraceae
Veraur	Asteraceae
Verbip	Asteraceae
Verfil	Asteraceae
Verhoc	Asteraceae
Vermyr	Asteraceae
Verrue	Asteraceae
Versch	Asteraceae
Verutr	Asteraceae
Vicsat	Fabaceae
Zehsca	Cucurbitaceae

Annex 4: Analysis of variance tables for variables which did not have significant variation amongst plant communities in the study area

Response: Electrical conductivity

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	0.18	0.036	1.69	0.14
Residuals	78	1.67	0.021		

Response: Organic carbon

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	133.9	26.7	2.1	0.07
Residuals	78	6.45	12.51		

Response: Silt

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	418.2	83.6	2.2	0.06
Residuals	78	2918.8	37.4		

Response: Phosphorus

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	10001	2000	1.3	0.88
Residuals	78	46816	600.2		

Response: Total nitrogen

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
as.factor(Community)	5	0.8	0.16	1.88	0.1065
Residuals	78	6.8	0.09		

Annex 5: Pair-wise comparisons mean values of environmental variables in different plant communities of the study area (Tukey's HSD (honestly significant difference))

A. Tukey multiple comparisons of altitude means 95% family-wise confidence level

Community	diff	lwr	upr	p adj
2-1	294.3	65.4	523.3	0.004
3-1	116.3	-122.6	355.3	0.7
4-1	215	-45	475	0.16
5-1	454.5	372.9	535.9	0.00
6-1	111	-148.9	371	0.8
3-2	-178	-382.6	26.6	0.12
4-2	-79	-308	149.7	0.9
5-2	80	11	148	0.01
6-2	-183	-412	45.8	0.19
4-3	98.7	-140.2	337.6	0.83
5-3	266	56.5	475.7	0.005
6-3	-5.15	-244	233	0.99
5-4	188	104.3	272	0.00
6-4	-103.9	-364	156.2	0.85
6-5	-289.3	-373.2	-205.5	0.00

B. Tukey multiple comparisons of slope means 95% family-wise confidence level

Community	diff	lwr	upr	p adj
2-1	14.7	1.3	28	0.02
3-1	11.7	-2.2	25.7	0.15
4-1	24.5	9.3	39.7	0.00
5-1	32.3	22.3	42.3	0.00
6-1	12.3	-2.8	27.6	0.17
3-2	-2.9	-14.9	8.9	0.97
4-2	9.8	-3.5	23.2	0.27
5-2	18.6	10.2	27	0.00
6-2	-2.3	-15.7	11	0.99
4-3	12.8	-1.2	26.8	0.09
5-3	20.8	11.7	29.8	0.00
6-3	0.63	-13.3	14.6	0.99
5-4	7.1	-3.2	17.3	0.34
6-4	-12	-27	3	0.19
6-5	-10.3	-20.6	-0.02	0.05

C. Tukey multiple comparisons of clay means 95% family-wise confidence level

Community	diff	lwr	upr	p adj
2-1	-6.9	-16.8	2.9	0.30
3-1	-13.4	-23.7	-3	0.003
4-1	-5.3	-16.5	5.9	0.74
5-1	-15.2	-25.2	-5.2	0.00
6-1	-7.8	-19	3.4	0.32
3-2	-6.5	-15.3	2.3	0.27
4-2	1.7	-8.2	11.5	0.99
5-2	-6.6	-15	1.9	0.21
6-2	-0.8	-10.7	8.9	0.99
4-3	8.2	-2	18.4	0.20
5-3	-1.95	-11	7.1	0.98
6-3	5.6	-4.6	15.8	0.60
5-4	-7.4	-17.7	2.9	0.29
6-4	-2.5	-13.7	8.6	0.98
6-5	4.2	-6	14.5	0.83

D. Tukey multiple comparisons of sand means 95% family-wise confidence level

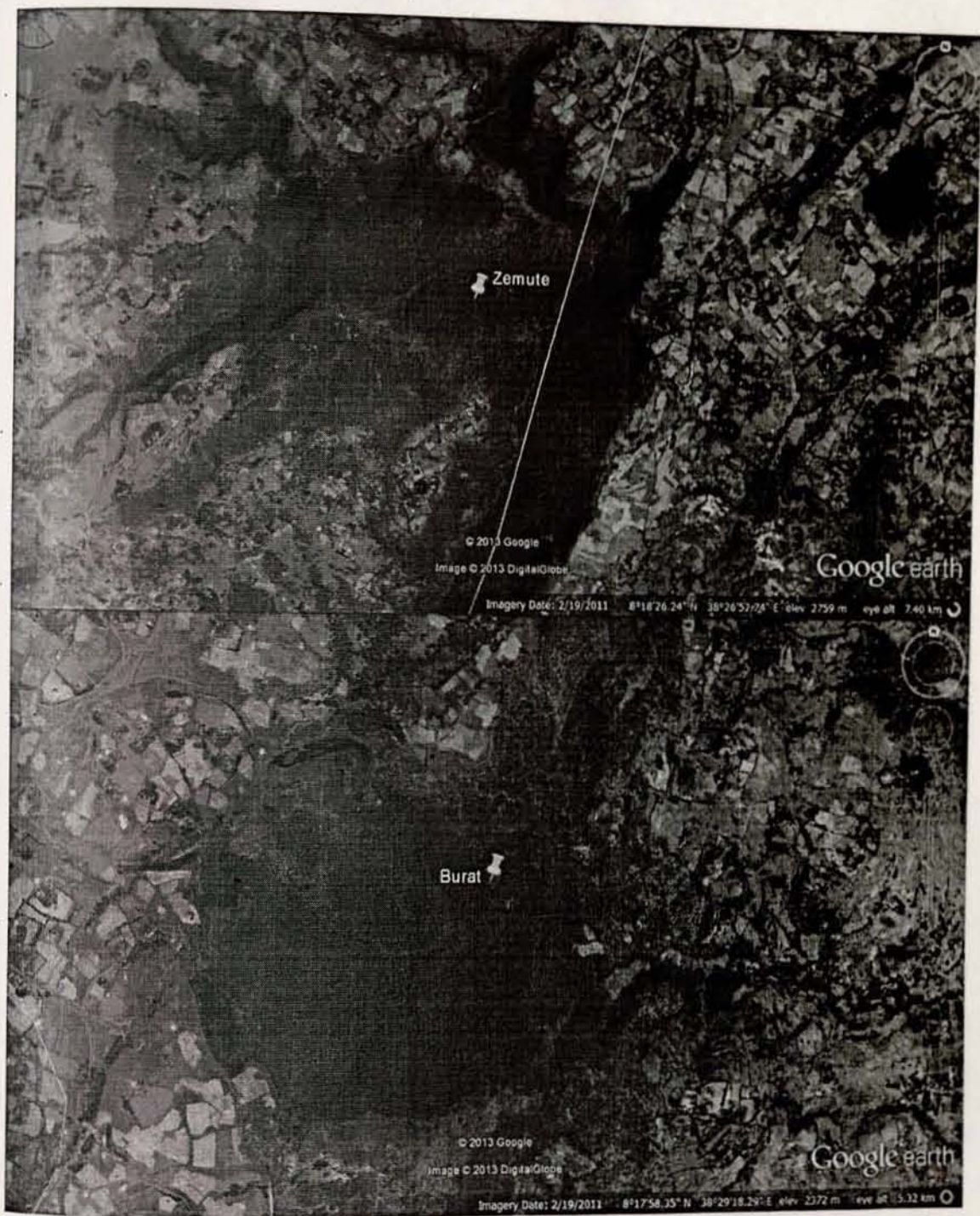
Community	diff	lwr	upr	p adj
2-1	3.7	-4.9	12.3	0.8
3-1	7.8	-1.2	16.8	0.12
4-1	4.5	-5.3	14.3	0.75
5-1	9.7	0.95	18.4	0.020
6-1	2.5	-7.3	12.3	0.97
3-2	4.1	-3.6	11.8	0.62
4-2	0.9	-7.8	9.5	0.99
5-2	5.6	-1.7	12.9	0.24
6-2	-1.1	-9.7	7.5	0.99
4-3	-3.3	-12.2	5.7	0.89
5-3	2.6	-5.3	10.4	0.93
6-3	-5.3	-14.3	3.7	0.53
5-4	3.9	-5	12.9	0.79
6-4	-2	-11.8	7.8	0.99
6-5	-5.9	14.9	3	0.38

Table E: Tukey multiple comparisons of disturbance means 95% family-wise confidence level

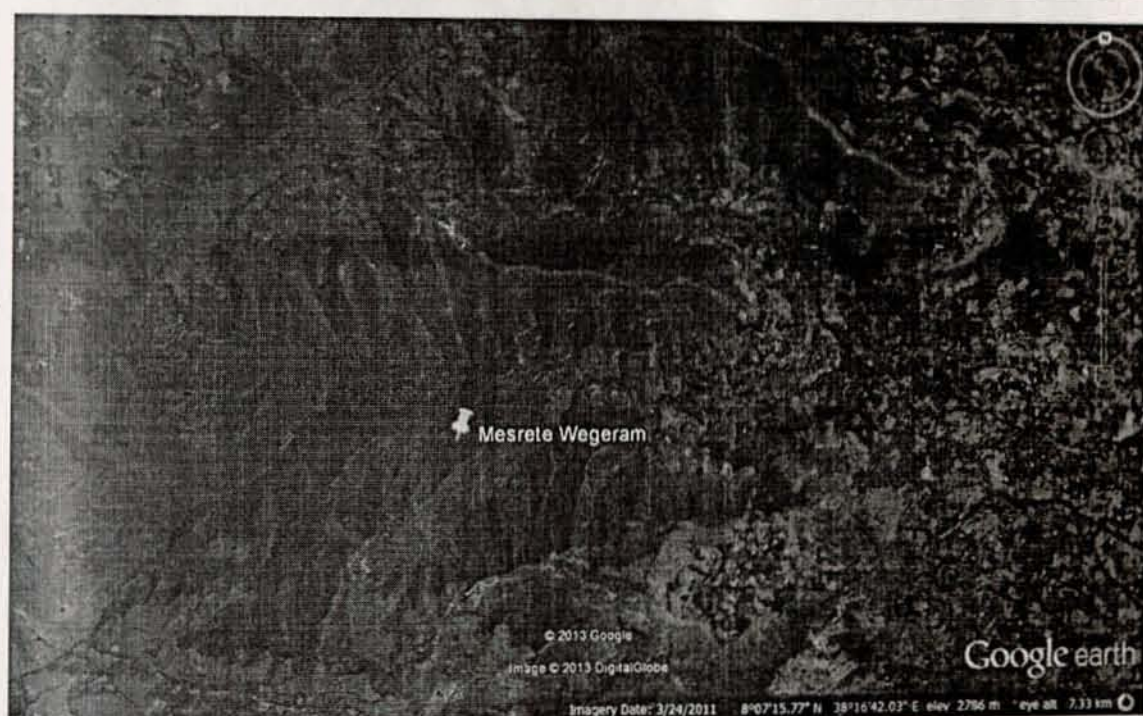
Community	diff	lwr	upr	p adj
2-1	1.6	-2.9	6	0.9
3-1	-0.94	-5.6	3.7	0.99
4-1	2.2	-2.9	7.3	0.81
5-1	9.2	4.6	13.8	0.00
6-1	-1.2	-6.3	3.9	0.98
3-2	-2.5	-6.5	1.5	0.45
4-2	0.6	-3.8	5	0.99
5-2	0.95	-2.9	4.8	0.98
6-2	-2.7	-7.2	1.7	0.5
4-3	3	-1.5	7.8	0.38
5-3	7.6	3.4	11.7	0.00
6-3	-0.23	-4.9	4.4	0.99
5-4	4	-0.7	8.7	0.13
6-4	-3.4	-8.5	1.7	0.4
6-5	-7.4	12	-2.7	0.00

Annex 6: Google earth images of the study sites











Annex 7: NMDS ordination diagram showing the direction of influence of environmental variables in the study communities

