Ecology, Carbon Stock Quantification and Formulation of Allometric Models for Some Trees of Sele-Nono Forest, Southwest Ethiopia: Implication for Biodiversity Conservation and Climate Change Mitigation

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June 2019

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

Addis Ababa University

Addis Ababa, Ethiopia

June 2019

ADDIS ABABA UNIVERSITY

GRADUATE PROGRAMMES

This is to certify that the thesis prepared by Alemayehu Kefalew Shembo, entitled "*Ecology, Carbon Stock Quantification and Formulation of Allometric Models for Some Trees of Sele-Nono Forest, Southwest Ethiopia: Implication for Biodiversity Conservation and Climate Change Mitigation*" and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Plant Biology and Biodiversity Management complies with the regulations of the University and meets the accepted standards with respect to originality and quality

Signed by Research Supervisors:

Name	**Signature**	**Date**
1. Prof. Sebsebe Demissew	________________	____________
2. Prof. Teshome Soromessa	________________	____________
3. __________________________	________________	____________
4.____________________________	_________________	____________

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Chair of Department or Graduate Programme Coordinator

DEDICATION

This paper is dedicated to my wife, Sara Sintayehu who married me while I was desparate, with empty pocket and a broken heart. I also dedicate this thesis to my lovely baby girl Makriyana Alemayehu who brings lots of happiness to my life.

Abstract

Ecology, Carbon Stock Quantification and Formulation of Allometric Models for Some Trees of Sele-Nono Forest, Southwest Ethiopia: Implication for Biodiversity Conservation and Climate Change Mitigation.

Alemayehu Kefalew, PhD Dissertation

Addis Ababa University, 2019

This study presented the vegetation ecology, carbon stock quantification and formulation of allometric models for some trees of Sele-Nono Forest, Ethiopia. A total of 90 permanent plots were distributed in the study area using stratified random sampling techniques. The ecological studies such as plant diversity analysis, cluster analysis, ordination analysis and vegetation structure were carried out using data obtained from 25 m x 25 m (625 m^2) plot size; whereas 35 m by 35 m (1225 m^2) plots superimposed on the 25 m by 25 m plots were used for carbon stock study. Shannon-Wiener diversity index was used to assess species diversity and evenness. A hierarchical cluster analysis was used to identify plant communities. Frequency, density, basal area, importance value indices (IVI), size class distribution and profile diagram were also used to analyse the vegetation structure of the study area. Density of seedling and sapling of woody species were computed to determine the regeneration status of woody species. Priority ranking of threats by the local people was used to rank the threats that have been affecting the forest. Canonical Correspondence Analysis (CCA) was used to study the influence of environmental factors on the distribution of plants in the study area. Regression graphs, paired t-test and cross validation statistics were used to validate existing and newly formulated allometric models. This study produced seven plant community types. Result showed that Sele-Nono forest is a reservoir of diverse vascular plant species (414 species) of which 59 were new records to the flora of Illubabore (IL) region. CCA suggests that a number of environmental factors such as elevation and slope (topographic factor), Organic matter and Nitrogen (edaphic factors) and disturbance were the main drivers for the current distribution of plant species in Sele-Nono Forest. The vegetation structure of the study forest was mainly characterized by low stature & 2-3 storey of trees with high density of stems (20, 939 stems/ha). Moreover, the forest was mainly characeterized by poor regeneration status of woody species. Besides this study validated some allometric models; and also presented newly formulated allometric models for some common trees in the study area. Results also showed that carbon is stored in forests predominantly in soils, above & below ground biomass, and lying dead woods respectively. It was also found that the mean total carbon stock density of the forest was estimated at 284.81±107.81 t C/ha. Moreover, the equivalence of atmospheric Carbon dioxide removed due to the current stand of Sele-Nono Forest was estimated at 157.12 Mega tons (Mt) of CO_2 ($1Mt = 10^6t$) indicating that the study forest is a potent place for carbon sinks and plays significant role in climate change mitigation. However, Sele-Nono Forest is also being affected by anthropogenic factors fundamentally due to deforestation for agricultural land expansion and degradation through selective logging. Hence, putting the forest in a biosphere reserve under UNESCO is paramount for sustainable conservation of the forest. Moreover, attention shall be given by the National REDD+ Ethiopia to sustain its role as carbon sink to mitigate climate change.

Keywords*: Allometric model, carbon stock, ecology, model validation, regeneration, ordination, vegetation structure, Sele-Nono Forest.*

Acknowledgments

This research work would not have been possible without the constant support and encouragement of my advisors Prof. Sebsebe Demissew, Prof. Teshome Soromessa and the late Professor Ensermu Kelbessa who passed away amid of this study. Their unreserved guidance, support, suggestions, effective follow-up of the research work were very much appreciated.

I whole-heartedly acknowledge my home institute, Debre Markos University (DMU), for sponsoring my PhD study. I also would like to extend my deepest gratitude to the Graduate Programme of Addis Ababa University (AAU) for funding this research work under the Thematic Research Project to cover the cost of all field and lab expenses. I thank also IDEA WILD for granting some field equipment. The Department of Plant Biology and Biodiversity Management (AAU) also deserves a warm appreciation for coordinating and facilitating many office related work during my study. Staff of Metu University, a University close to the study area, also deserves gratitude for their kind cooperation in facilitating access to their laboratory for parts of the research work. .

I would like to pass my sincere gratitude to Dr. Sandra Brown (Winrock International, USA), Dr. Adrien Djomo (Queen’s University, Canada), Prof. Ib Friis (University of Denmark), Dr. Yigardu Mulat, Dr. Yitebitu Moges (both from Ministry of Environment and Forestry & Climate Change, MoEFCC, Ethiopia) for providing valuable information related to the carbon stock study. Dr. Sandra Brown in particular is heartily acknowledged for providing useful references and email discussions; and for shaping and guiding my research work on carbon. Dr. Merga Belina (Department of Statistics, AAU) is also warmly acknowledged for his help in statistics particularly in relation to the modelling part. Dr. Addisie Geremew and Dr. Iris Stiers (both from Vrije Universiteit Brussel, Belgium) are greatly acknowledged for their help in enhancing my knowledge on multivariate analysis of vegetation data. Dr. Ermias Lulekal and Prof. Sileshi Nemomessa (both in AAU) are also deeply acknowledged for reviewing some sections of the thesis and provision of helpful comments.

I would like to extend my gratefulness to the staff members of the National Herbarium (ETH), particularly Mr. Melaku Wondaferash, for their cooperation with all aspects of the herbarium work, aside of their persistent and very friendly encouragements. Mr. Bamelaku Amentie (Remote sensing & GIS expert, AAU) is also truly acknowledged for his contribution in developing all the digital maps used in this thesis. The National Meteorological Services Agency of Ethiopia is acknowledged for providing meteorological data of Masha station (a nearby station to Sele-Nono Forest).

The following people are also acknowledged for providing valuable information on various aspects of the study forest: Ato Alemu Tadesse (Administrative Head of Sele-Nono District), Mr. Chala Lolasa, Mr. Ambachew Hagos, Mr. Bekalu Tamene and Mr. Tilahun (Higher officials of Oromia Forest and Wildlife Enterprise (OFWE), Sele-Nono District), Mr. Shambel Girma, Mr. Girma Deme & other staff members of the Ethio-Wetlands and Natural Resource Association (EWNRA) project in Sele-Nono forest. I am indebted to the inhabitants of the villages in Sele-Nono District, who invited me to their huts for overnight stays after fieldwork and for their wonderful hospitality and care throughout my stay in the study area. I also acknowledge the local people who were involved in this study during the field data collection for personal and professional support particularly Tamru Tadese, Fesseha Abeje, Semahato Shana, Kebede Tesfaye, Abedi, Elias, Mesfin, Endalkachew Wakjira and Yeshi. I acknowledge particularly the tree climbers who tirelessly measure relevant data that should be gained from tree climbing technique, without whom things would have been challenging.

I am very much indebted to my wife Sara Sintayehu and my baby girl Makriyana Alemayehu who made my trouble less and my blessings more during the course my PhD study. Their kindness, patience, prayers and encouragements during the course of my study was so much appreciated. My special gratitude also goes to my parent-in-laws (Yeshi Ene and Sintayehu Ayechew), brother-in-law (Abiye Sintayehu) and his wife (Selam Niguse) for their support through out the study period. Their inspiration and encouragement throughout the research work were also so much appreciated. My mothers Tsehay Eshete and Yeshi Teku, my father Kefalew Shembo, my brother Eng. Tesfaye Addis, Tilahun Kefalew, Abiyot Kefalew, Zemedekun Kefalew and sisters

Getenesh Addis, Yirgalem Addis, Selenat Addis, Zenash Kefalew, Tsege Kefalew also deserve sincer appreciation for their support in various ways. I also would like to thank Mr. Ayenew Germew, Negeso Bayissa and Fikirte Direse for their continuous moral support. My friends Dilnesaw, Deginet Chennene, Fetene Kasie, Semachew and Endawok, my colleagues Dr. Admasu Addi, Dr. Abiyot Dibaba, Dr. Getenet, Dr. Haimanot, Dr. Lewye, Dr. Asmamaw, Mr. Yohanes Mulegeta, Ms. Nuriya are acknowledged for their support throughout the years of the study period.

Last, but not least, I would like to extend my gratitude to a number of friends, colleagues and people (whose long list of names is recorded in my memory and diary), whom I encountered during the course of this research work, and from whom I received support on various aspects.

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List of Acronyms

AAU	Addis Ababa University
AGB	Above Ground Biomass
AGC	Above Ground Biomass Carbon Stock
CCA	Canonical Correspondence Analysis
CO_2e	Carbon Dioxide Equivalence
DBH	Diameter at Breast Height
FAO	Food and Agricultural Organization
Gt	Giga ton
H	Height
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
ME	Mean Error
MoEFCC	Ministry of Environment and Forestry & Climate Change
N	Nitrogen
OM	Organic matter
R	R Statistical Software
SNNPRs	South Nations, Nationalities and People Regional State
SW	Southwest
t	ton
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WBISPP	Woody Biomass Inventory and Strategic Planning Project
WWF	World Wide Fund for Nature

CHAPTER ONE

1. Introduction

1.1. Background of the study

It is well noted that biodiversity, which is an important element of natural resource, plays a key role to human survival through the provision of essential ecosystem services and ecological processes (UNFCCC, 1992; Armenteras *et al.*, 2009). Although the services are not fully appreciated by many in terms of the value they provide nature's contribution to people (ecosystem services) has to be used wisely taking into consideration the needs and aspirations of the present generation without compromising its ability to offer the needs of the upcoming generations (Holden, 2014). However, the current indiscriminate human actions are drastically causing biodiversity crisis and collapse of the associated ecosystem services to the extent of challenging the survival and continuity of life in general and human beings in particular (Laurance, 1999; Mani and Parthasarathy, 2006). This implies the interface between biodiversity and human wellbeing is very strong; and thus should be given sufficient considerations in scientific studies before the strong linkage is significantly and irreversibly altered. Researchers generally accept three scales of biodiversity, of which ecosystem diversity is the most complex one as it encompasses species and genetic diversity within it (Gaston and Spicer, 2004; Naeem *et al.*, 2009). Among the global ecosystems forests are thought to be home to over 80% of biodiversity on land (Myers *et al.*, 2000) and indispensable part of the solution for combating the impacts of climate change (UNFCCC, 2005).

Forest, according to FAO (2010), is defined as segments of a landscape with tree crown cover more than 10 % and a minimum height of 5 m at maturity in-situ in an area of more than 0.5 hectares. They are crucial habitats for hosting diverse organisms and store carbon from the atmosphere (Wilson, 1992; Pearce and Pearce, 2001; Wilson *et al.*, 2012). Globally, they are the dominant ecosystem of the world and covers approximately 30% of the planet's land area (Olson and Dinerstein, 1998; Olson *et al.*, 2001; FAO, 2010) that accounts to store more than 500 billion tons of carbon (Lal, 2004; Ruesch and Gibbs, 2008).

Of the global forests, tropical forests are believed to be the most species-rich ecosystem on earth (Hill and Hill, 2001). Moreover, although the forests cover only about 5-10% of the Earth‘s vegetation (Mutke and Barthlott, 2005; World Conservation Monitoring Centre (WCMC, 1992)), it is recognized as an important centre to counter balance the effect of climate change (Wright and Muller-Landau, 2006; Elliot *et al.*, 2013; Wilson *et al.*, 2012). It is said that tropical forests account for 50% of the Earth's total planet biomass (Kindermann *et al.*, 2008; Lewis *et al.*, 2009) and store 428 Gt of the terrestrial carbon (Ashton *et al.*, 2012; World Bank, 2012). The tropical forests are mainly distributed in tropical landmasses such as America, Asia and Africa which are situated between the tropic of Cancer and the tropic of Capricorn (Thomas and Boltzer, 2002).

About 30% of the tropical forest cover is thought to be found in Africa, which is accounting for 21% of its total land area and for 16% of the global forest coverage (Whitemore, 1997; Richards, 1996; Whitemore, 2008; Klopper *et al.*, 2002; FAO, 2006); which is also accounted for about 180-200 ton of carbon stock per hectare (Ruesch and Gibbs, 2000). Among the tropical forest ecosystems of Africa, the Afromontane forests, that cover about 8% (elevation > 1000 m a.s.l.) of the total tropical forest area (Spracklen and Righelato, 2014), are the most species-rich ecosystems housing more than half of African's flora (White, 1978; Sayer *et al.*, 1992; Kuper *et al.*, 2004) and stored considerable amount of carbon (Fehse *et al.*, 2002; Nyirambangutse *et al.*, 2017). These Afromontane forest are distributed along the mountain spots of Cameroon & Sierra Leone in the West to the Ethiopian highlands and the Somalia Ahl Muscat Mountains (in Oman) in the East; and from the Red Sea Hills in the north to the Cape region in the south (White, 1978; Friis, 1992; Linder *et al.*, 2005). More than 50% of these Afromontane forests are thought to be found in Ethiopia (Yalden, 1983).

Although there is controversy over the precise figure of the former forest cover in Ethiopia, it is thought that about 35-40% of the land area have been covered with forests (EFAP, 1994). However, by the 1950s the high forests declined to 16% of the total land area (Breitenbach, 1963) further rapidly dropped to 3.6% by 1980s (Tewolde BG Egziabher, 1991). In 2003, the forest cover was estimated to 2.3% (Shibru Tedla, 2003; WBISPP, 2004; FAO, 2005). In 2010 a study was conducted by Yitebitu Moges and his colleagues and they reported that the natural forests of Ethiopia accounted to store about 434.19 million tons of carbon, which is equivalent to about 1.6 billion megagram (Mg) of CO_2 from the atmosphere (Yitebitu Moges *et al.*, 2010). This clearly indicates that the Ethiopian natural forest (Afromontane and woodlands) plays a significant role in mitigating the effects of climate change. By now even if the country currently increased its forest coverage due to the new FAO forest definition (FAO, 2010), the Afromontane forest cover still declines to less than 2% (Ensermu Kelbessa, Pers. Comm). The remaining major dense forests in Ethiopia are found in the Moist Afromontane Forest (MAF) and Transitional Rainforest (TRF) of the Southwest (SW) Ethiopia (MOA, 1990; Reusing, 1998, 2000, Friis *et al.*, 2011).

Given the previous access restrictions of the SW forest (i. e., before 1900s) due to its unique physical setting, climatic conditions and biogeographical position, the area was not to the attention of researchers for long time in the history of botanical explorations comparing to other corners of Ethiopian vegetation (Meyer, 1965; Chaffey, 1978d; Friis, 2002; Demel Teketay, 2004; Friis, 2009). However, by the mid-1900s, which is often considered as a turning period by the botanist due to access roads (Mesfin Tadesse, 1993; 1994; Friis, 2011), some pioneered floristic work on the area were carried out (Logan, 1946; Chaffey, 1978d, 1979; Friis, 1979; Friis *et al.*, 1982; 1986). The outcome of these studies proved the SW forest to haven ecological and economic potential; and attracted many other researchers. These research efforts were instrumental in providing additional data to 'Conservation International' to include the the area as part of the Eastern Afromontane Hotspot giving recognition for being globally a key area for biodiversity conservation (WWF and IUCN, 1994; Barthlott *et al.*, 1999; Kuper *et al.*, 2004; Mittermeier *et al.*, 2004; Conservation International, 2006; Vivero *et al.*, 2006).

From those early efforts enormous data on the floristic composition, diversity, distribution and conservation status of the existing patch forests in the area were generated. Some of these studies include the work of Abayneh Derero (1998), Kigomo (1999); Kumelachew Yeshitela and Tamrat Bekele (2002), Tadesse Woldemariam (2003), Kumelachew Yeshitela and Taye Bekele (2003), Taye Bekele (2003), Zerihun Woldu and Kumlachew Yeshitela (2003), Getachew Berhan and Yoseph Assefa (2004), Kumelachew Yeshitela & Simon Shibru (2004), Mateos Ersado and Yoseph Assefa (2004), Taye Bekele *et al*. (2004), Feyera Sebeta *et al.* (2005), Dereje Denu (2006), Feyera Senbeta (2006), Schmitt (2006), Feyera Sebeta *et al.* (2007), Ensermu Kelbessa and Teshome Soromessa (2008), Kitessa Hundera and Bishaw Deboch (2008), Kitessa Hundera and Tsegaye Gadissa (2008), Tadesse Woldemariam *et al.* (2008); Sisay Nune (2008), Tsegaye Gobeze *et al.* (2009), Schmitt *et al.* (2010), Friis *et al.* (2011), Abreham Assefa *et al.* (2013), Hylander *et al.* (2013a), Hylander *et al.* (2013b), Teshome Soromessa and Ensermu Kelbessa (2013), Kflay Gebrehiwot and Kitessa Hundera (2014), Yohannes Mulugeta *et al.* (2015), Admassu Addi *et al.* (2016).

Moreover, carbon stock studies in this forest region indicated that the forest is an important area for carbon reservoir (Reusing, 1998; Yetebitu Moges *et al.*, 2000; Abebayehu Aticho, 2013; Mohammed Abaoli and Bekele Lemma, 2014; Vanderhaegen *et al.*, 2015). Despite these and much other related studies, the area still facing the challenge to conserve its vegetation and are becoming among the highly threatened ecosystems in Ethiopia. To protect these ecosystems of the SW forests, through designing and successfully implementing more appropriate measures, require complete inventory on the floristic composition and structural analysis of the species in the area. (Kneeshaw *et al.*, 2000; Zumeta and Ellefson, 2000; Adams and Hulme, 2001; Larsson and Danell, 2001; Taye Bekele, 2003; Schmitt *et al.*, 2010). Thus, it would be imperative to conduct floristic studies in forest patches of the SW forest which had not been addressed previously including Sele-Nono forest that the current study is being carried. It is also important to carry out research on carbon stock estimation of the forests inorder to generate income from any possible carbon trading and REDD+ funds to enhance forest conservation and climate change mitigation.

Taking the points indicated above, the current study was conducted in Sele-Nono forest with the aim of (1) documenting the floristic composition and diversity of plant species; (2) assessing the vegetation structure and regeneration status of the forest; (3) validating existing allometric equations for accurate carbon stock estimation in the above ground biomasses; (4) finding out the best height estimation method in the study area so as use justified tree height for the carbon stock study; (5) estimating carbon stock of the forest to imply its role for climate change mitigation; and (6) developing species specific allometric models for three most common tree species (*Albizia gummifera, Mimusops kummel, Syzygium guineense* subsp. *afromontanum*) in the study area.

1.2. Problem justification

As stated above, the study intended to address the above six components. Justifications are the following.

1. The forests in the southwest of Ethiopia are among the remaining high forests. However, the rate of deforestation is progressing at alarming rate of 5% exceeding the 2% deforestation rate at national level (WBISPP, 2000; Reusing, 2000). Thus researches focusing for sustainable conservation of these forests should be top priority of ecologist and conservation biologist. Literature shows that most of the floristic studies conducted so far in moist Afromontane forests (MAF) of the SW were concentrated on forest fragments of Jimma Zone (in Oromia Regional State), Keffa, Sheka and Benchi Maji Zones in the Southern Nations Nationalities and Peoples Regional (SNNPR) State and Godere District Forest (in Gambella Regional State). Studies on the Moist Afromontane forests of Illuababora Zone (in Oromia Regional State) are very scanty despite their important contribution to the total share of the SW forests. Taking the gap of information on the Sele-Nono forest, one of the largest natural forest in Illuababora Zone, there was a great interest to study the forest with emphasis on the floristic composition, plant diversity, vegetation structure and its regeneration status since these information provide the baseline data about the current status of the forest and consequently help to suggest appropriate measures for its sustainable conservation.
2. Sele-Nono forest is one of the intact natural forests that covers 91% of the Sele-Nono District. Thus, the forest can be considered as an important carbon sink, which is a major contributor for inducing climate change. The carbon storage in the forest need to be maintained to play its role in climate change mitigation. However, the actual

carbon stock of the forest is unknown. Thus, quantifying its current carbon stock in the forest is important to use it as a reference baseline for subsequent monitoring.

3. The standard approach to quantify forest carbon stock is through the application of allometric models (also called biomass models or allometric equations). However, developing general allometric models for Sele-Nono forest is laborious and time consuming and hence existing tropical generic allometric models which are valuable to the study area shall be compiled, evaluated on how far the prediction performance matches with the actual biomass of the local data sets (Chiyenda and Kozak, 1982; Picard *et al.*, 2014). Checking the efficiency of existing allometric models will give a chance to make comparisons among the proposed models and choose the one which is more accurate (or induces the minimum error magnitude) for the study area.
4. Tree height is regarded as a key parameter in carbon stock estimation of a forest. Omitting this parameter would be a major source of error (Chave *et al.*, 2005). Girardin *et al.* (2010) reported that there could be a 52% carbon stock overestimation in tropical forests when height was not incorporated in allometric equation. It is to be noted that the methods of tree height estimations include the use of clinometer, visual observation method and the use of DBH-H general allometric equations. To use clinometer for height measurement, one needs to go away from the tree at a distance of approximately the height of the tree to find a spot from which the peak of the measured tree can be visible, which is not feasible to our study area where the highest peak usually obscured by a different canopy trees. Korning and Thomsen (1994) and Larjavaara and Muller-Landau (2013) also claim the use of this method as a time-consuming technique for tropical forests. Thus, there is a need to look for other alternatives to better estimate tree height in the study area. This involves validation of visual estimation and/or other techniques using DBH-H allometries.

5. Formulation of site specific or species specific models are the most recommended techniques for better biomass estimation of a particular forest. In Ethiopia, a number of species specific allometric equations were developed by the Woody Biomass Project (WBISPP, 2000). Moreover, models for some Dry Afromontane species (Dawit Tekle, 2014; Eyosias Worku and Teshome Soromessa, 2015; Mehari Alebachew, 2015), some *Acacia* species (Getachew Eshete and Stahl, 1998), Enset (Mesele Negash *et al.*, 2013a) and Coffee (Mesele Negash *et al.*, 2013b) have also been developed in Ethiopia. Most of the previous equations mentioned were developed using felling (or destructive) method which is a tedious, time consuming, environmentally unfriendly and costly (Picard *et al.*, 2012). Thus there is a need to look for non-felling method for developing allometric equations. Consequently, in this research, non-felling method using tree climbing technique was used to develop allometric equations for three tree species (*Albizia gummifera*, *Mimusops kummel*, *Syzygium guineense* subsp. a*fromontanum*) that are more abundant in the study area.
6. Tree climbing method was considered as the best method for the validation and formulation of allometric models when compare with light detection and ranging (LIDAR) or other infeasible techniques which are quite expensive to employ. The choice of the 'tree climbing method' as the most appropriate method in the current study is due to its suitability with respect to the cost budget at hand and the minimum level of destruction it imposes. This method has been suggested to provide almost the same biomass estimation as that of the felling method (Vann *et al.*, 1998). Moreover, due to the apicultural activities in Sele-Nono District local people employ safe climbing skills. The use of indigenous skills that are environmentally friendly for collecting relevant data to formulate and validate allometric models for trees of the study area is very important.

1.3. Research questions, hypotheses and objectives

1.3.1. Research questions

The following were the main research questions for the study in Sele-Nono Forest:

- What is the floristic composition?
- What are the existing plant community types? How high is plant diversity in each community types?
- What are the most influential environmental factors that influence the distribution of vegetation in the study area?
- What are the most common threats to Sele-Nono forest? Which of these factors are most damaging?
- How does the vegetation structure of the forest look alike?
- What is the level of regeneration of the woody species?
- Which of the existing allometric models are more effective for accurate carbon stock estimation of trees, palms, tree ferns, lianas and bamboos?
- Is visual estimation technique more precise for tree height estimation?
- What are the wood density values of lying dead woods?
- How large is the total carbon stock density? What are the major carbon pools that store most of these carbons in the forest?
- What would be the amount of carbon dioxide equivalent mitigated by the existing stands of the forest?
- What are the established species specific allometric models?

1.3.2. Research hypotheses

- Sele-Nono forest is a reservoir of high plant species diversity;
- There are five plant community types in the study area;
- Altitude is the most influential environmental factor to influence the distribution of species in Sele-Nono forest;
- Deforestation and degradation are the most damaging threats to the study forest;
- Sele-Nono forest is a mature primary forest;
- The majority of the woody species in Sele-Nono forest have a good regeneration status;
- The use of different allometric equations would not significantly affect the results of biomass estimation of trees, palms, tree ferns, lianas, and bamboo in the forest;
- Visual estimation provides more precise tree height estimate in Sele-Nono forest;
- Lying dead woods are important source of carbon stock in the forest;
- Sele-Nono forest plays a substantial role in climate change mitigation;
- Species specific allometric equation of woody plants improve their biomass estimation.

1.3.3. Research objectives

General objective

The general objective of this study aims at investigating the vegetation ecology, carbon stock quantification and formulation of allometric models for some species in Sele-Nono forest inorder to use the findings for sustainable use of biodiversity and climate change mitigation.

Specific objectives

The specific objectives of the research were to:

- study the floristic composition, structure and the regeneration status of woody species in Sele-Nono forest;
- describe community types and diversity of plant species in Sele-Nono forest;
- validate possible allometric equations for estimating biomass and tree heights in Sele-Nono forest;
- to quantify the carbon stock of Sele-Nono forest;
- examine the contribution of the forest towards climate change mitigation

1.4. Structure of the dissertation

The main body of this thesis is organized in five chapters. The first chapter gives a general introduction encompassing a brief background about the theme of the study followed by established research questions, hypotheses formulation and objectives. The second chapter deals with literature review focusing on key concepts in vegetation ecology and indication of major gaps in carbon stock research in Ethiopia. The third chapter is the materials and methods section which includes description of the study area and details on the research methodology. Chapter four is the result section that presente the main findings of the research. The fifth chapter includes the discussion based on the results followed by conclusions and ending with appropriate recommendations.

CHAPTER TWO

2. Literature Review

2.1. Vegetation Ecology

2.1.1. Phytosociological study of vegetation: Historical and current situations

2.1.1.1. Traditional schools of phytosociology

Phytosociology (also known as plant sociology or quantitative plant ecology) is the science of vegetation classification based on species co-occurrence and its relation to the surrounding environment (Khan, 2014). The term phytosociology is derived from two terms called Phyto (means plant) and sociology (means assemblage or groupings) (Braun-Blanquet, 1932). The history of phytosociology have long traditions which began with subjective classification schemes in Europe (Whittaker, 1962; van der Maarel, 1975; Westhoff and van der Maarel, 1978). Literature indicate that there were four known schools of subjective phytosociology, namely the Zurich-Montpellier school, the Uppsala school, the Danish (Raunkaier) school and Hybrid schools (Kent and Coker, 1992). In this review section we concentrated our emphasis on the two most notable school of thought (Uppsala School of phytosociology and the Zurich-Montpelier School of thought) as the remaining two were little used or have been modifications of the Uppsala and/or the Zurich-Montpellier schools. Both the Uppsala and Zurich-Montpelier Schools admitted that vegetation could be classified into units (communities) though their assumptions and methods were different (Whittaker 1962; Mueller-Dombois & Ellenberg, 1974; Westhoff & van der Maarel, 1978; Mueller-Dombois, 1984; McIntosh, 1985).

The Uppsala School of phytosociology was the dominant thought of Northern Europeans and they defined plant communities often using a physiognomic approach (Noy-Meir and van der Maarel, 1978). This school used to practice dominant species criteria for naming plant communities which gives emphasis on the most easily noticed plant species in the upper storey of the vegetation. A good example in this school of thought is known from Du Rietz (1921; cited in Mueller-Dombois and Ellenberg, 1974). Du Rietz used the term 'Sociation' to designate plant community type with certain dominant species in each layer of the vegetation canopy indicating that the 'sociation' used to be designated as the basic unit of vegetation for the Northern European or Uppsala school of phytosociology. Du Rietz, also used the term 'consociation' to designate a group of 'sociations', usually with the same species dominant in the upper stratum of a several layered community (Du Rietz, 1931). From this it could be said that the 'sociation' approach could have been a useful concept for species-poor areas such as northern Europe and boreal regions where visually dominant species in the different strata could be easily recognized. However, this approach seem not applicable in areas with species-rich vegetation like those in tropics as the vegetation is too complex to visually identify dominant species..

The Zurich-Montpelier school of thought that emerged in central Europe, describes plant community types using floristic approaches (Kent and Coker, 1992). This school of thought was founded by the Swiss ecologist Josias Braun-Blanquet (1932); and for this reason it has been alternatively referred as Braun-Blanquet approach (van der Maarel, 1975). Braun-Blanquet considered plant community types as associations of plants derived from relevé (lists of plants in a delimited plot along with their cover/abundance estimates) and described using diagnostic species (Enright and Nunez, 2013; Peet and Roberts, 2013). The term association in this school of thought was entirely different from the Clements understanding of association who used the term to indicate a subdivision of formations that were often used to describe vegetation in wider geographical areas (Jennings *et al.*, 2003). This indicates that there were anomalies in the use of the terms like association before the 1900s. Later by

1910 the International Botanical Congress (IBC) held at Brussels (also called the Brussels Congress) agreed to use the term association exclusively in the sense of the Zurich-Montpelier School: i.e., units recognized mainly by diagnostic species (character and/or differential species) (Flahault and Schroter, 1910; Westhoff and van der Maarel, 1978; Peet and Roberts, 2013). They also agreed upon the term 'sociation' to designate a vegetation unit characterized mainly by dominance in the component layers (Mueller-Dombois and Ellenberg, 1974).

The Zurich-Montpelier school of describing plant community types is regarded as basic phytosociological framework of vegetation and have been widely followed by a number of vegetation ecologist including Mueller-Dombois and Ellenberg (1974), van der Maarel (1975) and Westhoff and van der Maarel (1978). This school follows the Braun-Blanquet approach of vegetation classification that involves analysis of the entire species composition of an area. This would be achieved by collecting complete species information from the studied field (Field phase) using releve technique, and constructing differentiated table (Analytical phase) for sorting the trends of species distribution between the sample stands (Campbell, 1974; Coetzee, 1974). Tabular rearrangement of relevés were subjective in that it was achieved by hand-sorting (Kent and Coker, 1992); and with this technique it was possible to sort certain species that would have strong preference for a particular groups to describe plant associations. This indicate that Braun-Blanquet do not support the dominant species criteria as the dominant are too often ubiquitous in plant communities, and hence their presence would not be ecologically informative for describing associations. Rather he preferred the fidelity criteria to name and describe plant associations (Braun-Blanquet, 1932; Peinado *et al.*, 2013).

2.1.1.2. Current situations of phytosociological studies

From literature it can be understood that classification was a tedious process in the traditional schools of phytosociology, and the subjective method of tabular arrangements were only suitable for relatively small sets of data. Although there were a number of approaches for subjective classification such as the sociation approach and Braun-Blanquate associated approach were regarded as the most known subjective approach of phytosociology. Indeed, the current situation of phytosociology basically follows the legacy of Braun-Blanquet approach with some reformulation and updates (van der Maarel, 1979; Podani, 2006).

However, in the current situation, phytosociological study of plants is attained using numerical techniques that uses computer programming rather than tabular rearrangements by hand as in the time of Braun-Blanquet. Computers were introduced into the processing of phytosociological data as early as the 1960s, which signifies the paradigm shift from subjective phytosociology into objective phytosociology (Williams and Lambert, 1960; van der Maarel, 1969; 1975; 1980; Gauch, 1982; ter Braak, 1986; Austin, 2005). The numerical techniques now available helps hundreds and even thousands of samples in one analysis (Oksanen, 2010; Oksanen *et al.*, 2016). It shall be noted that whenever we mean the numerical methods of classification are objective, we meant that for one sets of data, any researcher using the same numerical methods would obtain the same result (Kent and Coker, 1992).

2.1.2. Plant community and community types

Plant populations do not grow in isolation, but rather grow in a mixture of co-existing plant populations, forming communities (Kraft and Ackerly, 2014). Box and Fujiwara (2005) perceive plant community as a type of vegetation recognized by their floristic composition.

In natural vegetation plants often form associations as a plant community type (Werger and van der Maarel, 1978).

Plant association is defined as the collection or assemblage of plants growing together in a certain location that show a definite association or affinity with each other (Westhoff and van der Maarel, 1978). In practical association analysis, a community type is represented from the aggregation of sample plots distinguished by floristic composition (Mueller-Dombois and Ellenberg, 1974). Sites (sample plots) making up a community type are consistent in physiognomy and composition although they are found in scattered locations across a landscape (van der Maarel, 2005). A plant community type should also be named just as an individual plant or animals are named (Braun-Blanquet, 1932; Whittaker, 1962). The purpose of naming plant community types is to clearly offer a reference to each plant community so as to recognize and characterize them (Chytry and Tichy, 2003). The most frequently used system for recognizing a community type is using a combination of a pair of diagnostic species having higher degree of fidelity whose ecological relationships make them the most effective indicator (van der Maarel, 1975).

2.1.3. Theories about the nature of plant community structure

Literature sources indicate that there have been disputes and confusions on the nature of plant community structure; which was hotly debated by two American plant ecologists called Clements and Gleason (Goodall, 1963; Noy-Meir and van der Maarel, 1987).

Clements considered plant communities as a combination of plant species forming a clearly recognizable and discrete or distinctiveness vegetation entities which repeat themselves spatially over certain places (Clements, 1916). The term distinctiveness in the language of Clements was elaborated by van der Maarel (2005); and it was meant to refer to discontinuity (Figure 1) towards the surrounding vegetation (van der Maarel, 2005).

This discrete community concept of Clements was regarded as 'organismic concept of plant community structure' by Clemantesians. This was due to the fact that communities are combinations of plants, which he linked each of this plants with an 'organ' and/or 'organ-system' and when they pooled together they would form an 'organism', a term applied by Clements to mean that plant communities are combination of plants (Kent and Coker, 1992).

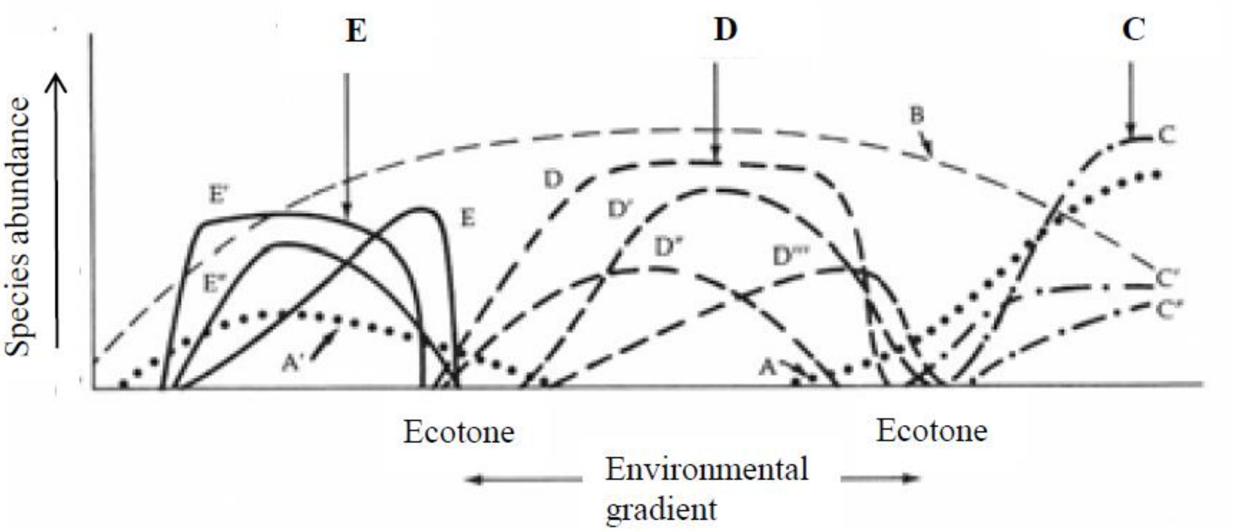


Figure 1. Possible representation of Clements view of discrete plant community structure (Modified from Crawley, 1997) (C, D, and E are distinct plant community types)

Gleason (1926) forwarded another controversial theory about plant community structure. He criticized and rejected Clements view of discrete community. He rather argued that plant communities are continuum in that they occur as random assemblages of adapted species along continuous environmental gradients usually by intergrading continuously, with gradual change in community composition (McIntosh, 1995; Austin, 2005). He associated this understanding with the coincidence of plant species to respond individually to the various environmental factors that varies continuously in space. This goes in line with the definition given by van der Maarel (1990) who defined plant communities as the outcome of interactions between individual plant species and the environment. This approach of perceiving plant community structure as an aggregation of independently operating plants along an environmental gradient has been referred as 'individualistic view' (Watt, 1947;

Crawley, 1997). The individualistic approach were considered as the best way of understanding plant community structure since its explanations were the results of studying phenomenon at individual species level (Leps and Smilauer, 2003). Because of this, the individualistic view of plant community structure was regarded as reductionist view, which was the opposite of Clements holistic view of plant community that examines all species together (Kent and Coker, 1992).

Gleason’s plant community were groups of plants sharing a common environment that interact with each other and to the physical environment (Kent and Coker, 1992). Subsequent work by Curtis & McIntosh (1951), Whittaker (1956), Bray and Curtis (1957) and Nicholson & McIntosh (2002) helped to solidify the continuum view of plant community. In line with this view, Curtis (1959) dictated the co-occurrence or association of plants as a consequence of shared environmental requirements. Whittaker also supported Gleason’s view and verbalized that for a plant association to achieve uniformity of vegetation, which is the result of environmental factors, is more important criteria than distinctiveness (Whittaker, 1967; Whittaker, 1978a).

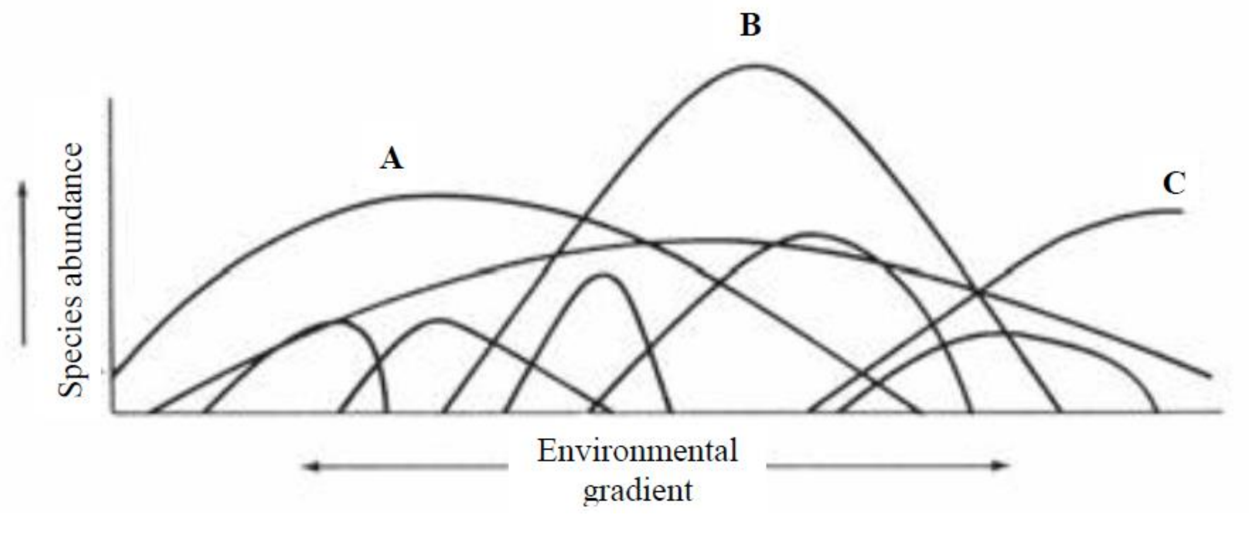


Figure 2. Possible representation of Gleason's continuum view of plant community structure showing each community (A, B, C) as an arbitrary section (Modified from Whittaker, 1975).

So from the above discussion of Figure 1 and 2, it could be understood that plant community are discrete (discontinuous) according to Clements in that they are demarcated from the adjoining communities abruptly and/or by narrow boundaries called ecotones; whereas they are continuous along environmental gradients according to Gleason in that they change gradually as they overlap to each other so that no discrete community type (i.e., with definite boundaries) can be identified in nature.

Even today, none of these views were falsified in the present day view of plant community (Allen and Hoekstra, 1992; Hoagland and Collins, 1997; Lortie *et al.*, 2004; Eliot, 2007); and contemporary ecologist rather conceptualizes plant community structures still in a different way (Kent and Coker, 1992; Crawley, 1997). For instance, Kent and Coker (1997) suggested that the most realistic point today seem to be near the Clements whereas others think that the modern view is very close to Gleason’s view of community structure since it is often difficult to tell exactly where one community ends and the other begins on the actual field areas due to the continuum nature of a vegetation (Austin, 2005). From the above discussions it can be seen that the structure of plant community still differs according to the perspectives of the modern ecologists too. But this days it is generally believed that the structure of plant communities shall be understood better using a combined approach of classification or phytosociological schemes (i.e., grouping of plant species into recognized and defines plant communities) and ordination schemes by arranging plant communities along environmental gradients as continuum (Crawley, 1997; Leps and Smilauer, 2003); which imply that both Clements and Gleason view are an important elements in the present day view of plant community structure.

Thus, it could be said that the todays’ perspectives about plant community structure lays somewhere in a middle ground position between Clements and Gleason's views. To be more specific contemporary ecologist, for instance, view plant community types as a mosaics of discontinuous vegetation units that may occur as relatively obvious ribbons across a landscape of a certain vegetation area (Kent and Coker, 1992); in which case it goes with the Clements view. On the other hand, the modern ecologist believes that plant associations in a community is the result of their interaction to the environment (Crawley, 1997), in which case they support the Gleason's individualistic view of plant community. It is probably because of the acceptance of those two polarized theory of Clements and Gleason that contemporary vegetation ecologist redefined plant community in a broader way as segments of vegetation characterized by four key features, which includes a consistent floristic composition, uniform physiognomy, occurrence in a particular environment, and scattered at several locations (van der Maarel, 2005).

2.1.4. Multivariate analysis in vegetation ecology: classification and ordination

Experience show that vegetation data are often voluminous and seemingly disorganized (Weekes and FitzPatrick, 2010). Likewise, environmental data that are directly associated to vegetation growth are complex and numerous indicating that plant community data are multivariate in nature (Williams and Lambert, 1960; Kent and Coker, 1992). Thus, it is clear that it would be hard for ecologists to easily interpret them unless the data are summarized (Lambert and Dale, 1964; Gauch and Whittaker, 1972; Gauch, 1982; Greig-Smith, 1983). Vegetation ecologist, as of 1960s, has been employing two kinds of tools of multivariate data analysis so as to simultaneously study the complex nature of plant communities (Williams and Lambert, 1960; Greig-Smith *et al.*, 1967; Whittaker, 1978a, b; Austin, 1987; Digby and Kempton, 1987). These techniques of multivariate analysis that require the use of appropriate computer programs are numerical classification and ordination, the former groups sample stands of vegetation into relatively homogenous units (Mueller-Dombois &

Ellenberg, 1974) while the later puts sample plots in order based on the information about the relationship between the individual sample stands (Wartenberg *et al.*, 1987).

2.1.4.1. Cluster analysis (Classification)

Cluster analysis is a system of categorizing vegetation (or sample vegetation stands) of an area into smaller, more homogenous vegetation units called associations (van der Maarel, 1990). Techniques of cluster analysis were claimed to have emerged in support of the Clements community unit theory, which is also called the Clements organismic view that aimed to divide the stands into clusters of high internal similarity with respect to their species (Kent and Coker, 1992). After the subjective method of traditional phytosociology (Braun-Blanquet, 1932), a number of objective methods of cluster analysis have been developed and summarized by a number of authors for instance as in Greig-Smith (1983), Digby and Kempton (1987), Leps and Smilauer (2003) and Zerihun Woldu (2012). Basically the methods of cluster analysis fall into hierarchical and non-hierarchical (partitioning) techniques (Duda *et al.*, 2001; Barber, 2016; Wildi, 2017).

Hierarchical clustering

Hierarchical clustering is an assembling technique of vegetation stands that could be classified into groups, the processes being repeated at different levels to form a tree (Finocchi and Petreschi, 2001). There are two types of hierarchical clustering methods, namely agglomerative and divisive. The main outcome of a hierarchical cluster analysis is a dendrogram, which is also called a tree diagram (Podani and Schmera, 2006; Sanderson and Ott, 2006) that could be cut at arbitrary heights to give a fixed number of clusters (Kent and Coker, 1992). A dendrogram is structured in such a way that all the sample plots are listed on the X-axis; whereas the Y-axis shows some measure of similarity or distance at which clusters join. There are several dissimilarity and distances indices used in ecological data analysis; the common ones are similarity ratio (SR) that ranges between 0 and 1 and euclidean distance (ED) whose result can be any size (Podani and Schmera, 2006).

Hierarchical Agglomerative Clustering

This method of clustering technique often referred as “bottom up method” since the clustering starts at the bottom and work upwards, beginning with the individual stands combing them to form successively more inclusive groups of stands (Digdy and Kempton, 1996). Such clustering would be achieved using various algorithms (computer programs) that ultimately portray results in a dendrogram (tree or linkage diagram) (Oksanen, 2010). Plots that are similar to each other are combined at low heights, whereas those that are more dissimilar are combined higher up the dendrogram (Kent and Coker, 1992).

Hierarchical Divisive Clustering

Divisive hierarchical clustering method is the opposite of agglomerative classification in that the clustering start at the top and work downwards, beginning with the whole collection of plots, and dividing them to form successive subclasses and ultimately form a more or less similar groups (Hill *et al.*, 1975). This method is not too common method for plant classification (Williams *et al*., 1966).

Partitioning (non-hierarchical clustering)

Partitioning is a method of classifying vegetation stands in the same level, not in hierarchy (Kent and Coker, 1992). It is used when one has a hypothesis regarding the number and patterns of segregated clusters and the relative location of sample stands in the clusters (Digby and Kempton, 1987). A number of computer programs exist for non-hierarchical clustering and the most common algorithms are summarized in Zerihun Woldu (2012). These include Partitioning Around Medoids (PAM), Clustering Large Applications (CLARA), Fuzzy Analysis (FANNY) and means Partitioning; their results would be displayed in the form of scatterplots, and/or silhouettes.

2.1.4.2. Gradient analysis (Ordination)

Gradients are spatially varying aspects of the environment which are related to species composition (Leps and Smilauer, 2003). Ecologists such as Tilman (1982), Austin *et al.* (1984), Austin and Smith (1989), Lookingbill and Urban (2005) and Dyakov (2010) summarized the different ecological factors into three basic gradients, namely indirect gradient, direct gradient and resource gradient. They defined indirect gradients as environmental factors such as elevation, slope, aspects, soil depth, etc. which indirectly affect vegetation composition of an area by influencing variables like temperature and precipitation, which would have direct effect on plant growth. Direct gradients are environmental conditions having direct physiological effect on plant growth but are not consumed by plants. For example, soil structure and pH are often listed examples of direct gradients that regulate plant growth and support plant physiological integrity (Whittaker, 1978a; Gonzalez *et al.*, 2013). Resource gradients are variable resources that can be consumed by plants for their growth (Tilman, 1982; Austin, 2005). Soil resources consumed by plants are often referred as essential elements (Hopkins and Huner, 2009; Taiz and Zeiger, 2010). These resources (or soil essential elements) includes Nitrogen (NO_3^-, NH_4^+), Phosphorus ($H_2PO_4^-$, HPO_4^{2-}), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulfur (SO_4^{2-}), etc. (Brady and Weil, 2008). Soil chemical elements such as Aluminium (Al^{+3}) are not often consumed by plants (Schulze *et al.*, 2005; Schmitt *et al.*, 2016), and would not be treated as a resource gradient during gradient analysis although its toxic levels to plants can sometimes be considered as an environmental gradient.

It is important to note that in practical field studies of vegetation, it is common to come across with a combination of several ecological factors at a time, for instance altitude, slope and aspects (all together in mountainous forest), soil moisture & soil salinity (all together for patch forests surrounding a lake). These are called complex gradients and are the most observed gradient in floristic studies (Cushman *et al.*, 2009).

Thus, gradient analysis is defined as an analysis about the influence of environmental gradients on the distribution of vegetation of an area so as to reveal maximum information about their ecological relationships (McIntosh, 1967; Whittaker, 1978a). The techniques of gradient analysis may be viewed as indirect gradient analysis (unconstrained ordination); or direct gradient analysis (constrained ordination or canonical ordination) (ter Braak and Prentice, 1988).

Indirect Gradient Analysis (Unconstrained Ordination)

Indirect ordination is a classical ordination technique designed to illustrate the spatial distribution of sample vegetation units (species or plots) so that more related samples would be arranged close together (Bray & Curtis, 1957; Curtis, 1959; Greig-Smith, 1983; Kent & Coker 1992). According to Whittaker (1967) indirect ordination is capable of displaying vegetation change in composition; and consequently, it is often considered as complementary data clustering method or representation method mainly used for exploratory purposes.

It is said that indirect ordination often performed when the gradients (environmental data) are unknown apriori (Austin, 1968); and the gradients are inferred from the pattern of the vegetation data displayed on the ordination diagram (Austin, 2005). In such analysis displaying of environmental factors in the form of arrows would not be shown on the ordination diagram suggesting that there is a possibility of ordering vegetation samples alone without aligning it with the environmental parameters. Indirect gradient analysis is usually performed using unconstrained ordination techniques such as principal component analysis (PCA) and Multidimensional Scaling (MDS) (Leps and Smilauer, 1999). Such ordination may include or calculate ‘stress or goodness (or poorness) of fit’ in R (Zerihun Woldu, 2012) so as to compare the potential of the techniques in reflecting the relationship between the unknown environmental factors and the species composition. The smaller the ‘stress’ value the better the method would be granted for representing the gradient analysis (Oksanen, 2015).

Direct Gradient Analysis (Constrained Ordination or Canonical Ordination)

The very objective of vegetation ecology is to generate hypothesis about the relationship between the species composition at a site and the underlying environmental factors. For this purpose, direct ordination, which was originally termed as direct gradient analysis by Whittaker (1956), was applied to test species-environment relationships and has been considered as the most popular ordination methods in community ecology (ter Braak, 1986; Digby and Kempton, 1987; Palmer, 1993; Leps and Smilauer, 2003; Kent and Coker, 1992; Austin, 2005). In general, ordination methods, which uses environmental variables in the ordination diagram, are called constrained ordination since the positions of the samples in the ordination are constrained by the environmental variables (Whittaker, 1967; Zerihun Woldu, 2012).

Direct ordination is conducted when the gradients (environmental factors) are duly known in advance and data are on hand; and consequently it is referred as environmental gradients by some authors (Whittaker, 1978a; Austin, 1980). Direct gradient analysis is performed using different techniques such as redundancy analysis (RDA), deterended correspondence analysis (DCA), canonical correspondence analysis (CCA) and correspondence analysis (CA) (ter Braak, 1988). Here ‘stress or goodness of fit’ need not be calculated; rather the explanatory power of each of the environmental factors are shown using the length of arrows on the ordination diagram (Oksanen, 2018). In the direct ordination analysis, only the environmental variables that would be significant in a stepwise selection (forward or backward selection) procedure would be considered important in explaining the composition of the species (Zerihun Woldu, 2012). However, this does not mean that environmental factors that are not significant are ecologically unimportant (Hilborn and Mangel, 1997).

2.1.4.3. Complementary approaches in multivariate analysis of vegetation data

In vegetation ecology, floristic data are often summarized and analysed using classification and ordination techniques (Muller-Dombis and Ellenberg, 1974; Digby and Kempton, 1987; Kent and Coker, 1992). However, there have been considerable debate about whether classification or ordination is more efficient in extracting and delivering generalizations about vegetation of an area (Lambert and Dale 1964; Greig-Smith, 1983). This was due to the fact that ordination and classification were initially seen as two competitive and antagonistic strategies in the past with respect to the different concepts about plant community structure, continuum or community unit theories (Austin, 2005).

It was claimed that the choice of either classification or ordination method depends on the ecological question to be answered (Gauch and Whittaker, 1972; Gauch, 1982). Classification aims at grouping individual stands into categories whereas ordination displays information about vegetation stands with respect to environmental gradients.

Contemporary ecologists are convinced to use both classification and ordination as a harmonized approach of data analysis since the combination has given them an integrated & holistic image about the structure of the vegetation they were interested to (Greig-Smith, 1983). This is called complementary analysis (Digdy and Kempton, 1987; Kent and Ballard, 1988). Some techniques in ordination clearly demonstrate such complementarity between classification and ordination by using the results of ordination to identify clusters either by enclosing them in polygons (Kent and Coker, 1992) or by assigning colors corresponding to the cluster codes (Zerihun Woldu, 2012).

2.1.4.4. How to choose classification and ordination techniques for research purpose

Both classification and ordination are regarded as orthodox approaches of multivariate analysis in vegetation ecology (Crawley, 2007). However, there are numerous techniques for both classification and ordination making users confusing to choose one from the others. For instance, the techniques in cluster analysis (classification) generally falls into hierarchical and non-hierarchical methods. However, hierarchical techniques are generally preferred to non-hierarchical (Kent and Coker, 1992). These authors elaborated that hierarchical methods are common used and shown in a denderogram that reveals different level of similarity or dissimilarity very clearly, and the different levels displayed on the dendrogram are often very helpful when it comes to making ecological interpretations.

Among the hierarchical classification, agglomerative hierarchical are the most preferred by ecologists (Greig-Smith, 1983; Digdy and Kempton, 1987; Kent and Coker, 1992; Crawley, 2007; Oksanen, 2010). In strengthening this point some ecologists often use the term “cluster analysis” for the agglomerative methods only (Leps and Smilauer, 2003). Computer programs for agglomerative hierarchical techniques are many in number . For instance, nineteen clustering programs (algorithms) were included in Zerihun Woldu (2012). In such situations, it is often difficult to decide a priori which algorisms may provide a more elegant and robust clustering. Thus, what is often recommended is to run more than one program to make comparisons among the resulting classificatory displays (dendrograms) so that it would be a matter of personal judgement to inspect & choose the algorithm which we think has resulted the best dendrogram (Digdy and Kempton, 1987). According to Kent and Coker (1992), the ‘best’ dendrogram is the one which allows a clear ecological interpretation.

Moreover, the choice of the dendrogram could be assisted by computing ‘cophenetic correlation’ to each dendrograms, which is regarded as a measure their classificatory ability

(Rohlf, 1974; Oksanen, 2015). Cophenetic correlation can be performed by running appropriate program in R; and accordingly the dendrogram with higher cophenetic correlation is believed to be an optimal dendrogram and hence shall be recommended for scientific research purpose (Zerihun Woldu, 2012; de Araujo *et al.*, 2014).

In ordination methods, a wide variety of techniques have been developed for analyzing vegetation data (Singh and West, 1971). The choice of an ordination method requires to know the nature of the input data, whether they are duly known and are at hand or not. If known then we shall use constrained ordination techniques, and if not we use unconstrained gradient analysis techniques (Okland, 1996; Zerihun Woldu, 2012). The second most striking thing we need to know is the nature of the data whether they are homogenous or heterogeneous or whether the relationship between species-environment data is linear or unimodal? or whether the change in species composition from place to place, or along an environmental gradients is low or high? (ter Braak, 1986; Jongman *et al.*, 1987; ter Braak and Prentice, 1988; Kent and Coker, 1992; Legendre and Legendre, 1998). These can be answered by calculating gradient length (GL) that measures an ecological turn over (beta diversity) of the vegetation data set (Legendre and Legendre, 1998 Okland, 1990; van der Maarel, 2005).

Short gradient length is an indication of low beta diversity of compositional gradients (i.e., low species turn over) and signifies that data are homogenous. On the other hand, long gradient length (GL) is an indication of high species turnover; and signifies that data are heterogeneous (Leps and Smilauer, 2003). ter Braak and Prentice (1988) generalized the assumption that species of homogenous data sets respond linearly along an environmental gradient whereas they respond unimodally if they are from heterogeneous data set.

Gradient length (GL) is the number of mean standard deviations (SD) of species occurring along the gradient and it is checked using the first axis of DCA (detrended correspondence analysis) in R (Hill and Gauch, 1980; Correa-Metrio *et al.*, 2014). Leps and Smilauer (2003) provided the threshold value for GL to decide which ordination techniques to be applied. For instance, PCA (for unconstrained ordination) and RDA (for constrained ordination) are most suggested techniques for gradient analysis when GL< 3SD (Leps and Smilauer, 2003) or if it is less than 2SD (ter Braak and Smilauer, 2002); whereas CA (for unconstrained ordination) and CCA (for constrained ordination) are most suggested techniques to be applied if GL is greater than 4SD (Leps and Smilauer, 2003). However, if the calculated GL is between these threshold limits, then either of the techniques could be used, and it would be up to the researchers for their personal judgement (ter Braak & Smilauer, 2002).

Thus, from this brief discussion, it could be reflected that checking GL is the first thing before we decide which ordination technique is to be used for gradient analysis in ecological studies.

2.1.5. The need to study floristic composition and structure in vegetation ecology

It is said that one of the ultimate practical goal of vegetation ecology is to identify areas that rationally demand conservation efforts (van der Maarel, 1980; Westhoff, 1983; Wilson *et al.*, 2009). In strengthening this fact Bakker (2005) claimed that vegetation ecologist should know how a plant community is organized. That is, what species compose the community; how abundant is each species; how do the species interact; and are some species increasing in abundance or declining over space. This mean that such and other related information is invaluable when vegetation ecologist intended to develop conservation plans for natural areas or recovery plans for threatened or endangered species.

In vegetation ecology, data on floristic composition and structure are generally obtained based on field survey of vegetation using the Braun-Blanquet methodology (Kent and Coker, 1992). This is due to the fact that this methodology is rapid and extensive method to gain the full floristic record of an area. In supporting this view Box and Fujiwara (2005) claimed that there is no better methodology developed yet than the usual phytosociological methodology (Braun-Blanquet method) for floristic inventory of an area.

The purpose of studying floristic composition is to obtain a complete checklist of plants that make up vegetation of a particular habitats. These lists of floristic composition are considered as botanical assets of that particular ecosystem (World Conservation Monitoring Center (WCMC), 1992). Such knowledge on botanical wealth of an area (species composition) helps in identifying target species for conservation purposes such as those that are useful economically and that are endemic & threatened ones (Mueller-Dombois and Ellenberg, 1974; Ensermu Kelbessa *et al.*, 1992; Kent and Coker, 1992). That is why vegetation ecologist insist on encouraging researches to focus on floristic composition of an ecosystem particularly at this special moment where ecosystems are highly vulnerable to different kinds of disturbances (Gomez-Diaz *et al.*, 2017). Organizations that aims at working on vegetation conservation such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) require data on the floristic details of an area to decide for their conservation action (Pool-Stanvliet *et al.*, 2018). From the floristic lists and its relative abundance, there is a possibility of computing which plant community types are richer and diverse in terms of their species and which are poor. With this information an ecologist/conservationist would be confident where to prioritize conservation efforts.

Structural analysis of an area is often a topic in vegetation ecology as this analysis are very vital for evaluating the vegetation status of an area; and to monitor the success of conservation effects (Woodward *et al.*, 2009; Pastorella and Paletto, 2013; Gao *et al.*, 2014). In vegetation ecology, the most usual structural attributes of vegetation include frequency, density, population structure, Important value Index (IVI) and so on among many others (Mueller-Dombois and Ellenberg, 1974). The importance of these attributes is to gain a desirable quantitative information on the structural status of a given plant community so as to shape the attention of conservationist where to budget more and how to give priority in their conservation actions (Kint *et al.*, 2000; Brown and Williams, 2016).

For instance, some plants could be represented by more number of individuals whereas others could be represented by few individuals/abundance (Odum, 1997). These occurrence of plants could be measured objectively by calculating percentage frequency and assigning each species into a desirable frequency classes following Raunkiaer (1934). Thus, such analysis would help ecologist to focus their priority to the conservation of plants that are infrequent and locally rare than for more frequent ones (Benayas *et al.*, 1999). Moreover, analysis on species density (number of individuals per area of a species) provides valuable information about species status (Kent and Coker, 1992). For instance, if a given plant species is represented by lesser density values than others then it would help ecologist to set activities that would cause increments in this species since these species may decline more in the near future if not appropriately managed (Pastorella and Paletto, 2013; Mahajan and Fatima, 2017).

Population structure of a species is defined as population dynamics of tree species in arbitrary diameter-height size classes to imagine the overall recruitment profile of trees (Peters, 1996). From studying population structure it could be roughly possible to group plant species into different patterns (Hutchings, 2009; Bierzychudek, 2013). For instance, when a species is characterized by greater number of smaller trees than big ones, it may meant that it has a good recruitment potential and shows healthy structure (Demel Teketay, 2005). However, when the population structure of a species only characterized by bigger trees and no or fewer younger trees, it surely reflects that such species is having limited recruitment and hence it demands conservation/management efforts (Simon Shibru and Girma Balcha, 2004). Information on such kinds of population structure of a tree species tells the history of the past disturbance to that species; and hence used to forecast its future trend which would further help ecologist to design proper management activities to enhance their recruitment potential.

Important value index (IVI) is another important structural parameter that uses to compare the ecological significance of a given species (Curtis, 1959). It does so since IVI of a species is computed from its extent of dominance, occurrence and abundance (Kent and Coker, 1992). Therefore, it is a good index for ranking species for management and conservation practices based on their ecological significance (Fekadu Gurmessa *et al.*, 2012). Ecologist often prioritize to conserve species having lower rank of IVI value whereas species with higher IVI would be recommended for monitoring (Odum, 1997; Pastorella and Paletto, 2013).

Thus, it can be concluded that studying the floristic composition and structure of vegetation are extremely indispensable tools for proper planning and directing our future management activities for sustainable biodiversity conservation.

2.2. Review on carbon stock

2.2.1. Carbon sequestration and forests’ role for climate change mitigation

Concern about global climate change is current and top issues (Pomerance, 1989; IPCC, 2017). Atmospheric concentration of greenhouse gases (GHGs) is said to be increasing when emissions are larger than removals (Hegerl *et al.*, 2007; Bernal *et al.*, 2017); and indeed it is happening. According to the report by the United Nations Framework Convention on Climate Change (UNFCCC), Carbon dioxide (CO_2) is considered as the major anthropogenic greenhouse gas that furnishes more to climate change (UNFCCC, 2007). For instance, over the past 150 years, the amount of carbon in the atmosphere has increased by 30% as indicated in the report of the Ecological Society of America, (ESA, 2006). This widespread and growing concern over global climate change has led to extensive international negotiations, among which the 1992 Rio environmental conference (UNFCCC, 1992) and the 1997 Kyoto Protocol (UNFCCC, 1997; Pershing and Tudela, 2003) were the notable ones.

Because climate change risks are coming to be very worrying, a process called carbon sequestration for lowering the effects of climate change has been given an important place on the international climate change policy of UNFCCC (1995). Carbon sequestration can be defined as a process of taking out carbon from the atmosphere and setting it down in a reservoir (Houghton, 2005). It is thought to be a promising means for reducing atmospheric carbon dioxide. In biological sense, this process is perceived as the transfer of atmospheric CO_2 and storing it in long lived pools (IPCC, 2003). A number of practices for biosequesterating carbon from the atmosphere have been proposed which includes ocean and terrestrial carbon sequestration. Ocean sequestration is defined as storing of carbon in the ocean through direct injection and/or enhancing the productivity of ocean biological systems (e.g., algae) through fertilization; whereas terrestrial sequestration is defined as storing of a large amount of carbon in soil and vegetation (Brown, 2002; Gibbs *et al.*, 2007).

Among terrestrial sequestration, forests play an important role in the global carbon cycle (IPCC, 2007; Gorte, 2009). According to FAO (2010) about 90% of the world terrestrial carbon is stored in forest. Thus, one strategy for mitigating greenhouse gas emissions and thus possible climate change is to increase the amount of carbon stored in forests as it is well recommended by IPCC (IPCC, 2003). The UNFCCC also advocates the quantification of CO_2 reduced from the atmosphere and stored by forests for favoring tradable carbon commodity (UNFCCC, 1997). Following this advocacy, researchers have developed various methodologies for estimating forests' role in mitigating climate change through its role of carbon sequestration (Brown, 1997; MacDicken, 1997; Jenkins *et al.*, 2003; Chave *et al.*, 2005, 2014).

2.2.2. REDD+: Etymology and its implication for climate change mitigation

The effect of climate change is indeed affecting the life of many people throughout the World. It is the result of emissions of greenhouses gases (GHGs) to the atmosphere (IPCC, 2017). Many of these GHGs causing climate change are emitted from industrialized countries such as USA, China and European Union, EU (Averchenkova *et al.*, 2016) whereas Africa in this regard contribute little (Eleri, 2017). The main contributing factors from Africa and other developing countries are emissions from deforestation (Nabuurs *et al.*, 2007). With respect to this IPCC has estimated the loss of approximately 13 million hectare of forest lands due to deforestation across the globe making forests as a responsible ecosystem for approximately 17.4% of all anthropogenic GHG emissions (IPCC, 2007; Nabuurs *et al.*, 2007). Other authors also reported the emission of 1.3-1.6 billion tons of Carbon dioxide per year due to deforestation of tropical forests (Watson *et al.*, 2000).

Related reports were a stimulating factor for conference of the parties (COP) of the United Nations (UN) to develop a concept of reducing emissions from deforestation known as RED in 2005 at COP 11 in Montreal, Canada (UNFCCC, 2005; Pistorius, 2012). The development of RED program was to mitigate climate change by subsidizing financial rewards to countries that have reduced deforestation (UNFCCC, 2005) so as to encourage them to decrease their impact on deforestation. But later, the scope of RED (Reducing emission from deforestation) was discussed at COP 13 in Bali (Indonesia) and agreed to incorporate emission reduction not only from deforestation but also from degradation, and hence RED evolved into REDD (UNFCCC, 2007).

After a year (i.e., in 2008) the subsidiary body for scientific and technical advice (SBSTA) of UNFCCC conducted its 29th conference in Poznan (Poland); and declared to include activities related to forest conservation, sustainable forest management and enhancement of forest carbon stocks to effect climate change mitigation in developing countries (UNFCCC, 2008). The addition of these activities shifts the evolution of REDD into REDD+, the 'plus (+) sign' being referring to forestry activities that ultimately improves livelihoods and biodiversity conservation to enhance emission reductions (Holloway and Esteban, 2009; Parrotta *et al.*, 2012). Probably because of this importance that REDD + is currently considered amongst the important international negotiations (Minang *et al.*, 2009). These days' countries that are taking actions to reduce emissions from forest lands are benefiting from REDD+ financial incentives as in for example Ethiopia (Yisehak Dinku, 2017) and other African countries (Unruh *et al.*, 1993; Ciais *et al.*, 2011; Mercer *et al.*, 2011) although the subsidiary are not equivalent to compensate the damages come about due to the effects of climate change.

2.2.3. A perspective on the experience of previous carbon stock research works in Ethiopia: major methodological gaps and suggestions

Ethiopia as a country of tropical Africa with significant forest carbon resource (Brown, 1997; Yitebitu Moges *et al.*, 2010) and a land with relatively good forest coverage (15.5 %) (MEFCCC, 2017) should have been benefited much from REDD+. This in fact would require data. In relation to this Ethiopia after it has officially launched the national REDD+

program in 2009 and became an official member of the UN-REDD Program in 2011 (Yetebitu Moges and Eyob Tenkir, 2014; Melaku Bekele *et al.*, 2015), it has conducted a number of carbon stock research works such as Wolde Mekuria *et al.* (2009); Mesfin Sahile (2011); Adugna Feyissa *et al.* (2013); Tulu Tolla *et al.* (2013); Getachew Tadesse *et al.* (2014); Abel Girma *et al.* (2015); Alefu Chinasho *et al.* (2015); Hamere Yohannes *et al.* (2015); Marshet Tefera and Teshome Soromessa (2015); Muluken Nega *et al.* (2015); Tibebu Yelemfrhat and Teshome Soromessa (2015); Habtamu Assaye and Zerihun Asrat (2016); Fentahun Abere *et al.* (2017); Abyot Dibaba (2018); Admassu Addi (2018); Beyene Belay *et al.* (2018). Many of these studies were basically tier 2 type as they used general allometric equation established for broader forest category (IPCC, 2003), typically Brown (1997) & Chave *et al.* (2005; 2014) by assimilating their field data as inputs. This way of reporting carbon, however, is unlikely to be sufficient for crediting under REDD+ (Pelletier *et al.*, 2010; Hewson *et al.*, 2013). Those research outputs, based on the methodology they followed, could be placed in one category, which we can call it ‘category I’ for clarity purpose in this review. In such category, the fundamental standards in carbon stock researche such as the use of verified models and slope factors were missed.

Researchers who have long years’ experience on carbon stock estimation such as MacDicken, Powell, Delaney, Brown, Walker, Pearson, among many others suggested that to make tier 2 effective, all models should undergo quality checks through validations before they are applied (MacDicken, 1997; Powell and Delaney, 1998; Brown *et al.*, 2004; Pearson *et al.*, 2005, 2007; Walker *et al.*, 2012). From these references we can say that what was actually recommended for carbon stock estimation was to use a generic model that has been validated with local data. The validation could be done using some equations that might work for the forests one wants to study (IPCC, 2003; 2006). This is using five larger trees (or more if possible) since smaller DBH trees often fit into a larger number of equations

(Brown, 1997; Jenkins *et al.*, 2003; 2004; Lambert *et al.*, 2005; Navar, 2010; Ebuy *et al.*, 2011). Thus, it can be suggested that future research works on carbon stock estimation using tier 2 should not follow the previous trends as in category I, which is mainly manifested by estimating carbon stocks using unverified general allometric equation. This is because such approaches in category I is against the standard operational procedure (SOP) that should have been followed as a state of science in any carbon stock research works (Walker *et al.*, 2012). The SOPs are methodologies developed by groups of scientists in Winrock International Institute to avoid methodological disparity and subjectivity (IPCC, 2017); and to accurately and efficiently estimate carbon stocks (Brown *et al.*, 2004). According to this organization the use of general allometric equation based only on climatic similarity, which was used in category I, is highly condemned (Walker *et al.*, 2012).

The researches that we categorize as ‘category I’ have been conducted for almost the last one decade in Ethiopia; and has played pertinent contributions for developing our understanding about carbon stock research. But the same line of thinking would not help the country for the future as the upcoming researches should transform to quality reports that would be influential for convincing donors to get a better financial rewards (World Bank, 2009; Streck *et al.*, 2013; Frechette *et al.*, 2014; Pearson *et al.*, 2016). This can be achieved by sticking to SOP manual. This kinds of carbon stock research works which we referred here as category II in this review were very rare in Ethiopia.

Moreover, most of the studies that were categorized under category I in this review were on sloppy areas. However, area correction due to the slope were not considered in their studies. Experts on carbon stock research such as MacDicken (1997), Pearson *et al.* (2005); Walker *et al.* (2012) strictly recommend the use of adjusted plot size whenever sample plots are falling on sloppy terrain so as to reflect the true horizontal distance. Terrains are said to be sloppy when the slope is greater than 10% (or 6^{o}); whereas it is claimed to be non-sloppy if it is less than 10%. Slope of a plot is measured using clinometer following Karki *et al.* (2016).

The method of slop correction could be done for each nests or only for the major plot if we think that the impact of slope only impacts those trees near the edge of the plot, which are often referred as edge trees or borderline trees (MacDicken, 1997). Correction for true horizontal plot length can be calculated by projecting the plot length measured in the field along the slope using the following formula (Brown *et al.*, 2004).

$$Corrected\ length = sloped\ length\ \ of\ the\ plot\ X\ Cos\ \theta$$

Where: corrected length = length of the plot agreed upon flat terrain (m), also called true horizontal plot length; sloped length = the apparent length of the plot (m) measured in the field along the slope, and is supposed to be adjusted for horizontal projection; Cos θ = cosine of the slope angle in degree.

Thus, adjusted plot area can be computed from the product of corrected length of the plot and width of the plot (Pearson *et al.*, 2005). The advantage of slope correction is that it slightly extends the length of the plot in the field so that each of the plots will yield the same area as if the plots were established on flat terrain (Walker *et al.*, 2012; Watson *et al.*, 2013). For example, for a plot that has laid on a slope >10% and if we are working in the 35 m length plot then the new plot size will be larger than 35 m in length and thus a tree that was considered “out” at the edge may now be “in” as the slope-corrected size may now be sufficiently greater than 35 m to count the tree in. For practical purpose, it is often recommended to prepare printed table in advance that contain the corrected length of the plots for each of the appropriate slope in the manner prepared by Subedi *et al.* (2010). The table should be covered with water proof material and should be overseen in the field as part of the field equipment (MacDicken, 1997).

Slope factor should also work for correcting transect lines that is often used for dead wood data collection (Brown *et al.*, 2004). It is known that the method that is recommended to collect for lying dead wood needs to establish transect line in the same way as recommended by Walker *et al.* (2012). According to these authors two 50 m transects line or rope should be designed at right angles to each other. The correct length (L_{field}) of transect can be calculated using the following formula assuming that the default transect length on flat terrain is 50 m.

$$L_{field} = \frac{L_{flat\ ground\ (i.e.,50\ m)}}{\cos(\theta)}$$

L_{field} = corrected length of transect line (m) to be used in the field, $L_{flat\ ground}$ = length of transect agreed upon in the flat terrain for various slope gradients based on a 50 m transect on flat ground, (which is always 50 m), $\mathrm{Cos}(\theta)$ = cosine of the slope angle in degree. Like for main plots, it is recommended to take printed copy of this sheet into the field for quickly establishing the transect lines.

Therefore, the lesson forwarded in this review is to focus on the SOPs, particularly the use of validated allometric equation and adjusted plot size so as to make sure carbon stock estimation by researchers in line with the IPCC standards.

2.2.4. The development of species specific allometric models: Methods and research efforts

Allometric models are mathematical equations applied to estimate biomass and carbon stocks in forests at different scales (Gibbs *et al.*, 2007). The model can be species specific when elaborated to a particular species or general if it is used for different species. Some authors emphasized the use of general allometry (Brown *et al.*, 1989; Jenkins *et al.*, 2003; Zianis and Mencuccini, 2004; Chave *et al.*, 2005; Brown 1997; Gibbs *et al.*, 2007; Chave *et al.*, 2014). However, the use of these models for all species is troublesome since tree biomass depends on environmental and genetic factors that vary from region to region. Therefore, biomass equations aimed to estimate biomass of a particular species in a given place is believed to provide more accurate estimates (Ter-Mikaelian and Korzukhin, 1997; Araujo *et al.*, 1999; Litton and Kauffman, 2008; Basuki *et al.*, 2009; Navar, 2009b; Ebuy *et al.*, 2011; Mandal *et al.*, 2013).

Although developing species specific and site specific allometric equation is the most accurate method to apply, the question of building such equations remain a challenge. Literature surveys indicate that there are basically two broad alternatives for local species specific model development, namely felling (Brown, 1997, Chave *et al.*, 2005) and non-felling method (Navar, 2010a; Navar, 2010b).

Among the felling method, the most common practice involves measuring the biomass directly by harvesting the tree and oven drying & weighting the actual mass of each of its compartments (Kangas and Maltamo 2006; Augusto *et al.*, 2009; Vieilledent *et al.*, 2012). The alternative form of felling method is explained very well in various scientific literature where it involves falling a tree and measuring the volume of bole and larger branches to get its biomass from the multiplication of the measured volume and its wood density with smaller branch and leaves biomass integrated using other approaches (Navar, 2010; Walker *et al.*, 2012). The non-felling methods may use simple remote sensing (Houghton *et al.*, 2001; Foody *et al.*, 2003; Hofstad , 2005; Houghton, 2005; Saatchi *et al.*, 2007; Goetz *et al.*, 2009; Asner *et al.*, 2010; Goetz *et al.*, 2011; Mesfin Sahle, 2011, Ahmed *et al.*, 2013;

Nigatu Wondrade *et al.*, 2015), light detection and ranging (LiDAR) techniques (Means *et al.*, 1999, Lefski *et al.*, 1999a,b; Asner *et al.*, 2011; Zhao *et al.*, 2012; Colgan *et al.*, 2013; Hunter *et al.*, 2013), Photograph methods (Montes *et al.*, 2000) and tree climbing method (Vann *et al.*, 1998; Dawit Tekle, 2014; Eyosias Worku and Teshome Soromessa, 2015). In either of the methods of model development a great number of local allometric equations have been reported throughout the world since the innovation of the allometric concept in the 1920s by Julian Huxley (Huxley, 1924; Huxley, 1932; Strauss, 1993) with a major emphasis on species of temperate North America (Ter-Mikaelian and Korzukhin, 1997), tropical South America (Navar, 2009), Europe (Zianis *et al.*, 2005) and Sub-Saharan African Countries (Henry *et al.*, 2011). It is believed that 70% of the species specific biomass equations of the Sub-Saharan African countries were developed in Ethiopia (Henry *et al.*, 2011).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

The study was carried out in Sele-Nono forest, approximatly 700 Km SW of Addis Ababa (between 7^{o}40’- 8^{o}9.5’ N and 34^{o}55.5’- 35^{o}27’ E). It is located in Sele-Nono District of Illuababora Zone, Oromia Regional State. The District has a total area of 165,324 ha, which is divided into twenty administrative Kebele (the smallest administrative units), namely Arbe, Asendabo, Bontu Korma, Decha, Derba, Derbeta, Gemeches, Haro, Kimo, Kombolcha, Kopi, Nono Berbersa, Onose, Qoti, Selase, Sochoso, Tupi, Waka, Welketesa and Yakema (Figure 3). The natural forest covers about 91% of the district, and ranges between an altitude of 840-2448 m asl. It is situated at 100 Km away from Metu town and 50 Km away from Masha town. The study area is bordered on the Southwest by Gambela region, on the North by Bure, on the Northeast by Halu, and on the Southeast by the Southern Nations, Nationalities and Peoples Region (SNNPR) (Figure 3).

3.2. Socio-economic information

Large area of the District (91%) is covered by forest whereas the remaining 9% were covered by settlements. The forest is a vital economic and social pillar for the lives of many people living in and around it. It is also a natural habitat for wild coffee (*Coffea arabica*) and spices like ginger (*Zingiber officinale*), Cororima (*Afromomum corerima*) and Timiz (*Piper capense*) which are essential commodities in national and local trade. The forest consists of important plants such as *Schefflera abyssinica* and *Manikira butugi* that contribute for quality honey production. These apicultural practices and small scale coffee farm are the main sources of incomes of the farmers. The local people also earns their livelihood from growing different types of annual and perennial crops such as Enset (*Ensete* *ventricosum*), Godore (*Colocasia esculenta*), *Dioscorea* spp. and the likes. Moreover, non-timber forest products (NTFP) such as the use of lianas, bamboos, fern trees, including hunting and selling various items to towns are among the important sources of their livelihood. Selling chat (*Catha edulis*) is also becoming a means of subsistence within the past few years. Cereals such as maize, barley, teff, and beans, peas, and different kinds of spices are the major subsistence crops cultivated on farm fields (SNDAO, 2015). The local community also do have a deep-rooted culture of forest conservation, which is referred as Kobo system, that allow them to use a certain forest landscape (also called Kobo forest) only for honey production and other NTFPs.

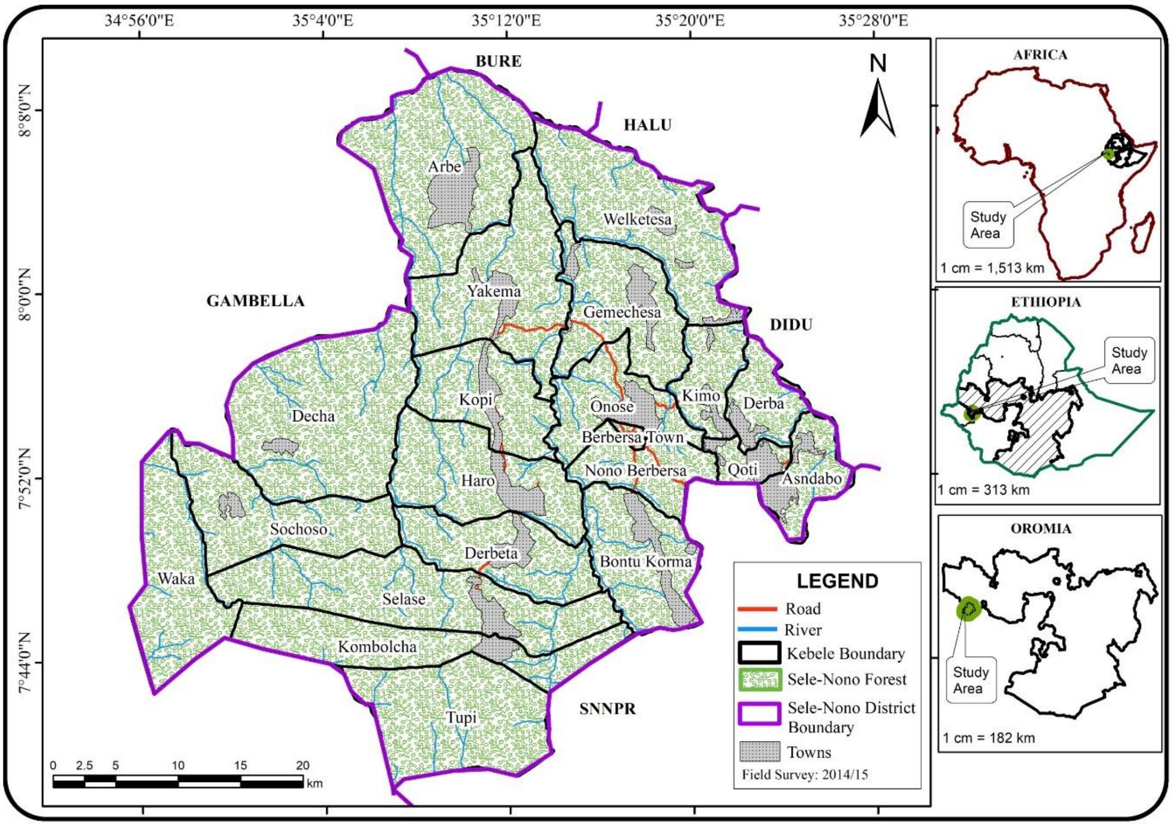


Figure 3. Map showing the location of the study forest

3.3. Physical and biological settings of the area

3.3.1. Climate of the area

Sele-Nono receives eight months of rainfall, which extends from February to September with even distribution of rainfall (Figure 4). The rainfall data collected from Masha meteorological station (nearest station to Sele-Nono forest) indicated that the area receives very high annual rainfall reaching up to 2200 mm in some peak years. The monthly mean maximum and mean minimum temperature of the area is 24.8°C and 10.1°C, respectively. The mean annual temperature is 16.9°C with slight variation from year to year (Figure 4). The rainfall pattern shows low rainfall in January and February, gradually increasing to the peak period in June to August and then declining in October and November.

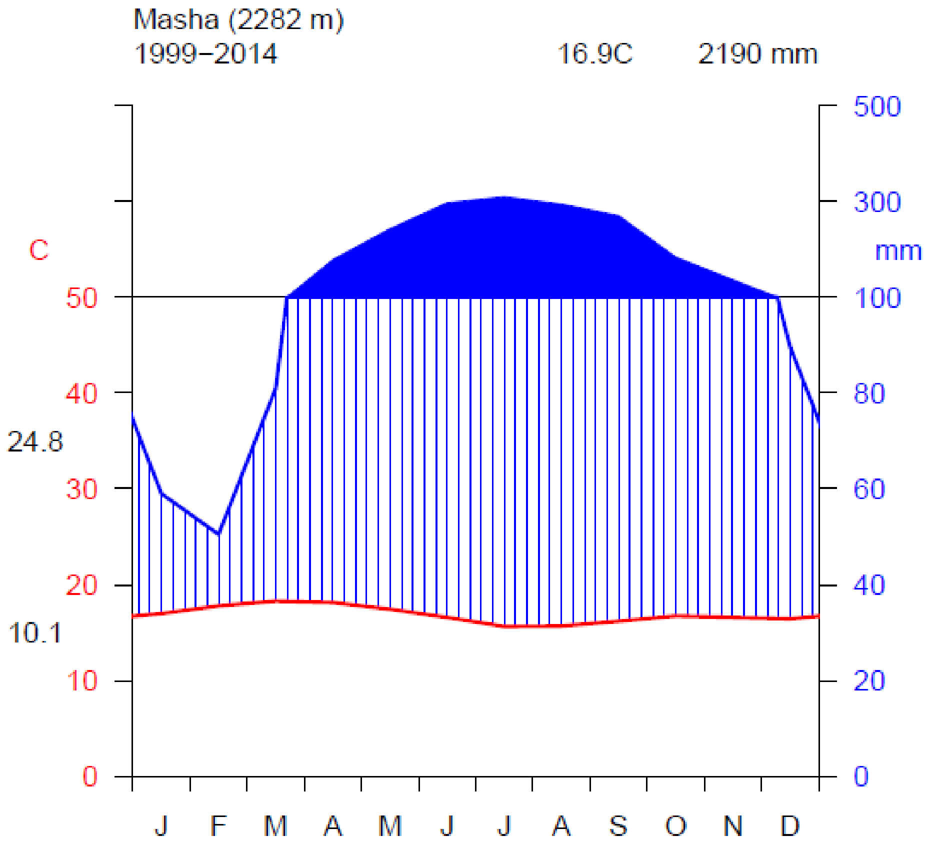


Figure 4. Climadiagram of Sele-Nono Forest showing rainfall distribution and temperature variation from 1999-2014 at Masha. Data source: National Meteorological Agency (2015).

3.3.2. Geology and soil

The geological formation of the study area falls within the geological structure of the Horn of Africa. The basement land of southwest Ethiopia, which includes the study area, is supposed to contain Precambrian rocks with tertiary lavas directly lying on the crystalline basement (Mohr, 1971). According to this author, the tertiary lavas were altered by the eruption of large amount of ash and coarser fragmental materials forming a trap like series on the region. According to FAO (1988), the soil in the study area belongs to nitosol soil group although other types of soils like acrisols, regosols, vertisols, fluvisols and cambisols also occurs. This report goes with the report by the Sele-Nono District Agricultural Organization (SNDAO, 2015). The report of Agricultural Organization also indicated the soil pH of the District ranging from 6. 4 to 6. 6 and hence it may be categorized as acidic.

3.3.3. Vegetation of the area

The most recent vegetation types in Ethiopia is documented in Friis *et al.* (2011). According to the authors three forest types are recognized in SW forest of Ethiopia, namely the Moist Afromontane Forest (MAF), Transitional Rainforest (TRF) and riverine forest. All these vegetation types were also noted in Sele-Nono forest. The MAF is characterized by characterstic species such as *Pouteria-adolfi-friederici* which is emergent out of the lower continuous lower canopy trees like *Prunus africana*, *Syzygium guineense, Olea welwitschii, Schefflera abyssinica, Croton macrostachyus*, *Ilex mitis.* The TRF is characterized by the prescence of *Pouteria altissima, Anthocleista schweinfurthii, Manilkara butugi*, *Morus mesozygia*, *Trilepisium madagascariense.* The riverine forest type is often represented by vegetation along the rivers such as Baro; and is characterized by species such as *Ficus sycomorus, Mimusops kummel, Phoenix reclinata*.

3.4. Research Methods

3.4.1. A study on the floristic composition and diversity of plants in Sele-Nono forest

3.4.1.1. Sampling technique

Preliminary field investigations at Sele-Nono forest was carried out in March 2013. After the visit, it was decided to employ stratified random sampling technique as the study area was a large size forest with little prior knowledge about it by the researcher. For this purpose, the study area was initially mapped using Digital Elevation Model (DEM) technique. Then it was stratified into six strata following the maximum recommended strata number suggested by MacDicken (1997) based on 275 m elevation differences. Sampling plots were allocated proportionally along each stratum (Table 1 below) after area for each stratum were calculated using ArcGIS.

Table 1. Stratification of the study area and total number of plots allocated to each stratum (S)

Strata No.	Elevation range for each strata (m, asl)	Total area (forest & village) of each strata (ha)	Total village areas in each strata (ha)	Total net forest areas in each strata (ha)	Proportion of forest areas in each strata (%)	Total number of plots allocated to each strata
S 1	2182-2448	18490.44	117.35	18373.08	12.22	11
S 2	1994-2181	42025.49	5279.31	36746.17	24.44	22
S 3	1646-1993	45673.67	8927.49	36746.17	24.44	22
S 4	1378-1645	33827.22	421.61	33405.61	22.22	20
S 5	1109-1377	23637.48	253.55	23383.93	15.55	14
S 6	840-1108	1670.28	0	1670.28	1.11	1
Total	**840-2448**	**165324.60**	**14999.33**	**150325.27**	**100**	**90**

The allocation of sampling points was done by making geographical grids on the map of the area before going to the field. The grids were made by dividing the map of the study forest in latitude and longitude coordinate using a one minute (1’) grid scale, which is equivalent to 1.85 Km actual distance on the ground (Appendix 1A). Then some of the intersection points of the grids from each stratum were randomly chosen as a sample point (sample plot) using lottery method; and plot numbers were given randomly to each of the sampling points using the same lottery technique (Appendix 1A, 1B). Those waypoints of the plot coordinates on the map (Figure 5) were saved in GPS; and they were placed on the ground of the actual study area using GPS navigation after ridding to the nearest town (Appendix 1B). The Germin GPS device we used was of high quality with a proportional error of less than 5 meters.

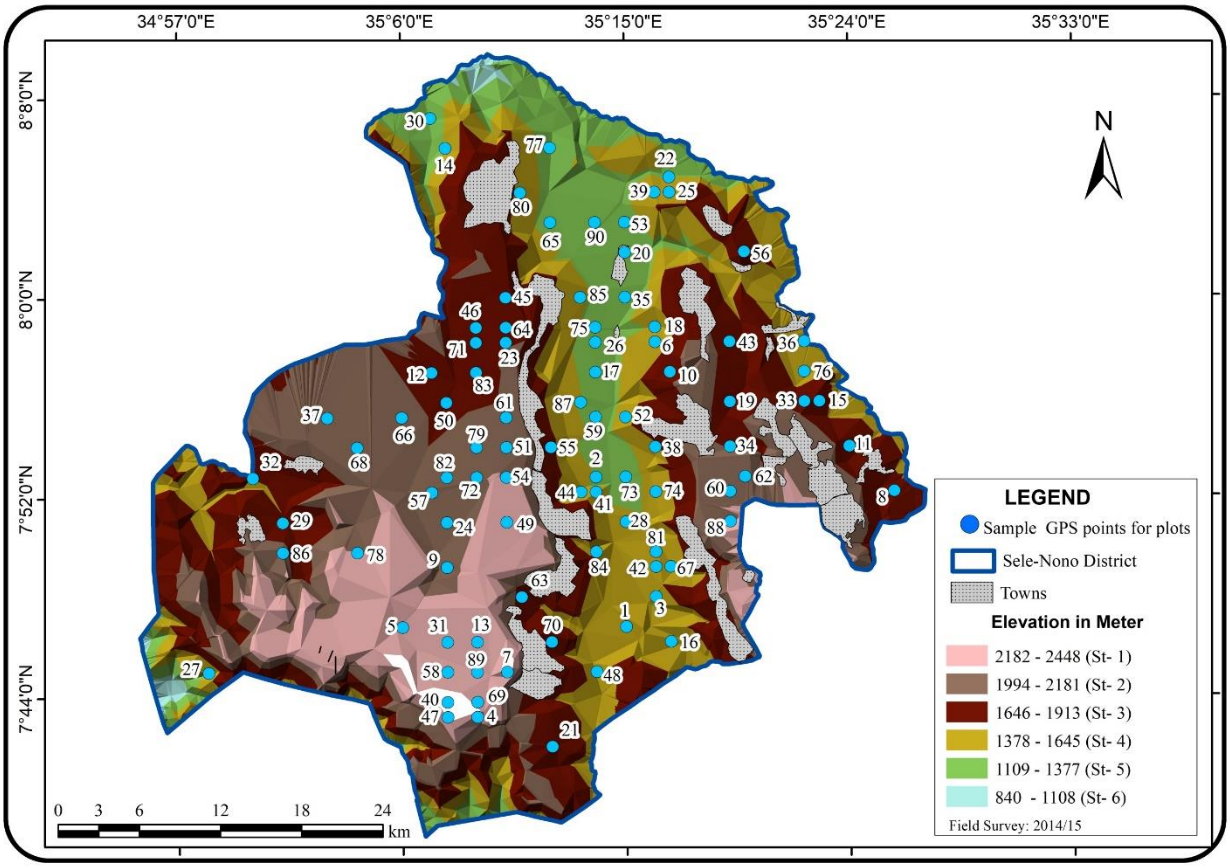


Figure 5. Location of permanent sample plots in the study area. Numbers on the map are plot numbers

3.4.1.2. Plot design and data collection

Plot design and vegetation survey

Field data collection on the vegetation of Sele-Nono forest was carried out following the releve approach (Braun-Blanquet, 1932; van der Maarel, 1979; Podani, 2006) from November 2014 to February 2016. Considering the size of the forest, variation of the vegetation and associated environmental factors, a total of 90 (25 m by 25 m) permanent plots were established. Plot size was determined using the published table by van der Maarel (2005) and based on previous experiences from other SW forest of Ethiopia since the minimum area curve method was difficult to map in the study area. The practical use of a minimum area curve for plot size determination was also criticized for moist tropical forests (Kent and Coker, 1992; van der Maarel, 2005). The 25 m by 25 m plot size was adopted in this study as this size is an average plot size between the 20 m X 20 m plot size (Tadesse Woldemariam *et al.*, 2008; Feyera Senbeta *et al.*, 2014) and 30 m X 30 m plot size (Ensermu Kelbessa and Teshome Soromessa, 2008; Yohannes Mulugeta *et al.*, 2015), which were the most widely used plot sizes for floristic study in SW forests of Ethiopia. All woody species with DBH >2.5 cm & rooted within each plots were recorded. Canopy cover (the percentage of ground area covered) of all trees (>1.5 m in height) were assessed in the entire plot (25 m x 25 m), while shrubs were measured in the 5 m X 5 m subplot designed in the centre of the main plot. Cover of herbaceous plant species was surveyed in five 1m^2 subplots within each sample area; four of which were arranged at the four corners of the main plot and one was at the centre of the 25 m^2 subplot (Figure 6). The cover abundance for herbaceous species was estimated by calculating the average cover abundance of each herb species existing in five subplots established inside large plot. Then, the abundance and/or percentage cover estimates recorded in the field were converted into cover-abundance values (Appendix 2) according to 1-9 modified Braun-Blanquet ordinal scale (van der Maarel, 2005). Plant species which were not within the plots (for trees) or subplots (for shrubs and herbs) but encountered during our field walk were also collected and recorded only as ‘present’ to enrich the floristic composition of the study area; but not included further in the data analysis (Mueller-Dombois and Ellenberg, 1974).

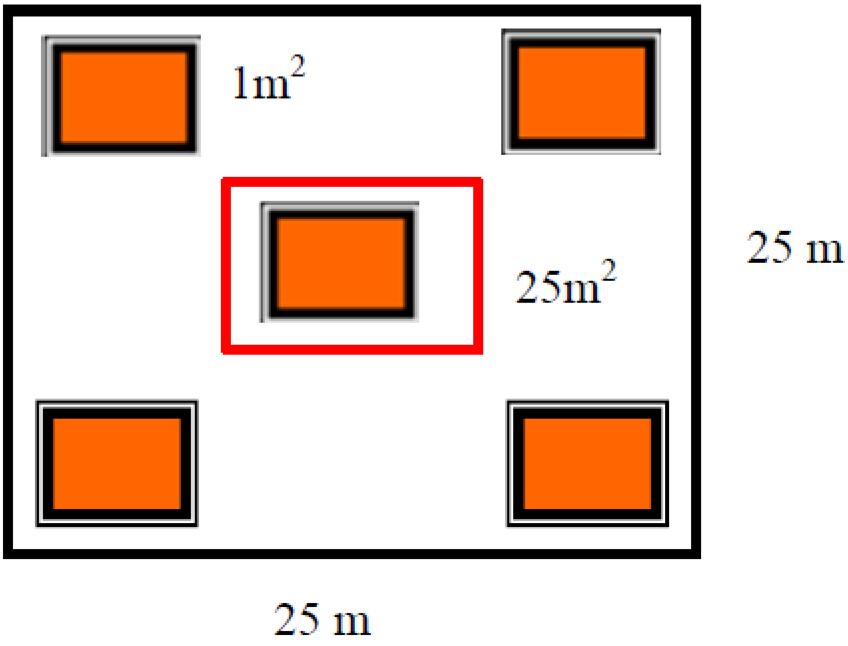


Figure 6. Design of plot layout in the study area

Environmental data collection

The environmental factors (altitude, slope, aspect, disturbance and soil characteristics) were determined for each of the main plots so as to explain possible differences in plant communities by their corresponding environmental factors. Disturbance on each plot was estimated objectively based on ordinal scales from zero to five following checklist developed for this study (Appendix 3). GPS was used to record the altitude and position (latitude and longitude) of the sampled plots. Compass and Clinometer were used to measure aspect and slope of the plots respectively. Aspect was codified according to Zerihun Woldu *et al.* (1989). Composite soil samples were collected at a depth of 30 cm by pooling soil samples from all the five subplots. These soil samples were air dried; and analysed for total nitrogen (N), available phosphorus (P), organic matter (OM), pH, Potassium (K), Calcium (Ca), Magnesium (Mg), Cation exchange capacity (CEC) and texture (sand, silt and clay) at the National Soil Test Laboratory of Ethiopia.

Data collection on threats of the forest

Semi-structured interviews, using checklists prepared in advance (Appendix 4), were conducted with informants of the local people to understand the threats of the forest under study. For this purpose, a total of 40 informants who were born or lived most of their lives in the study area were chosen. Thirty of the informants (5 from each strata) were randomly selected following Alemayehu Kefalew *et al.* (2015). The remaining 10 of the total informants were key informants who were believed to have immense knowledge on the past and present changes of the forest and many of these were clan leaders. The Key informants were selected based on the recommendation from the local people, local authorities and development agents (DAs) in the study area.

Plant identification

Plant species that were easily identifiable were recorded on field. Other species were temporarily stored in a plastic bag; and then pressed and brought to the National Herbarium (ETH) of Addis Ababa University (AAU) where they were dried, deep frozen and identified. The identifications were first performed using Natural database for Africa (2011) and keys of published volumes of *Flora of Ethiopia and Eritrea* (Edwards *et al.*, 1995; Hedberg and Edwards, 1989; Edwards *et al.*, 1997; Edwards *et al.*, 2000; Hedberg *et al.*, 2006; Hedberg *et al.*, 2009) and later supported with identification by comparisons with already authenticated dried specimen in the Herbarium. At last, all the Latin names of the plant species were confirmed by taxonomic experts in Addis Ababa University (AAU).

3.4.1.3. Vegetation and environmental data analysis

Descriptive statistical methods such as percentage frequency method of data analysis was employed using Microsoft Excel spread sheet.

A species accumulation curve (SAC) of the data was drawn to ensure that we had collected an adequate number of plots for the study using "library (vegan)" package in R (Oksanen *et al.*, 2011) (Figure 7).

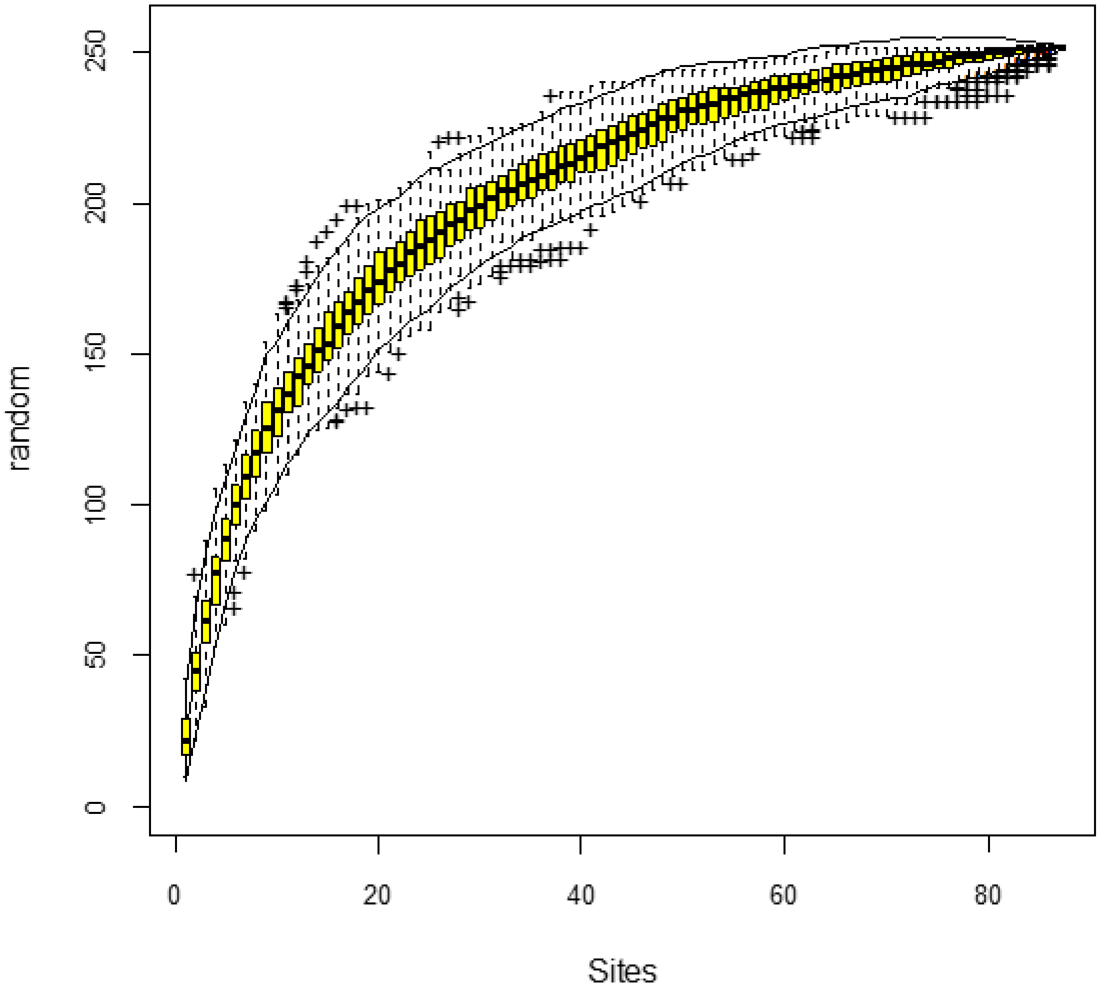


Figure 7. Species accumulation curve showing the relationship between the numbers of quadrats and the number of plant species in Sele-Nono forest

For recognizing and describing plant community types, Agglomerative hierarchical cluster analysis using dendrogram was used as it is the most commonly recommended classification system in vegetation ecology (van der Mareel, 2005). First, a program for determining the optimal number of clusters was applied using R (R Core Team, 2013) for a priori specification of the number of clusters (K) (Figure 8).

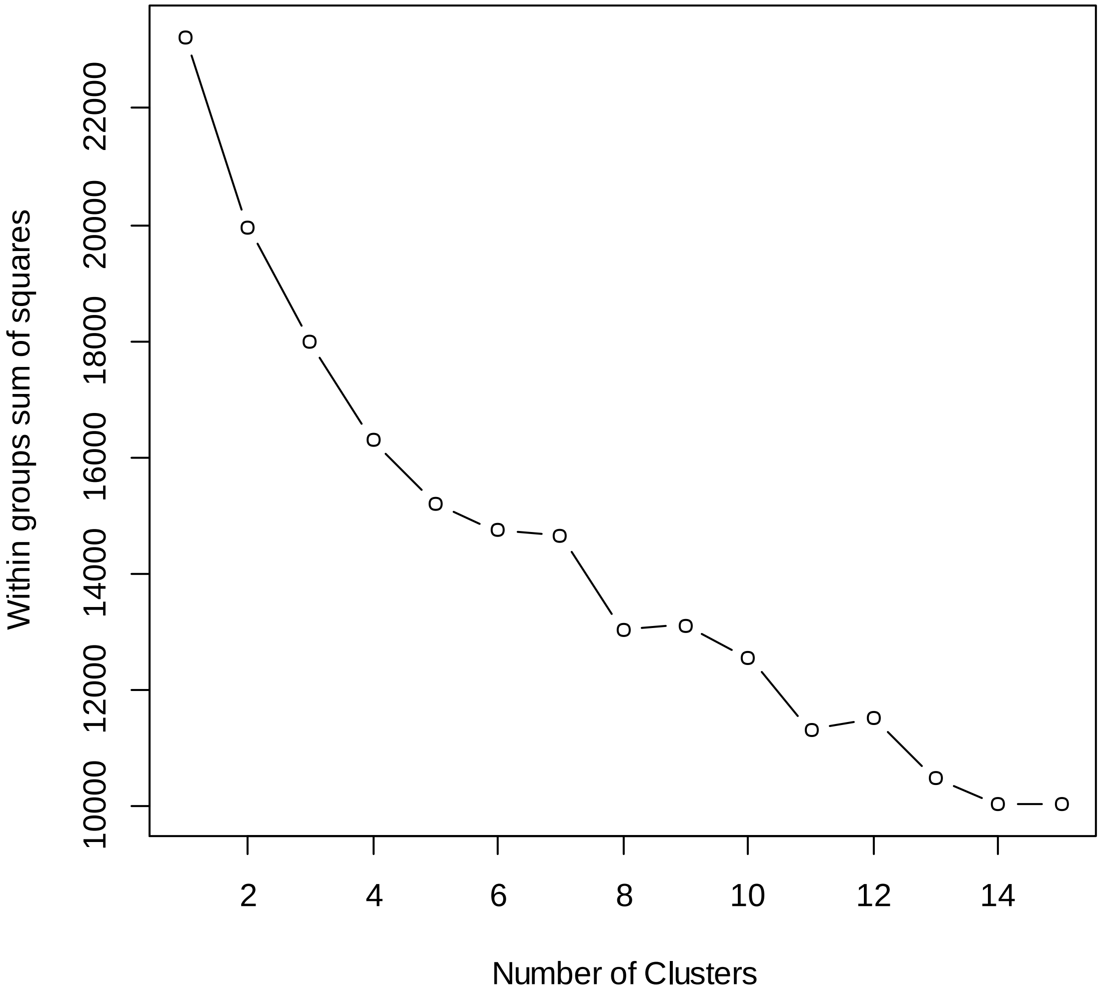


Figure 8. Determination of optimal number of clusters corresponding to plant community types in Sele-Nono forest.

Then, the dendrogram was performed using Euclidean distances with the 'cluster' and 'gclus' packages in R. Such Euclidean distances has also been used in other studies to develop the dendrograms in cluster analysis (Feyera Senbeta, 2006; Tadesse Woldemariam *et al.*, 2008; Mamo Kebede *et al.*, 2013). The agglomerative strategy used in grouping the clusters was Ward's method as it is the most recommended clustering strategy to produce reasonably compact clusters (McCune and Grace, 2002; Zerihun Woldu, 2012). The cophenetic correlation coefficient, which is regarded as criteria of successful classification, was calculated to infer the goodness of fit of the dendrogram. Synoptic table analysis was used to name and describe community types.

Outlier analysis was conducted to dropout rare species from the analysis (species which occur three or fewer times in the data matrix) using 'the function dropspc in the library labsdv' (Roberts, 2010) as rare species are noise to the cluster analysis. The abundance data of the remaining plants were Hellinger transformed prior to analyses (Zerihun Woldu, 2012; Aerts *et al.*, 2006). Normality of the environmental variables was checked visually using histograms and with the Shapiro-Wilk normality test (Ghasemi and Zahediasl, 2012; Das and Imon, 2016). Based on this analysis all the measured environmental variables except altitude, slope, aspect, and sand data were log10 (x+1) transformed.

Plant diversity measures such as Shannon-Weiner (1949) index of species diversity (H'), richness (S) and evenness (J) were computed in R (R Core Team, 2013) to analyze the status of plant diversity in the established plant community types (Kent and Coker, 1992; McCune and Grace, 2002); and to infer the impact of humans on the spatial distribution of the vegetation (Magurran, 2004; Leitner and Turner, 2001). Moreover, Whittaker (1972) alpha and beta diversity was calculated using R software to assess the heterogeneity of plant species within the clusters. Whittaker beta diversity (β_w) was also performed using R to define the overall heterogenity of the plant species in Sele-Nono forest along the established communities (R Core Team, 2013). Analysis of Variance (ANOVA) followed by Post hoc (LSD) was also performed to evaluate the significant variation in mean values of calculated diversities among the established plant community types using SPSS version 20.0 (Onaindia *et al.*, 2004).

Mantel test was first applied to see if there is a significant correlation between the species composition and environmental variables (Legendre *et al.*, 2015). Constrained ordination technique was then used to display the relative contribution of the measured environmental variables using canonical correspondence analysis (CCA) since a gradient length (GL) on a preliminary detrended correspondence analysis (DCA) showed that the species respond unimodaly (GL of 4.62 > 4SD) to environmental gradients (Leps and Smilauer, 2003). The environmental variables that were only significant in a forward selection procedure (Monte Carlo permutation tests, n = 999) were considered important in explaining the floristic composition of the study area and thus included on the CCA diagram. All data processing was performed using R (R Core Team, 2013).

3.4.1.4. Analysis of forest threat factors

Priority ranking on the major threats of the study area was done with key informants following Martin (1995) to screen and find out the key human impacts which are aggressively threatening the forest. Other qualitative information gathered through informant interviews were used to complement the quantitative analysis.

3.4.2. Vegetation structure and regeneration status of Sele-Nono forest

3.4.2.1. Plot design and data collection

The main plot (25 m X 25 m) that were used for floristic composition and plant diversity study was also used for studying the vegetation structure and regeneration status of the study area. All the woody individuals with DBH >2.5 cm and height >1.5 m were recorded and counted in each plots (25 m x 25 m); whereas shrubs were measured in a 25 m^2 (5 m X 5 m) subplot designed in the center of the main plot (Figure 9, left). DBH was measured using a meter tape and height (H) was estimated visually (for relatively smaller trees) or using appropriate DBH-H allometric model (for bigger trees). Woody individuals with DBH < 2. 5 cm (seedlings and saplings) were counted throughout the entire plots. For this purpose, the major plots (625 m^2) were divided into five blocks, each 5 m X 25 m, to ease the counting of seedlings and saplings (Figure 9, right). Individuals with DBH < 2. 5 cm and H < 1. 5 m were considered as seedlings & those that were with height greater than 1. 5 m were regarded as saplings.

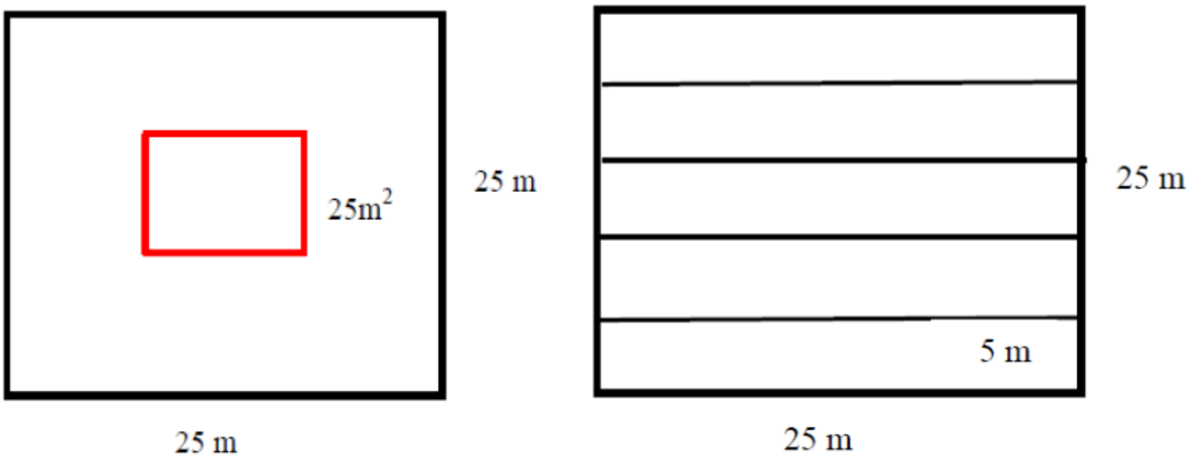


Figure 9. Design of plot layout in the study area (left: design for structural data collection of vegetation, right: plot design for seedling and sapling counts).

Moreover, a plot size of 61 m long and 7. 6 m wide were used to roughly illustrate profile diagram of a forest stand following Richards (1952). The spatial variation of canopy shape and size, diameter & distance between the trees were estimated visually and a rough pencil illustration were made on field from stands of one to three stripes per strata. Photographs from each stripe were also taken to support the rough drawings. This was done to give a mental picture about the physiognomy (external appearance) of the forest stands and mimicking the stratification of the different plant community types in Sele-Nono forest. For this purpose we draw them thoughtfully and purposively from a stripe that we think are typical to reflect the different existing natural settings in each of the strata in terms of stratification (Kuiper, 1988).

3.4.2.2. Analysis on the vegetation structure of Sele-Nono forest

The structure of Sele-Nono forest was described by analyzing height (H) and DBH size class distribution, Importance Value Index (IVI), and by analyzing representative profile diagram of plant community types identified in this study.

The size class distribution of woody plants in this study was assessed by categorizing the frequency of the density of woody plants along a predetermined DBH and/or height classes in the same way as used by Feyera Senbeta (2006) who did vegetation structural analysis for some southwest and southeast moist forests of Ethiopia. Population structure of the woody species were inferred from the histograms displayed for some typical woody species of Sele-Nono forest. The histograms were constructed by categorizing the density of the individuals along the DBH class following Feyera Senebeta (2006) so as to use this tool to set conservation priority following Getachew Berhan and Yoseph Assefa (2004) who made a detail analysis of similar kinds of work for some other moist forests of the southwest Ethiopia.

Importance Value Index (IVI) was analyzed from the summation of the relative density (RD), relative frequency (RF) and relative dominance (RDo) (Muller-Domboise and Ellenberg, 1974; Kent and Coker, 1992). These three components of IVI were calculated for all woody species of Sele-Nono forest following the methods of Curtis and McIntosh (1951) as follow:

$$Relative\ density\ (RD) = \frac{Density\ of\ a\ species}{Sum\ density\ of\ all\ species} X100$$

$$Relative\ frequency\ (RF) = \frac{Frequency\ of\ a\ species}{Sum\ frequency\ of\ all\ species} X100$$

$$Relative\ dominance\ (RDo) = \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species} X100$$

Where density (count of individuals of a species per unit area), frequency (number of times a species occurs in a given number of sample plots) and dominance (the amount of space occupied by the stems of a species; and is measured by basal area in m^2 per hectare basis) were computed as follow

$$Density\ (D)\ per\ hectare\ = \frac{Total\ No.of\ individuals\ of\ a\ species}{sample\ size\ in\ hectare}$$

$$Frequency\ (F)\ in\ \%\ = \frac{No.of\ quadrats\ in\ which\ the\ species\ occurs}{Total\ No.of\ quadrats\ examined} X100$$

$$Dominance\ (Do)\ in\ m^2/ha\ = Basal\ area\ (BA) = \frac{\pi(DBH)^2}{4}, where\ \pi = 3.14$$

The frequency of the woody species was categorized into five classes following Raunkiaer percentage frequency classes (Raunkiaer, 1934). The five classes were named as constantly present species, mostly present species, often present species, seldom present species and rarely present species for those species occurred in 81-100% of the plots, 61-80% of the plots, 41-60% of the plots, 21-40% of the plots and 1-20% of the plots, respectively.

The vertical structure of Sele-Nono forest was analyzed following the method recommended by the International Union for Forestry Research Organization (IUFRO) (Lamprecht, 1989). Moreover, a more or less realistic scheme of profile diagram which we think are representative of each plant community types were constructed with the aid of a computer painting using the field drawings and field photo as inputs.

3.4.2.3. Analysis on the regeneration status of Sele-Nono forest

The regeneration status of Sele-Nono forest was done to predict the future condition of the woody species; and it was determined from the analysis of both the composition and total density of the seedlings (SE) and saplings (SA) counts. This technique is used to suggest conservation priority of the woody species.

3.4.3. A study on the validation of existing allometric models

3.4.3.1. Sampling design and methodological framework

Different sampling techniques were employed in this particular study. Ten bigger sample trees irrespective of the kind of species were used for validating tree allometric equations. Of these tree samples, six of them were chosen from all strata (one from each strata) and the remaining four tree samples were taken by choosing one sample tree from strata one to strata four (Figure 10). Our sampling strategy also included palms and fern trees as they are structurally important elements of the Sele-Nono forest. Five palm samples were used for validating possible palm allometric equations. The five palms were collected from strata 3, 4 & 5 as they are mainly found between an elevations of 1000-1700 m asl (Figure 10). Sample fern trees were also collected to validate possible fern tree allometric equations. Five sample fern trees were collected from strata two as the fern trees were predominantly found along the riversides in this strata. Five lianas were also taken into consideration, one from each strata except strata six, as the sixth strata which occurs at lower altitude did not have abundant lianas, for validating existing liana allometric equations. Five bamboos were also considered for validation test of bamboo allometric equation from the first strata as they are only concentrated there above the elevation of 2300m asl in the study area (Figure 10). All the samples for validation data sets were randomly chosen from forests of nearby villages in the desired strata (Figure 10).

The dendrometric variables included in this study were the diameter at breast height (DBH), diameter at stump height (DSH), wood density (ρ) and total height (H). Although palms and fern trees are taxonomically belonging to “tree” life form, they are structurally unusual when compared to broad leaf trees. Hence, they are considered into different category known as “palms” and “fern trees” when they are needed for carbon stock analysis due to the internal organization and structure of their stem, which is the main storage area of carbon (Niklas, 1993a,b; Henderson *et al.*, 1995; Negrelle, 2002, Vieira *et al.*, 2008; Alves *et al.*, 2010). This mean that ‘palms’ and ‘fern trees’ are not treated with equations developed for forest trees (Pearson *et al.*, 2005; 2007; Walker *et al.*, 2012; Djomo *et al.*, 2016). Thus, all the dendrometric variables were considered for the ten sample tree individuals; whereas only DBH & H were measured for the palms (*Phoenix reclinata*) and fern trees (*Cyathea manniana*). Only DBH measurement were undertaken for the sampled lianas and highland bamboos (*Arundinaria alpina*).

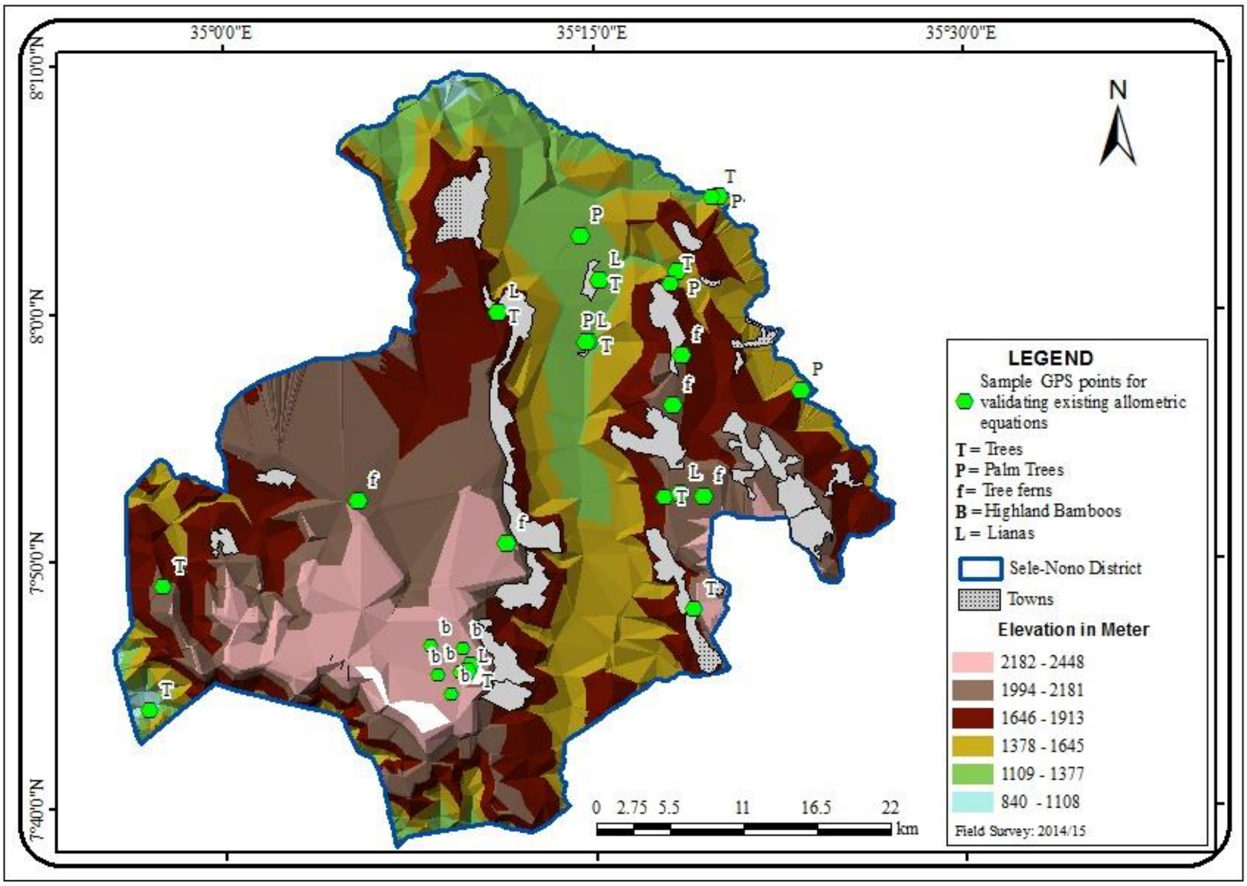


Figure 10. Map of the study area showing the samples and their GPS locations

3.4.3.2. Consent statement

Consents have been made with all the research participants of the local people to use their knowledge of tree climbing technique for data collection purpose. Moreover, consent was also made with individuals /authors who are not included in the reference list to include them in the body of the manuscript as suggested by Eccles *et al.* (2011) and Shamoo and Resnik (2015).

3.4.3.3. Quality assurance

Literate field crews who can read and write were hired from the local community of the study site. Then, all recruited crews were trained very well about standard operating procedures (SOP) of tree climbing to assimilate it with their conventional rope-climbing practices; and to master them on how to record data on the data collection sheet (Appendix 5). Attention was given to ensure the safety of climbers. The performance of the field work was monitored and followed by the candidate.

3.4.3.4. Data collection for actual biomass determination of samples

Validation is compulsory before applying the suspected general allometric equation for forest biomass estimation (Zianis *et al.*, 2005; Vadeboncoeur *et al.*, 2007; Condit, 2008; Dietz and Kuyah 2011; Zhao *et al.*, 2012). But still validating proposed allometric equations using destructive (harvest) methods is impractical in Sele-Nono forest; and hence it would be desirable to use the most appropriate approach. Rope-tree climbing is a method more appropriate approach for trees and palms of the entire Southwest forest. Limited samples (only 5 individuals) using felling method was used for fern trees, lianas and bamboos to validate and verify their corresponding existing allometric equations.

(i) Observed above ground biomass determination of sample trees and palms

Relevant data for sample trees and palms were obtained from field measurements using rope-tree climbing technique (Figure 11) following the suggestions of Risley (1984), Davis (2005), Picard *et al.* (2012) and Gimenez *et al.* (2017). Total height for each samples were measured directly during the course of the climbing for dendrometric measurements. This is because cutting or harvesting of trees is strictly prohibited in Sele-Nono forest due to conservation restrictions. Moreover, undertaking destructive sampling of trees is very expensive, labor intensive and time consuming for the researcher. On top of this fact, using other alternatives like scaffolding, ladders, towers and/or hydraulic lifts were not affordable and manageable during the life span of this study. On the contrary tree climbing is part and parcel of the culture of the study area and the people of the whole southwestern part of Ethiopia in general as their main livelihood economy is apiculture that have stayed with them for centuries or millennia; and hence more applicable, easily manageable and environmentally friendly.

Figure 11. Rope-tree climbing method for measuring biomass of bole and large branches of sample trees (A-tough rope of a climber carried by the researcher, B- tree climber climbing along bole of a stem and data recording on the questionnaire by another crew member on the ground, C-climbing along the stem of large branches, D- a tree climber is landing along the rope after finishing his measurements; All photos by Alemayehu Kefalew, 2015 at Sele-Nono forest).

Then, the climbers have taken measurements that would be used to calculate the Smalian volume of stump (Appendix 5 A), bole (Appendix 5 B) and large branches (Appendix 5 C) (Figure 11) following Cailliez (1992) and Gimenez *et al.* (2017). Moreover, very limited destructive sampling has been conducted to get wood discs from smaller branches

(Appendix 5F), and these were taken to Addis Ababa University (AAU) Ecophysiology laboratory for wood density determination following the standard protocol (Appendix 6B). The biomass of stumps, bole and large branches were calculated from the product of their volumes and the estimated wood density (Appendix 7A, B, C).

The biomass of small branches (i.e., branches with basal diameter less than 10 cm) were estimated using the product of their Smalian volume and the estimated wood density of each of the trees. This was done in such-away that three randomly chosen small branches based on their basal diameter (one type with basal diameter of 7.5 to 10 cm; second type was with basal diameter ranging 5 to 7.5 cm and the third type was with basal diameter of 2.5 cm to 5 cm) were trimmed; and Smalian volume were measured. Then, the biomass of each trimmed small branches were totaled and averaged to determine the mean biomass of a small branch (Appendix 5D). Then the total biomass of small branches was obtained by extrapolating the averaged biomass to the total number of small branches (Appendix 7D).

Biomass of foliage (twigs with basal diameter less than 2.5 cm and leaves together with the attached inflorescence, seed and/or fruit) were estimated following wet-dry mass ratio techniques. This was done in such-away that all the foliage from each of the randomly chosen small branches were removed completely and weighted separately for their total fresh mass (Appendix 5E). Then each of this fresh weight were summed and averaged to determine mean total fresh weight per small branch (Appendix 5E). Then subsample fresh weight (300-500 gm) were taken from the well mixed composite foliage samples to Ecophysiology laboratory (AAU) to determine subsample dry weight (Appendix 6A); the result of which extrapolated to the total foliage biomass per small branch and further extrapolated to total foliage biomass of the sample tree by multiplying it with the total number of small branches (Appendix 7E) following the suggestion given by Brown (1997).

Finally, the total above ground biomass (AGB) of each sample tree was computed by summing the biomass of stumps, bole, large branches and small branches (Appendix 7F).

For palms, the Smalian volume of bole (also called caudex or trunk) was calculated by summing Smalian volumes of trunk sections (Appendix 8A); whereas the biomass of crown (fronds) were estimated by trimming single leave (or frond) from the head of a caudex and estimating its biomass through wet-dry mass ratio and extrapolating it for the total count of leaves (or fronds) of the crown (Appendix 8B). Thus, the total AGB of a palm is the sum of the biomass of the bole and the crown (Appendix 8C).

(ii) Observed above ground biomass (AGB) determination of sample fern trees, lianas and bamboos

Felling method for sample fern trees were employed to find out their actual AGB. After felling the stems (caudex) of each sample fern trees were divided into manageable size and measured for their total fresh weight on field. Out of the total fresh weight of each caudex about 500-1000 gm subsamples were brought to Ecophysiology laboratory (AAU) to determine their oven dry mass, the result of which were extrapolated to the total biomass of caudex of each sample fern trees (Appendix 9A). For biomass determination of the fronds total number of leaves (pinna) were initially counted for each sample fern tree. Then, one segment of a frond (also called a pinnae) were randomly picked and completely measured for its total fresh weight; and about 200-300 gm subsamples were brought to AAU to determine its oven dry mass. This result was extrapolated to the total biomass of the frond using wet-dry mass ratio techniques (Appendix 9B). The total biomass of each sample fern tree was calculated from the sum of the biomass of their caudex and fronds (Appendix 9C).

Stem biomass of lianas were obtained by multiplying its Smalian volume with its wood density (Appendix 10A). However, volume of the stems was estimated using felling or destructive method as climbing method was not applicable. Once the samples of lianas were completely harvested, measurements for calculating their stem Smalian volume were undertaken on field following De Aguiar *et al.* (2017). Moreover, 2-3 wood discs from the stem of each sample ramets were brought to AAU for wood density determination. The biomass of leaves of the sample lianas were estimated using wet-dry mass ratio technique (Appendix 10B). Thus, the total biomass of each sample ramets were obtained from the sum of the biomass of stems and leaves (Appendix 10C).

Bamboo biomass was estimated using the traditional harvesting method (Yuen *et al.*, 2017). In this method sample bamboos were completely harvested from each age-class as indicated in Kassahun Embaye *et al.* (2005). This age identification was made following the indicators used by Wimbush (1945) and Banik (1997) (Table 2). All the culms of the sampled bamboos, after completely removing attached branches and leaves, were divided separately into manageable size; and total and subsample fresh weights were measured on field for each samples. The culm subsample fresh weight (300-500 gm) of each bamboo sample were kept in plastic bag and brought to AAU to determine its oven dry weight, the result of which were extrapolated to estimate total biomass of the culms of each bamboo samples (Appendix 11A).

The foliage (attached branches and leaves) that were completely removed from each culms were measured separately on field for their total fresh weight, from which their subsamples (100-300 gm) were taken to AAU to determine their oven dry weight. This oven dry weights of the sub-samples were extrapolated to estimate the total foliage biomass of each sampled bamboo (Appendix 11B). The total biomass for each of the sample bamboos were obtained by summing the biomass of their culms and foliage (Appendix 11C).

Table 2. Age indicators of highland bamboo for age classification of bamboos in Sele-Nono forest

S/N	**Age Indicators**	**Bamboo age (yr.=Year)**		
		Young bamboo (Age less than 1yr.)	**Matured bamboo (Age 2-3 yr.)**	**Old bamboo (Age older than 3yr.)**
1	Internode epiphyte	No epiphyte	Little moss rarely appear	Moss & Lichen are prevalent
2	Sheath ring at node & branches	Fresh sheath covering fully or partly all the nodes	No sheath, few & ragged sheath on the lowest nodes if present	No sheath
3	Culm color	Dark green	Faded/pale green	Yellowish
4	Culm appearance & texture	Fresh appearance & Smooth looking	Slightly rough	Dry appearance & rough surface

iii) Laboratory method of wood density and foliage biomass determination

In converting the Smalian volume for standing samples of trees, palms, lianas, fern trees, and bamboos into biomass, we should ensure the use of the proper kind of wood density. The wood densities used in this study were the basic wood density, also called green density (not air dry density or oven dry density) since the Smalian volumes were measured on the standing green (or fresh) woods. For this, the collected sample wood discs were brought to Ecophysiology laboratory (AAU) (Figure 12A) and were immersed in open jar filled with water for 48 hours so as to rehydrate or saturate them (Figure 12B). Measuring cylinder capable of holding the samples was filled with water, and each sample was entirely submerged in the water using a thin wire of negligible volume (Figure 12C) as used by Vieilledent *et al.* (2012). Then the volume of each sample was determined using water volume displaced by each discs in a graduated cylinder (Figure 12D). After recording the fresh volume, the wood discs were dried in a conventional oven at 105^{o}C to a constant weight (usually for 48 hours) (Figure 12E). Then, the wood density for each sample was determined using the ratio of their oven dry weight (gm) measured on electronic balance (Figure 12F) and their saturated volume (cm^3).

Figure 12. Procedures showing wood density determination of a typical tree species at Ecophysiology laboratory, AAU. A) collecting wood discs to laboratory, B) Rehydrating them, C & D) Measuring volume of discs, E) Oven-drying them , F) Measuring oven dry weight of discs.

In case where there were two or more wood density for an individual sample, then the average density was taken as a constant wood density for that individual sample. Similarly, the biomass of sub sample fresh leaves was determined by drying them in an oven at 70^oC until constant weight was achieved (usually achieved when these were kept for 24 hours).

3.4.3.5. Compilation of proposed biomass models

Not all the allometric equations known so far in the globe were compiled and proposed in the validation work of this study. Equations that are supposed to be included in this study were gained through interview and document/web analysis (Google Scholar, Web of Science, Scopus database and Research Gate). Interviews were conducted with persons who are engaged on either the development of new equation or scholars who made use of already developed allometric equations (Table 3). The interview was done in person, by email or phone targeting on and/or around what allometric equations they would suggest taking the climate and vegetation type of Sele-Nono forest into consideration. Details of the interviewees are listed in Table 3 after making consent with them.

Table 3 Lists of key resource persons contacted in person or by email or phone

S/N	Name	Country	Organization	Title
1	Dr. Yitebitu Moges	Ethiopia	Ministry of Environment and Forestry, MEFCC.	REDD+ Secretariat, Ethiopia
2	Dr. Yigardu Mulat	Ethiopia	Ministry of Environment and Forestry, MEFCC.	Researcher on Ethiopian Bamboo
3	Dr. Sandra Brown	USA	Winrock International	Research Scientist on carbon accounting & modelling
4	Dr. Adrien Djomo	Canada	Queen’s University	Author of tree allometry for African tropical forests.
5	Dr. Stanlay	USA	Nature conservancy, Arlington	Director of Conservation

From both the interview of key resource persons and document collection, the following equations that we think might work for our study area were summarized (Table 4).

Table 4. Proposed biomass allometric equations for Sele-Nono forest compiled for the purpose of validation

S/N	**AGB component**	**Authors**	**Suggested allometric equation (result of interview & review documents)**
1	Tree	Brown (1997)	$AGB = \exp(-2.289 + 2.649 \times \ln DBH - 0.021 \times \ln(DBH)^2)$
		WBISPP (2000)	$AGB = 0.3658 * DSH + 0.1144 * (DSH)^{2.2}$
		Chave *et al.* (2005)	$AGB = 0.0509 \times \rho D^2 H$
		Chave *et al.* (2014)	$AGB = 0.0673(\rho(DBH)^2H)^{0.976}$
		Djomo *et al.* (2016)	$AGB = \exp(-2.308 + 1.325 * \ln(DBH) + 0.469(DBH)^2H + 0.802 * \ln(\rho))$
2	Palm	Hughes (1997)	$AGB = \frac{\exp((5.7236 + 0.9285 * \ln(DBH^2)) * 1.05001)}{1000}$
		Brown *et al.* (2000)	$AGB = 0.3999+7.907*H$
		Winrock International	$AGB = 6.666+12.826*H^{0.5}*\ln H$
3	Tree fern	Brown *et al.* (2000)	$AGB = \frac{-4266348}{[1-(2792284 * \exp(0.313677 * H))]}$
		Stanlay *et al.* (2003)	$AGB = 1423.4 * \exp(0.3233 * H)$
		Beets *et al.* (2012)	$AGB = 5.4 * 10^{-3} * ((DBH^2)H)^{1.19}$
4	Liana	Putz (1984)	$AGB = \exp(0.12+0.91*\log(BA \text{ at } DBH)$
		Gerwing & Farias (2000)	$AGB = \exp(0.07+2.17\ln(DBH))$
		Gehring *et al.* (2004)	$AGB = \exp(7.114+2.276\ln(DBH))$
		Schnitzer *et al.* (2006)	$AGB = \exp(-1.484+2.657\ln(DBH))$
5	*Arundinaria alpina* bamboo	Yigardu Mulatu and Masresha Fetene (2013)	$AGB(<1 year) = \exp(0.172*DBH)$ $AGB(1\text{-}3 year) = \exp(0.289*DBH)$ $AGB(>3 year) = \exp(0.30*DBH)$

Note that ‘‘exp’’ indicates the natural logarithm (e =2.71828), AGB =above ground biomass in Kg, ln is the natural logarithm, DBH is in cm, H is in m and ρ is in g cm^{-3}

3.4.3.6. Data analysis

Regression graphs were plotted to visually infer the accuracy of the models (closeness of predicted values to the true value) (Zianis and Mencuccini, 2004; Vieilledent *et al.*, 2012) and to assess which models are over estimating and/or under estimating the actual observed biomass (Appendices 7G, 8D, 9D, 10D & 11D) of corresponding dataset from Sele-Nono forest. A student paired t-tests were also used to check whether the mean observed biomass of the samples are significantly differing with the corresponding predicted biomass using previous models (Seaman *et al.*, 1991; Zar, 1996; Basuki *et al.*, 2009; Williams and Abdi, 2010, Addo-Fordjour and Rahmad, 2013). Moreover, in order to quantitatively evaluate the performance of each of these models, cross-validation statistic (MacCoun, 1998; Gupta *et al.*, 1999) such as the Root Mean Square Error (RMSE), Prediction bias or errors and Prediction Residuals Sum of Squares (PRESS) were determined as shown in Table 5 below. For simplicity the name of the first author of the models were used throughout the analysis.

Table 5. Cross validation statistics to assess performance of the different models

S/N	Cross validation statistics	Equations
1	Mean error (ME)	$\mathrm{ME} = \frac{1}{n}\sum_{i=n}^{n}(P_i - O_i)$
2	Relative error (RE)	$\mathrm{RE} = \sum_{i=1}^{n}\left(\frac{P_i - O_i}{O_i}\right)$
3	Mean relative error (MRE), also called Average deviation or Bias in this paper	$\mathrm{MRE}\ (\%) = \left(\frac{\mathrm{RE}}{n}\right) X100\%$
4	Root mean square error (RMSE)	$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$
5	Prediction residuals sum of squares (PRESS)	$\mathrm{PRESS} = \sum_{i=1}^{n} e_i{}^2$, where $e_i = O_i - P_i$

P_i is the predicted biomass for the ith sample, O_i is the observed biomass for the ith sample, n is the number of observations, e_i refers to a residual of the ith sample, $\sum$ refers to summation (*or total*)

The best model should be the one with the lowest cross validation statistical values, which is an indication of prediction bias or deviation. To identify the best models for each AGB components of Sele-Nono forest, rank analysis was employed. In such analysis the models were ranked first according to the rank of the absolute values of each cross-validation statistic, then the ranks were summed and the summed ranks were ranked again to give an overall model efficiency.

3.4.4. A study on tree height estimation method in Sele-Nono forest

3.4.4.1. Sampling procedure

Out of the six strata established for the study area, five of them were chosen purposively for this particular study as they are larger size strata neglecting the sixth strata for data collection (Figure 13). In each stratum, a randomly identified local village circumscribed by forests were chosen; and plots (35 m X 35 m) were laid after moving 1km away from the boundary of the villages towards the forest to avoid edge effect. The purpose of the plots (overall 5 plots in number) were to make the sample tree selection easy (Figure 13). In each of the plot, a total of 10 individual trees focusing on visually medium and bigger trees were randomly chosen for data collection that would be used for evaluating the suitability of the proposed tree height estimation methods for the study area.

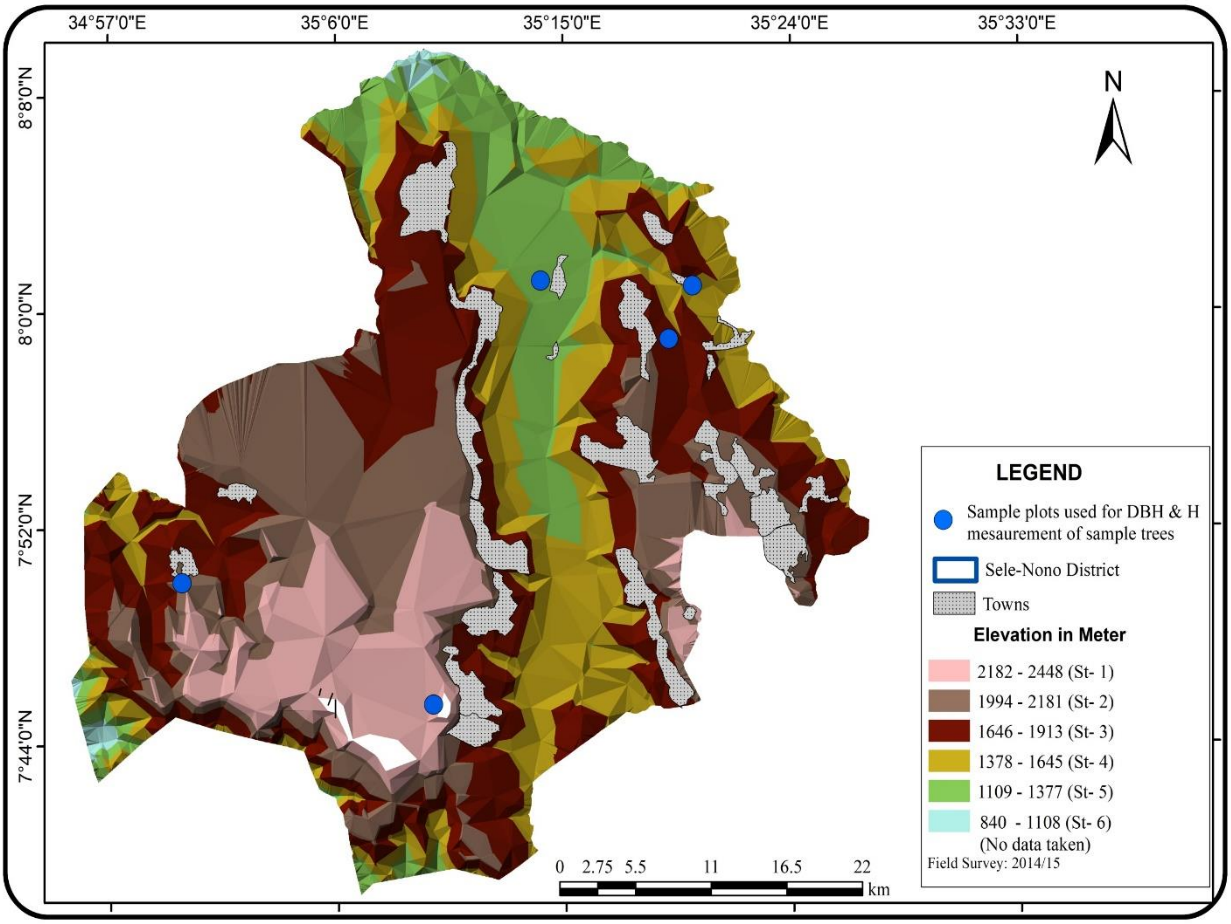


Figure 13. Plot points of data collection used for validating methods of tree height estimation

3.4.4.2. Method of data collection

Measurement of actual height for each of the sample trees were measured using rope climbing technique (for measuring height of taller trees) and/or using calibrated and graduated bamboo measuring stick (to measure the height of shorter trees). Shorter trees are contextually referred in this text as trees that are weak to support tree climbers, whereas trees that can be climbed are referred as taller trees. The tree height measurements were carried out by 5 tree climbers, each of them measured ten trees (Appendix 12).

Quality assurance in measuring the actual heights of sample trees

A half day oral training about how to take and/or read measurements were delivered to all the climbers (crews). After we make sure that they don’t have a problem of reading measurements, we took them to the field for practical tree height exercises. The practical training of the tree climbing method began in an open field, first with measurement of a vertical pole, then measurement of a vertical tree whose top was clearly visible, then trees whose tops were partially or fully obscured. The training was extended until all the technicians consistently obtain similar heights to the height measured by the researcher using clinometer. This process helped the researcher to identify one, among the five crews as "star crew" for being very sharp with his measurements when compared to the tree height measurement made by the researcher using clinometer. Then all the crews finally moved to Nono-Berbersa forest (which is a nearby patch forest to Berbersa, capital town of Sele-Nono District) to repeat the exercises. The exercise was done on eight randomly chosen trees, two trees per crew of the four crews and all the eight trees were re-measured for their height by the "star" crew for comparison purpose (Table 6). Accordingly, the error estimates as a measure of quality assurance (QA) showed that measurement errors (ME) due to individual differences among the crews was low (ME <10%) as computed using the following equation (Pearson *et al.*, 2005).

$$\mathrm{ME}\ (\%) = \frac{(\text{Measured height of a tree} - \text{Remeasured height of the same tree})}{\text{Remeasured height}}\ \mathrm{X}\ 100$$

Table 6. Tree heights measurement error (%) by technicians

S/N	Tree species	Height measured (m) by the technicians	Height remeasured (m) by the star technician	Measurement Error (%)
1	*Elaeodendron buchananii*	35	31	12.90
2	*Diospyros abyssinica*	20	23	-13.04
3	*Ilex mitis*	32	27	18.51
4	*Celtis africana*	28	29	-3.44
5	*Olea welwitschii*	35	33	6.06
6	*Syzygium guineense*	21	24	-12.5

7	*Croton macrostachyus*	22	19	15.78
8	*Apodytes dimidiata*	24	21	14.28
	Mean	27.125	25.875	**4.82**

Compilation of proposed height estimation methods of trees in Sele-Nono forest.

Tree-height estimation methods that are supposed to be included in this study were gained through document/web analysis (Google Scholar, Web of Science, Scopus database and Research Gate). Accordingly, tree height estimation methods of trees for the study area were proposed, which includes visual estimation and DBH-H allometries (Table 7).

Table 7. Proposed methods of tree height estimation in Sele-Nono forest

	Methods	**Description of the method(s)**	**Author/s**
I	Visual method	Height visually estimated on field	…………………
II	DBH-H model	Height estimated from DBH	
	•Feldpausch1 model	Log(H) = 0.6757+0.6521log(DBH)	Feldpausch *et al.* (2011)
	•Feldpausch2 model	Log(H) =0.4307+0.6514log(DBH)+0.0109	Feldpausch *et al.* (2011)
	•Brown model	H= exp (1.0710 + 0.5677ln(DBH))	Brown *et al.* (1989)
	•Niklas model	$H=1.70*(DBH)^{0.535}$	Niklas (1993)

3.4.4.3. Data analysis for validating tree height estimation methods

We compared tree height (H) estimates using visual estimation technique and DBH-H allometries with the actual heights obtained by tree climbing method so as to assess which height estimation method is more precise to the study area. For this purpose, we used Bland-Altman (BA) method of validation analysis using XLSTAT software. This method is the most popular method that has been used in analyzing regression models when compared with other methods such as Deming regression and Passing-Bablock regression methods (Bland and Altman, 1987). This is because the regression is too complicated as the slope and intercept can be affected by lack of linearity, presence of outliers, and a narrow range of test results. Cross validation statistics were also used to analyze the accuracy of the methods through calculating the bias induced due to the choice of the models. We applied this statistic since the BA plot by itself (without statistical calculations) does not provide sufficient information about the errors of the method. On top this, we claimed that estimate of tree height within 10 % bias would be regarded to be reasonably accurate in this study.

3.4.5. Carbon stock study in Sele-Nono forest

3.4.5.1. Plot design

The sample plot locations that have been used for floristic study of Sele-Nono forest were also used here for carbon stock study. For this purpose, 35 m X 35 m (1225 m^2 equivalent to 0.1225 ha) permanent plots were superimposed on the 25 m X 25 m plot that were developed for the floristic study. The overlaying of this plot on the previous floristic plot was to capture the large trees which would be excluded if a small sample plot were used. The 25 m X 25 m were seen as a nest plot to collect data on medium trees with DBH 20 cm to 50 cm. This plot further nested into 7 m X 7 m subplot (to collect data on small trees and lianas with DBH of 5 cm to 20 cm), and 3 m X 3 m subplot (to count saplings/trees with DBH less than 5 cm) (Figure 14). Each plot in the nest was viewed as being a separate plot. This plot design was chosen since it is the recommended design from the horses' mouth (Walker *et al.*, 2013) and it satisfies the rule of the minimum plot size criteria of 0.1 ha (1000m^2) for studying carbon stock assessment of a natural forest as it can be understood from the standard operational procedure (SOP) (Walker *et al.*, 2012). This plot size has also been used by other researchers in other parts of the southwest forest of Ethiopia (Vanderhaegen *et al.*, 2015; De Beenhouwer *et al.*, 2016; Abyot Dibaba, 2018; Admassu Addi, 2018)

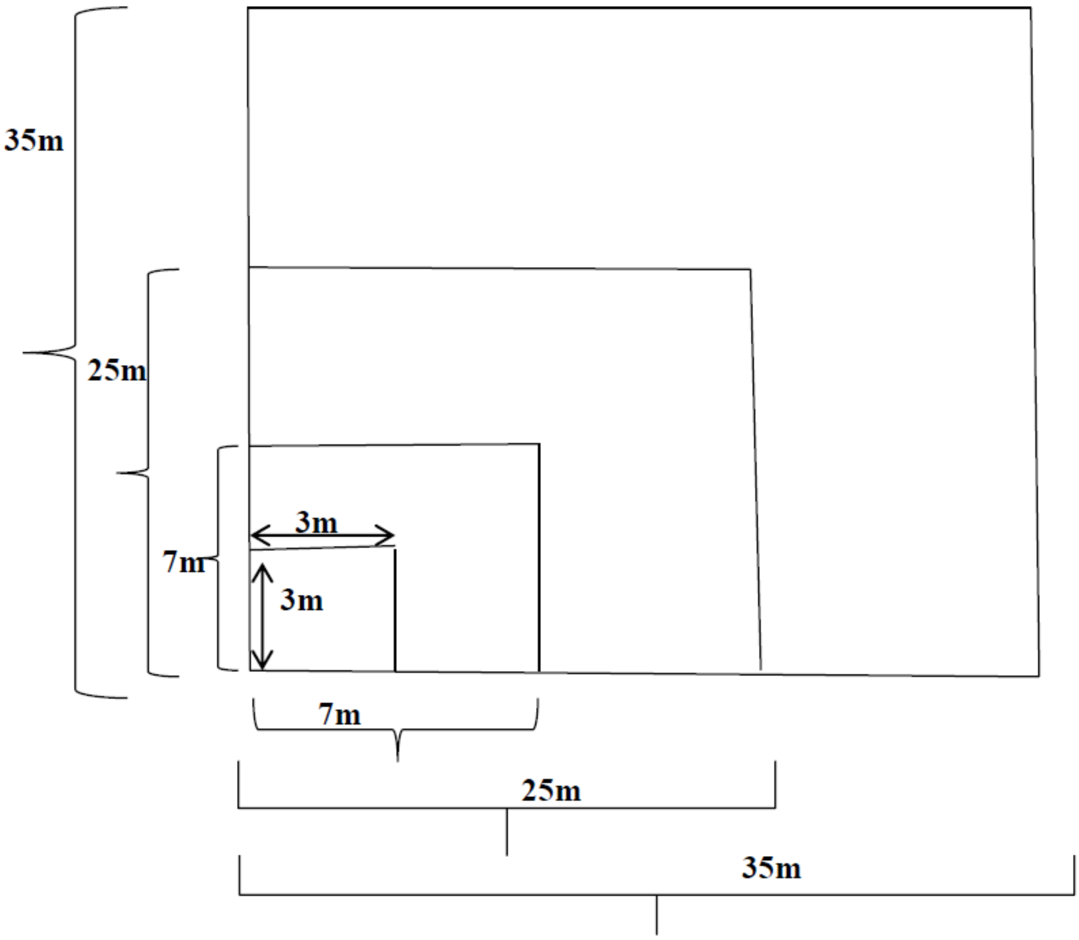


Figure 14. Nested sample plot type (shape and size) used for the measurement of trees in the study area.

Moreover, 5 m X 5 m subplot was designed in the middle of the 25 m by 25 m nested plot to collect canopy diameters and height of shrubs which are relevant data for their biomass estimation. In addition, soil samples for carbon analysis was surveyed in five 1m^2 quadrats within the 25 m X 25 m nested plots; four of which were arranged at the four corners and one was at the centre of the 25 m^2 subplot used for shrub data (Figure 15).

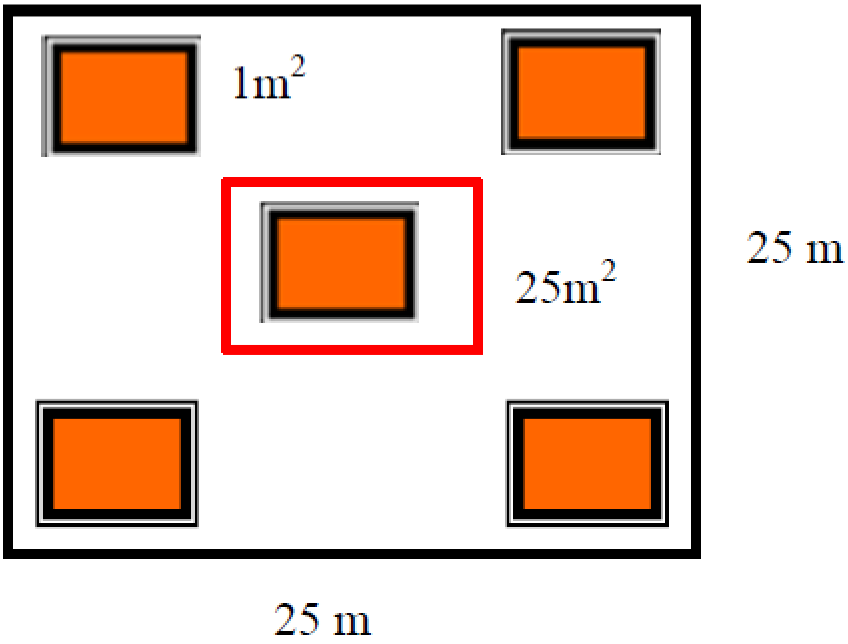


Figure 15. Plot design within the 25 m X 25 m nest plots for shrubs and soil data

On top of this, four 1m^2 plots (1m X 1m) that were radiating 100 paces away from the centre of the 35 m X 35 m plot was used for gathering data for biomass estimation of herbs and litters (Figure 16). The locations of the four plots were determined randomly following the direction of a 'second hand' of a watch when it was looked incidentally.

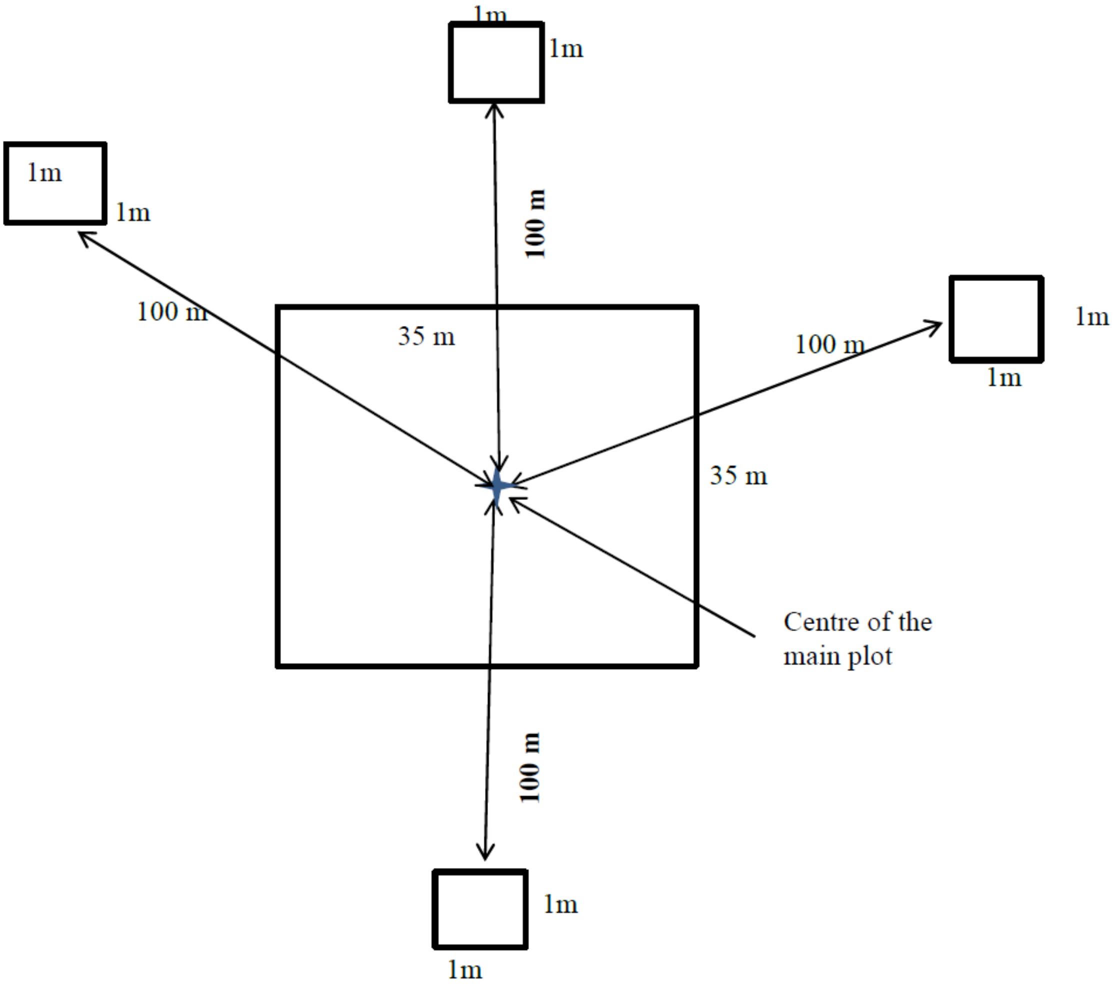


Figure 16. Example of locating four plots of size 1 m X 1 m radiating 100 m away from the centre of the main plots for collecting data related to herbs and litters biomass.

A summary of plot size used in the study area is shown below (Table 8).

Table 8. Plots (main, nested or sub plot) sizes and measured above ground biomass components

Plot size (0% slope)	Biomass pool	DBH class	Remark
1m X 1m	Litter & herbs	………	Also used for soil samples
3 m X 3 m	Sapling	< 5 cm	For counting saplings
5 m X 5 m	Shrubs	………….	
7 m X 7 m	Small trees & Lianas	5 cm -20 cm	
25 m X 25 m	Medium trees	20.1 cm-50 cm	
35 m X 35 m	Big trees	>50 cm	

3.4.5.2. Data collection: field measurements and related calculations

i) Aboveground biomass measurement

In this study, the AGB measurement includes the measurement of trees (including live and dead trees, palms, bamboos and tree ferns), lianas, shrubs and saplings.

Tree measurements: All trees (live and dead) including tree ferns and palms over a minimum diameter of 5 cm in the proper nested plots were measured for their DBH (using measuring tape) and Height (estimated using locally verified DBH-H allometry).

Bamboo measurement: DBH measurement for each age classes of bamboo was measured in the proper nested plots. Age classes were determined following Wimbush (1945) and Banik (1997).

Liana measurement: Lianas are expected to be an important component of the moist southwest forests of Ethiopia in general (Kumelachew Yeshitela and Simon Shibru, 2004; Feyera Senbeta *et al.*, 2005) and so is expected in Sele-Nono forest in particular. It is known that lianas should be measured for their DBH in the strict sense at 1.3m ($d_{1.3}$) parallel with the lianas, not perpendicular to the ground. However, we measured their DBH vertically (d_{vert}) at 1.30 m (d_{vert}) above the ground within the 7 m X 7 m small nested plots. For each liana, we converted the $d_{(vert)}$ into the diameter at 1.3 m along the stem ($d_{1.3}$) using Schnitzer *et al.* (2006) equation shown below so as to use this diameter to calculate the liana above-ground biomass (van der Heijden and Phillips, 2009).

$$d_{1.3} = 0.070 + 1.02 * d_{vert}$$

Shrub measurements: shrubs are shorter individuals with high basal ramification that results a high crown area making shrubs to resemble inverted cone shape (Cerrillo and Oyonarte, 2006). Thus, we measured the maximum height of the shrubs (h) and average crown radius (r) to estimated volume of shrubs (assuming conical geometry) which would be used for their biomass estimation. Accordingly, we estimated volume (V) of each shrub in the proper nested plot as follow

$$V = \frac{1}{3}\pi r^2 h$$

This method of volume estimation of shrubs has also been used elsewhere in the southwest forests of Ethiopia (Vanderhaegen *et al.*, 2015; De Beenhouwer *et al.*, 2016) for their biomass assessments.

Sapling measurements: sapling for the sake of carbon stock study is defined as trees whose DBH is less than 5 cm. Measurement for saplings involve the establishment of 3 m X 3 m plot outside the permanent plots and was laid randomly for each stratum. All sapling individuals within each plot were counted (let say this 'C'), completely harvested and weighted on field for their total fresh weight using hanging balance. Then, some part of them (often 500 gm) were brought separately to AAU, dried in the oven and extrapolated for the total dry weight (lets say this 'Tw') of saplings at each stratum. Finally, the total dry weight of the saplings (Tw) were divided by their total number (C) so as estimate an average dry weight of a typical sapling individual as follow.

$$\text{Average biomass of a typical sapling individual (per stratum)} = \frac{\mathrm{T_w}}{\mathrm{C}}$$

Dead wood measurements: Carbon dioxide (CO_2) might be captured when a plant is alive but remain stored even when it is dead. Hence we considered dead woods as an important source of carbon pools in the study area. Moreover, we classified deadwoods of the study forest as standing dead woods (dead tree if the height is greater than 1.3 m and stumps if the height is less than 1.3 m) and lying dead woods if they are not upended (Pearson *et al.*, 2005; Pearson *et al.*, 2007). On top of this we considered the standing dead woods as part and parcel of the above ground biomass components whereas the lying dead woods as a separate independent biomass/carbon pool. Accordingly, the standing deadwoods were measured for their DBH and height (H) concurrently with live trees in the appropriate nests within the permanent plots; and they were marked as ‘Dead’ on the datasheet.

In this study, trees were considered dead if there were no green leaves present on them. Moreover, since we collected data during the dry season where trees may drop their leaves we used a machete to strike a branch or stem to verify whether the cambium is dead or not so as to assure whether the tree is deciduous or dead. In the current study area standing dead trees were found to be three types like those illustrated in the document of Indonesian Ministry of Forestry (2011) (Figure 17).

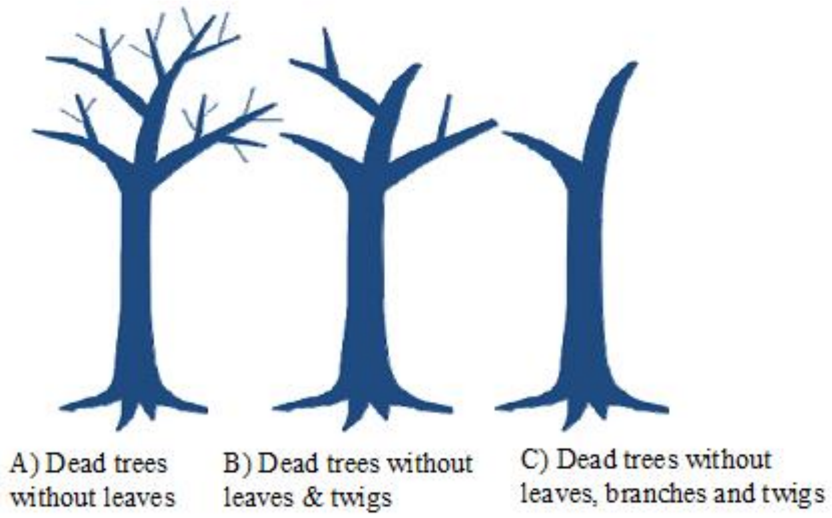


Figure 17. Rough illustrations showing the types of standing dead woods in Sele-Nono forest, a-c (Modified from Indonesian Ministry of Forestry, 2011).

The standing dead trees like the case in A and B (Figure 17) behaves live trees, and hence DBH and height (H) were measured according to the same protocol as live trees. However, when a standing dead tree is just the bole (Case C, Figure 17) and behaves like a truncated cone, we measured DBH and H to estimate its volume as follow (Pearson *et al.*, 2005).

$$Volume\ of\ bole = Volume\ of\ truncated\ cone\ (V_T) = \frac{1}{3}\pi h(r_1^2 + r_2^2 + r_1\ X\ r_2)$$

Where h=the height in meter, r_1 is the radius at the DBH of the tree and r_2 is the radius at the top of the tree. In case where measuring r_2 is difficult, we have applied tapering equation as follow as recommended by Walker *et al.* (2012).

$$D_{top} = D_{base} - \left[H * \frac{D_{base} - DBH}{130/100}\right]$$

Moreover, for stumps (standing dead trees not reaching DBH), heights (h) and diameter at their midpoints were measured for calculating their volume using cylinder formula (Larjavaara and Muller-Landau, 2009a).

$$Volume\ of\ stump = Volume\ of\ cylinder\ (V_c) = \pi r^2 h$$

ii) Measuring lying dead woods

Lying dead wood is defined in this study as all woody material on the ground with a diameter >10 cm. Smaller diameter pieces of woods were sampled as part of the litter pool. Like standing dead woods, we also categorize the lying dead woods (LDWs) of the study forest into three decay classes, namely sound (recently fallen), intermediate (partly rotten) and rotten (very rotten, but not completely rotten) using machete test following Walker *et al.* (2012). This was done by striking the wood with a machete and check their decay status. When the blade bounces off and produced sound it was considered ‘sound’; when it entered slightly it was ‘intermediate’, and when it caused the wood to fall apart into pieces it was considered ‘rotten’ (Larjavaara and Muller-Landau, 2010; MacDicken, 1997; IPCC, 2003). For the purpose of biomass estimation of LDWs, two important data were considered on field. These were diameters and wood densities for each classes of LDWs using line-transect methods (Warren and Olsen, 1964)

The line transect method used in this study involved laying out of two 50 m transect lines on flat terrain basis (L=100 m) at right angles outside the main plot. Actual length of transect line used on field was variable based on the degree of the slope of the terrain

(Appendix 13). Direction of the first line was randomly determined after walking 100 paces from the centre of main plot and the second line placed at right angle to the starting point of the first line (Figure 18).

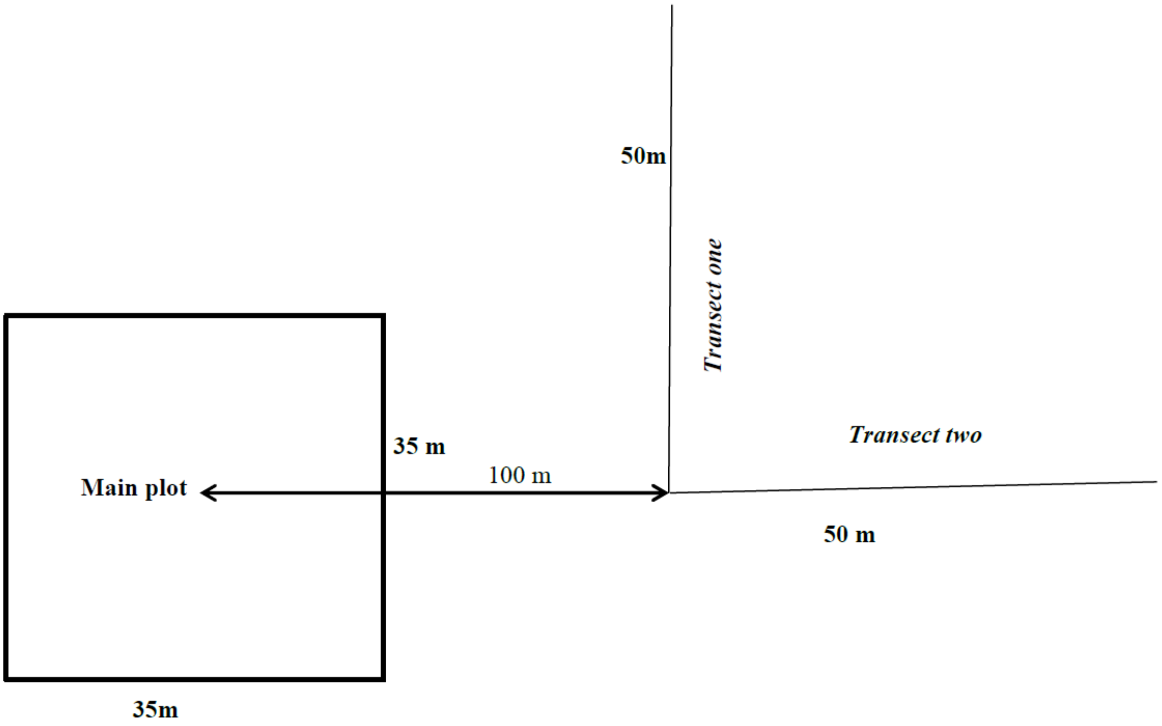


Figure 18. Example of layout of line transects method used on flat terrain to estimate volume of lying dead woods

The random determination of the first transect line follows direction of a “second hand” of a watch when looked at a random moment. Then, the diameter of each pieces of LDWs (d_1, d_2, d_3……. dn) that were intersected along the length of the line were measured. Diameter tape was used to measure the diameter of the dead wood, and this was done after making sure that the route was clear before placing our hand beneath the log. We measured lying dead woods if (a) at least 50% of the log was viewed above the ground, and (b) the sampling line crosses through at least 50% of the diameter of the log. Then the measured diameters were used to compute the volume (m^3/ha) of each classes of LDWs following

Warren and Olsen (1964), Harmon and Sexton (1996) and Larjavaara and Muller-Landau (2009b)

$$\text{Volume of LDWs} = \pi^2 \times \left[\frac{d1^2 + d2^2 + d3^2 \ldots\ldots..dn^2}{8L}\right]$$

Wood density for each classes of LDWs were computed using Machete test in the field (to identify the classes of LDWs) and Archimedes principle in the lab (to measure the volume of the LDWs). For this purpose, 90 samples of dead wood discs in each density class were collected using a hand saw; and they were taken to Ecophysiology laboratory (AAU) to measure their dry mass using oven drying and their volume from floatation method following Harmon and Sexton (1996).

$$\text{Density of wood discs of LDWs} = \frac{\text{Dry mass of the disc}}{\text{Volume of the disc}}$$

Finally averaging the wood densities of each class of LDWs were made to calculate their respective mean wood densities.

iii) Herbs and Litter biomass measurements

All the herbaceous vegetation growing within the plot areas designed for herbaceous biomass data collection ($1m^2$) was cut at the ground level (see Figure 16). Similarly, all the litters (forest floors including LDWs with diameters less than 10 cm) within the same plots were collected and weighed after completely removing the herbs. Then, about 200-500 gm of evenly mixed composite samples of herbs and litters were separately sub-sampled in a plastic bag and brought to the Ecophysiology laboratory (AAU). Then, they were oven dried at 70°C until constant weight were achieved (Jina *et al.*, 2008) so as to determine their moisture content, from which their total dry mass can be inferred.

iV) Soil organic carbon measurement

Two kinds of soil samples were considered for this particular study, one is core soil samples (for bulk density determination) and the other is composite soil samples (for determining soil organic carbon concentration). Both soil samples were collected from sub plots designed for this purpose at 30 cm depth (MacDicken, 1997) as much of the soil carbon is expected to be stored in the first 30 cm (FAO, 2001). The composite soil samples are subsamples of soils collected from all the five sub plots after being evenly mixed. About 150 gm of the composite samples were collected in cloth bag to represent each main plots, and they were air-dried, well mixed, ground up and then passed through a 2mm mesh size stainless steel sieve so as to analyse the percentage of organic carbon (% C) at the National Soil Testing Laboratory, Ethiopia. Moreover, undisturbed core soil sample (Volume of a core = 98 cm^3) for bulk density analysis was also taken at the predetermined depth from the centre of the 5 m X 5m sub plot following Blake and Hartge (1986) and Berenguer *et al.* (2015). The core soil sample then brought to Metu University, Ethiopia (a nearby University to the study area) and bulk density was determined in the laboratory after drying the core samples at 105^oC for 72 hours (MacDicken, 1997) and dividing this dry weight of soil by the volume of the core sampler, which is 98 cm^3 as follow.

$$\text{Soil bulk density} = \frac{\text{Mass of oven dry soil (g)}}{\text{Volume of soil sample (cm}^3\text{)}}$$

3.4.5.3. Biomass and carbon stock quantification in Sele-Nono forest

i) Estimation of aboveground biomass

Estimation of the aboveground biomass of trees, palms, tree ferns, lianas and bamboos

The biomass of trees, palms, tree ferns, lianas and bamboos were estimated using verified allometric models with local data from Sele-Nono forest. Accordingly, the biomass equation developed by Chave *et al.* (2014), Brown *et al.* (2000), Stanlay *et al.* (2003), Schnitzer *et al.* (2006), Yigardu Mulatu and Masresha Fetene (2013) models were used for estimating the biomass of trees, palms, tree ferns, lianas, bamboos in the study area respectively (Table 9).

In this study we designated the trees as ‘true’ trees so as to distinct them from other forms of plants having tree-like growth forms such as palms and tree ferns.

Table 9. Allometric models used for biomass estimation of AGB components in Sele-Nono forest

S/N	AGB component	Equations used in this study	Authors
1	Tree (‘true’ trees)	$AGB=0.0673(\rho(DBH)^2H)^{0.976}$	Chave *et al.* (2014)
2	Palm	$AGB=0.3999+7.907*H$	Brown *et al.* (2000)
3	Tree fern	$AGB = 1423.4 * \exp(0.3233 * H)$	Stanley *et al.* (2003)
4	Liana ramet	$AGB=\exp(-1.484+2.657\ln(DBH))$	Schnitzer *et al.* (2006)
5	Bamboo	$AGB(<1year) =\exp(0.172*DBH)$ $AGB(1\text{-}3year) =\exp(0.289*DBH)$ $AGB(>3year)=\exp(0.30*DBH)s$	Yigardu Mulatu & Masresha Fetene (2013)

Note that ‘‘exp’’ indicates the natural logarithm (e=2.71828), AGB =above ground biomass in Kg/m^2, ln is the natural logarithm, DBH is in cm, H is in m and ρ is in g cm^{-3}

The specific wood density (ρ) values used for tree biomass estimation was available from Getachew Tadesse *et al.* (2014) who worked in a very similar geographical environment in southwest Ethiopia. When the wood density of trees was not available from the lists of Getachew Tadesse *et al.* (2014), the wood density values developed for Ethiopian vegetation was applied (Getachew Desalegn *et al.*, 2012). When the wood density values was not available from Getachew Desalegn *et al.* (2012) and Getachew Tadesse *et al.* (2014), then the African wood density database (Carsan *et al.*, 2012; Rayes *et al.*, 1992; Vieilledent *et al.*, 2012); and Global wood density data base (Zanne *et al.*, 2009) were used. Moreover, the mean wood density value of 0.55 g/cm^3 was used for those species with an unknown wood density. The total AGB of each of the above components listed above (Table 9) was estimated based on corrected plot area (Appendix 13) since biomass and/carbon measurements are normally reported on a horizontal projection basis for plots falling on sloppy terrain (Slope > 10% or 6^o) (Pearson *et al.*, 2005; Brown *et al.*, 2011; Walker *et al.*, 2012).

Aboveground biomass estimation of shrubs

Above ground biomass of each shrubs were estimated using a cone volume ($V = \frac{1}{3}\pi r^2 h$) and its wood density (ρ) (Carswell *et al.*, 2009; Walker *et al.*, 2012).

$$AGB_{shrubs\ (Kg/m^2)} = \left(\frac{1}{3}\pi r^2 h\right) * \rho$$

Where the wood density (ρ) data for each species were extracted from the appropriate published data.

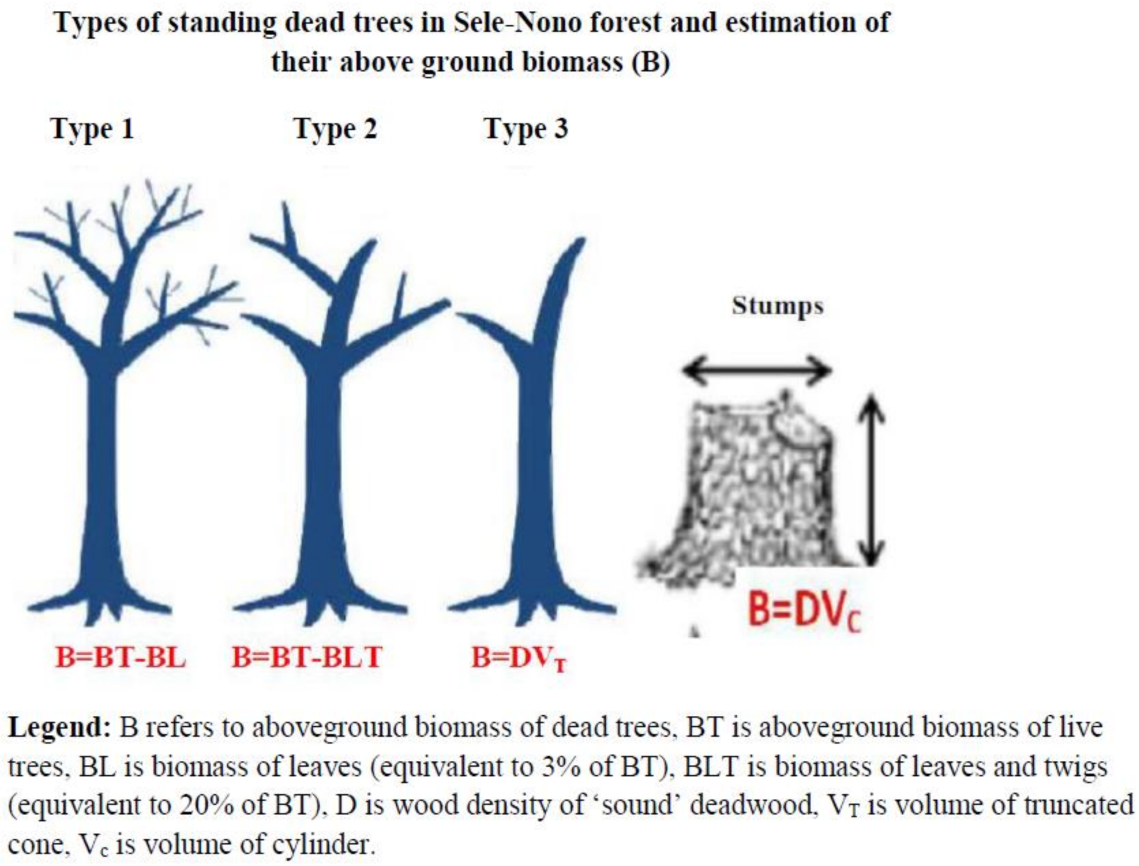
Estimation of saplings above ground biomass

The biomass of saplings was estimated non-destructively using ‘sapling count’ method in the 3 m X 3 m nested plot (Walker *et al.*, 2012) that was designed within the 35 m X 35 m plot (i.e., by counting the number of sapling individuals within the given plot and multiplying that by the average dry weight of an individual sapling).

$$AGB_{saplings\ (Kg/m^2)} = Average\ dry\ weight\ of\ a\ sapling\ X\ total\ number\ of\ saplings$$

Estimation of above ground biomass of standing dead trees

For standing dead trees of type 1 (the dead tree that lost only leaves) and type 2 (standing dead trees which lost leaves and twigs), we have applied deduction method (Pearson *et al.*, 2005); whereas for standing dead trees of type 3, above ground biomass were estimated from its volume (assuming truncated geometry) and wood density (ρ). The biomass of stumps was also estimated from its volume (assuming cylindrical shape) and the wood density (ρ) estimated for sound lying dead woods (Figure 19).



Legend: B refers to aboveground biomass of dead trees, BT is aboveground biomass of live trees, BL is biomass of leaves (equivalent to 3% of BT), BLT is biomass of leaves and twigs (equivalent to 20% of BT), D is wood density of 'sound' deadwood, V_T is volume of truncated cone, V_c is volume of cylinder.

Figure 19. Illustrations showing the ways of estimating above ground biomass of standing dead trees

Thus, the total above ground biomass of standing dead trees was computed as follow

$$AGB_{standing\ dead\ trees\ (Kg/m^2)} = \sum_{i=1}^{n} i$$

$where\ i\ refers\ to\ AGB\ of\ individual\ dead\ trees\ of\ type\ 1, 2, 3\ and\ stumps$

Estimation of total above ground biomass of a plot and its carbon stock

The total above ground biomass density (Kg/m^2) of each component was converted to ton per hectare (t/ha) using a conversion factor of 10 (Dossa *et al.*, 2008). Then the total above ground biomass density on each plot (and/or nested plots) was computed by summing all the above ground biomass components of a forest; and its carbon stock was computed using conversion factor of 0.47 (IPCC, 2003).

$$AGB_{total(per\ plot)} = AGB_{trees} + AGB_{palms} + AGB_{tree\ ferns} + AGB_{lianas} + AGB_{bamboos} + AGB_{shrubs} + AGB_{saplings} + AGB_{standing\ dead\ trees}$$

ii) Estimation of below ground biomass and carbon stocks

Root biomass, which is also referred as below ground biomass (BGB), is often estimated from root-shoot ratios (R/S) by taking 20% of aboveground biomass (MacDicken, 1997; Pearson *et al.*, 1997; IPCC, 2003). Thus, total BGB on each plot (t/ha) were computed by summing all BGB for all AGB components. Then this was converted to root carbon stock using conversion factor of 0.47 (IPCC, 2003).

$$BGB = 0.20 * AGB$$

iii) Estimation of lying dead woods biomass and carbon stock

The biomass of lying dead woods (LDWB) for each plot was estimated by multiplying the volume and wood density of each classes. The carbon stock in lying dead woods were computed by multiplying their total biomass by the conversion factor of 0.47 (IPCC, 2006).

$$LDWB = \text{Volume of LDWs X Wood density}$$

iV) Estimation of herbs and litters biomass and carbon stock

The amount of biomass in herbs (HB) and/or litters (LB) per unit area was estimated as follow as used by Pearson *et al.* (2007).

$$HB = \frac{Sub\ sample\ dry\ weight\ (gm)}{Sub\ sample\ fresh\ weight\ (gm)}\ X\ \frac{Total\ fresh\ weight\ of\ the\ sub\ plot\ (Kg)}{Sample\ area\ of\ the\ subplots\ (m^2)}$$

Thus, the dry mass was extrapolated to biomass density (t/ha) by using conversion factor of 10 (Dossa *et al.*, 2008). The carbon stock in herbaceous and litter biomass was calculated by multiplying their biomass by 0.47 (IPCC, 2006).

V) Estimation of soil carbon stock

The carbon stored in soil is usually in the form of organic carbon; and the amount of this carbon stock (SOC) per unit area of soil was determined following the method of IPCC (2003) as follow

$$SOC\ (tC/ha) = \%C * \rho * D * 100$$

Where C is soil organic carbon concentration as determined from the laboratory analysis & expressed as a decimal fraction, ρ is soil bulk density (g/cm^3) calculated from undisturbed soil using core sampler, D is depth of the sample soil layer which is 30 cm; and 100 is a conversion factor unit from g/cm^2 to t/ha.

3.4.5.4. Quantification of the total carbon stock & amount of atmospheric carbon dioxide equivalence (CO_2e) removed by Sele-Nono forest

The total carbon stock density of the forest was calculated by summing all the carbon stock densities of each carbon pools using the following formula provided that all carbon values were reported on a horizontal projection.

I. The carbon stock density of a plot was calculated as follow

$$C_{plot} = C_{AGB} + C_{BGB} + C_{LB} + C_{HB} + C_{LDWB} + C_{soil}$$

Where, C_{plot} = Carbon Stock Density [t ha^{-1}]

C_{AGB} = Carbon Stock in Above Ground Biomass [t ha^{-1}]

C_{BGB} = Carbon Stock in Below Ground Biomass [t ha^{-1}]

C_{LB} = Carbon Stock in Litter Biomass [t ha^{-1}]

C_{LDWB} = Carbon Stock in lying dead woods Biomass [t ha^{-1}]

C_{HB} = Carbon Stock in Herbs Biomass [t ha^{-1}]

C_{soil} =Carbon stock in soil (Soil Organic Carbon) [t ha^{-1}]

II. Carbon stock density (tons C/ha) for each stratum was computed by multiplying the average carbon stock of a plot by its area (ha).

$$C_{Stratum} = \left(\frac{\sum C_{plot}}{n_{plot}}\right) x Area\ of\ stratum$$

III. To obtain total carbon stock of the forest, we summed up all the carbon densities in each stratum.

$$C_{whole\ forest} = \sum C_{stratum}$$

IV. To estimate the amount of carbon dioxide equivalence (CO_2 e) that have been effectively removed from the atmosphere and stored in the forest, we multiplied the total carbon stock by the conversion factor of 3. 67 assuming that each ton of stored carbon is equivalent to 3.67 ton of CO_2 removed from the atmosphere.

$$CO_2eq. = carbon\ stock\ of\ the\ forest \times 3.\ 67$$

3.4.5.5. Data analysis

Estimated biomass and/or carbon stock data were analysed through descriptive statistical analysis using SPSS software version 20. Descriptive statistics such as percentage and mean values along with the standard deviation (SD) were used to summarize the biomass and/or carbon stocks in each carbon pools of the study area.

3.4.6. Formulation of species specific allometric models in Sele-Nono forest

3.4.6.1. Sampling procedure

To collect sample trees for developing and validating species specific models for the proposed species (*Albizia gummifera*, *Mimusops kummel*, *Syzygium guineense* subsp. *afromontanum*), we first set a prototype sampling procedure for a particular species so as to draw a similar working procedure for the other species. This prototype was done for *Albizia* *gummifera*, a randomly choosen species. For this purpose, five out of the six strata of the study area were chosen purposively based on the knowledge of the local people about the presence of *Albizia gummifera* tree neglecting one strata with the elevation of 840 m to 1108 m asl for data collection (Figure 20). Then 2 to 4 small local villages circumscribed by forests for each stratum were chosen purposively based on their proximity to the target species; and plots (35 m X 35 m) were laid after moving 1km away from the boundary of the villages towards the forest to avoid edge effect. The purpose of the plots was to make the sample tree selection easy; and the location of the plots were entirely based on the knowledge of the people of the local villages about where to get the desired *Albizia* tree (Appendix 14 shows a flow chart that briefs the sampling design).

With this procedure, tree climbing for biomass measurements were made at 40 plots (one individual from one plot) from all the five strata. From each stratum, two individuals of all types (small, medium and large sized *Albizia*) regardless of the size of the strata were considered producing a total of six individuals in each stratum. Such plot allocation technique is referred as equal allocation (Desta Hamito, 2001). This procedure gave a total of 30 individual trees (10 small, 10 medium & 10 large trees) for developing allometric equation. In this study we operationally defined small albizia if the DBH ranges from 10-30 cm, medium albizia if it ranges from 30.1 to 60 cm; and large albizia if the DBH exceeds 60 cm. Additional ten trees of all DBH classes (2 small trees, 3 medium and 5 larger *Albizia* trees) were also used for validation test. This was done in such a way that the small and medium trees were sampled randomly from any two and three strata respectively; whereas the five large trees sampled from each of the five strata). Thus, the total number of trees sampled in this research was 40, with diameters (1.30 m or above buttress) ranging from 10 to 95 cm (30 for modelling, and the remaining 10 were for validation).

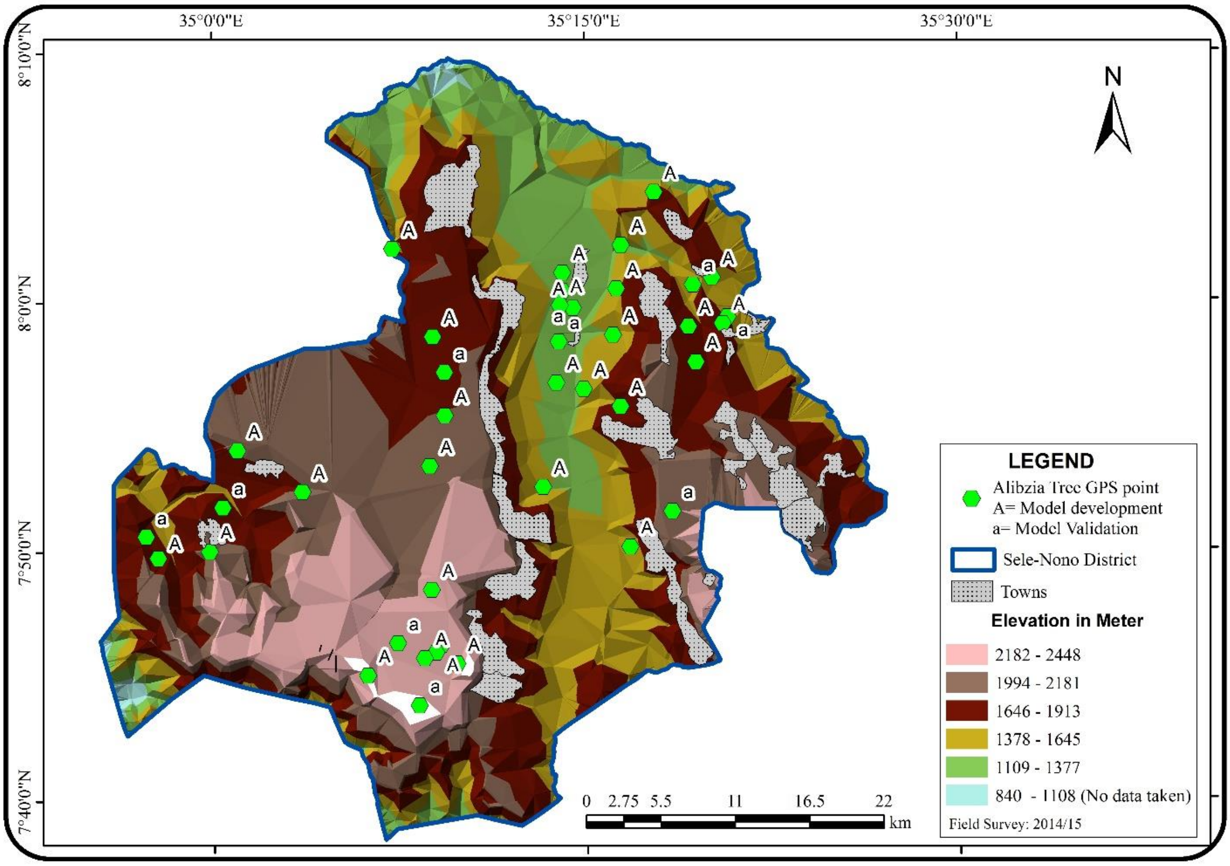


Figure 20. Plot points set for collecting sample *Albizia* trees to model its biomass in the study area

The sample plots used for *Albizia* (Figure 20) were also used as a reference plot to collect samples for the remaining species (*Mimusops kummel*, *Syzygium guineense* subsp. *afromontanum*). Sample trees of *Syzygium guineense* subsp. *afromontanum* and *Mimusops kummel* were collected in the same manner as it was for *Albizia* from the same plots or deliberately from nearby places based on the knowledge of the local people about where to find them.

3.4.6.2. Data Collection (Biomass calculation) procedure

The independent variables included in this study were DBH, height (H) and wood density (ρ); and they were measured for each tree following Walker *et al.* (2012). DBH was measured before the tree climbing began. Total height of each tree was accurately measured from the climbing result. The wood density for each tree sample was estimated from wood discs of visually larger small branches (SBs) following Vann *et al.* (1998) and Picard *et al.* (2012).

The dependent variable is the tree biomass; and it was measured using tree climbing method (Figure 21). During tree climbing, measurement for the length and diameter at each end of the fragmented stem sections were recorded including for all forks and large branches with a small end diameter (SED) greater or equal to 10 cm over bark (Walker *et al.*, 2012).

Figure 21. Tree climbing method for diameter measurement of bole (A) and larger branches (B, C, D) of trees.

In addition, the stump height and its lower and upper diameters were also measured. All length or heights were measured in meters and all diameters in centimetres. Volume over bark of stump, bole and large branches (branches with basal diameter greater than 10 cm) was calculated from the sectional measurements using Smalians formula, V=$\pi\ L\ (\frac{d_1^2+d_2^2}{8})$, as used by Henry *et al.* (2010), Ebuy *et al.* (2011) and Nam *et al.* (2016) where V is the volume of sections of the trunk and big branches, L is the length of the section, d_1 and d_2 are the diameters of the smaller and larger end of the section, respectively. The total volume of each sample trees of all the tree species were obtained by summing the volume of the sectional measurements. Then, this total volume was multiplied by the average wood density of disc samples to estimate the biomass of the stump, bole, and large branches (Appendix 7A, B, C).

For small branches (SB) (branches with basal diameter smaller than 10 cm), the biomass was estimated following Brown (1997) extrapolation scheme. In this method, about three SBs that were virtually different in basal diameters were randomly selected, completely trimmed with local machete and the average of their biomass was determined. The average biomass was determined after carefully removing all the twigs (shoots arising from SBs; less than 2.5 cm in diameter) and attached foliage and calculating their biomass as usual from the sum of the product of the volume of each section and the average wood density. The total biomass of all the SBs is calculated as the number of SBs multiplied by the average biomass per SB (Appendix 7D).

The twigs and attached leaves (altogether referred as foliage) that were carefully removed from each trimmed branches were measured separately (W_{fresh}) in the field (Colgan *et al.*, 2013). Sub-sample foliage for each trimmed branch were weighted using spring hanging weighting scale ($W_{fresh,sample}$) and brought to Ecophysiology laboratory (AAU) and oven-dried them at 70°C until constant weight were reached ($W_{dry,sample}$). The biomass of the foliage for each of the trimmed SB was estimated using dry-wet ratio$\left(W_{dry} = W_{fresh} X \frac{W_{dry,sample}}{W_{fresh,sample}}\right)$. The biomass computed in this way for all trimmed branches were added and divided by the number of trimmed branches to get the average foliage biomass per SB. The gross biomass of the foliage of each tree was computed from the product of average foliage biomass per SB and total number of SB per tree (Appendix 7E). The biomass of the inflorescence (flowers or fruits) whenever available were also measured likewise and added to the total biomass of the twigs.

3.4.6.3. Data analysis

Multiple linear regression method was used to study the relationship between the above ground biomass (AGB) and predictor variables from Dendrometric data (DBH, H and ρ) of trees measured on field in the study site. However, initial examination on the dependent variables using Quantile-Quantile (Q-Q) plot showed that their relationship was nonlinear. Thus, the natural logarithmic transformation was used to induce correction for both non-normality and heteroscedascity and to make their relationship linear, a prerequisite for the regression method. Accordingly, the response variable (i.e., our logarithmic transformed above ground biomass) was found not significantly ($p > 0.05$) deviating from the assumption of normality, which is checked using Q-Q plot and Shapiro-Wilks's test of normality (Figure 22) as used in Ali *et al.* (2016).

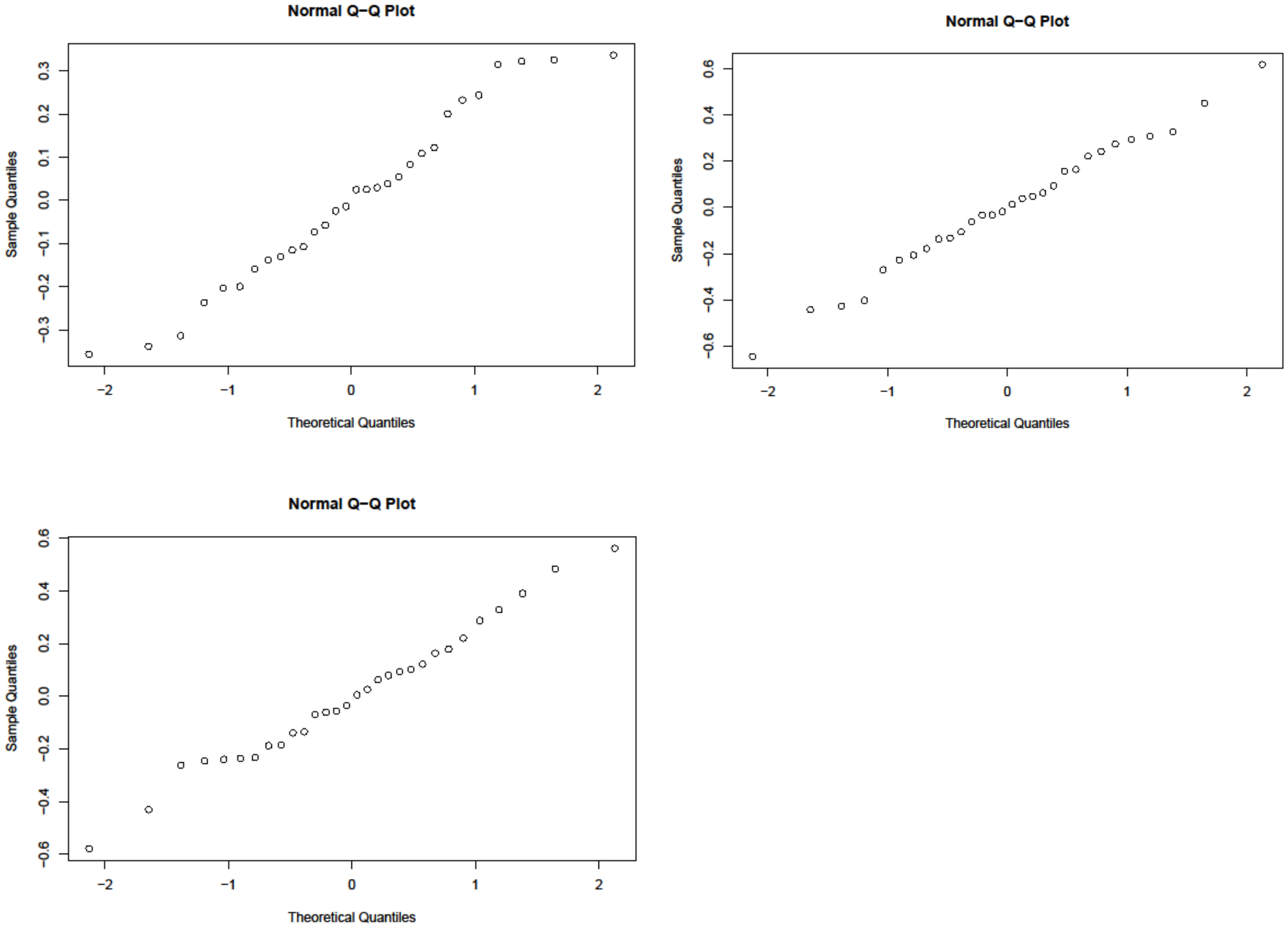


Figure 22. Test of normality using Q-Q plot for the log transformed aboveground biomass of *Albizia gummifera* (top left), *Mimusops kummel* (top right) and *Syzygium guineense* subsp. *afromontanum* (bottom) (note that sample quantiles are expected residual values; Theoretical quantiles are observed values).

Possible candidate models (also called allometric equations) of the trees were formulated using R software from their corresponding independent variables (R Core Team, 2013).

Model performance were carried out for all established candidate models using various goodness-of-fit statistics in R, namely Residual Standard Error (RSE), adjusted coefficient of determination (Adj.R^2) and Akaike's Information Criteria (AIC). The best performing models were those having the lowest RSE and AIC values accompanied by higher adjusted R^2 values. The candidate equations were ranked according to each goodness-of-fit statistics, the ranks summed and sums ranked to give an overall equation performance rank.

Validation of the current tree models were made by comparing our new equations established in the study area to previously published general allometric equations (Table 10). This analysis was done using graphic methods.

Table 10. Equations used to validate the newly formulated equations of trees in the study area

Authors	**Suggested allometric equation**
Brown (1997)	$AGB = \exp(-2.289 + 2.649 \times \ln DBH - 0.021 \times \ln(DBH)^2)$
WBISPP (2000)	$AGB = 0.3658 * DSH + 0.1144 * (DSH)^{2.2}$
Chave *et al.* (2005)	$AGB = 0.0509 \times \rho D^2 H$
Chave *et al.* (2014)	$AGB = 0.0673(\rho(DBH)^2 H)^{0.976}$
Djomo *et al.* (2016)	$AGB = \exp(-2.308 + 1.325 * \ln(DBH) + 0.469 (DBH)^2 H + 0.802 * \ln(\rho))$

CHAPTER FOUR

4. RESULTS

4.1. Floristic composition and diversity of plants in Sele-Nono forest

4.1.1. Floristic composition

A total of 414 vascular plant species representing 108 plant families (Appendix 15) were compiled in this study. This floristic list indicated that Sele-Nono forest constitute about 6% of the flora of Ethiopia and Eritrea. Out of these species only 335 species were collected from the plots and the remaining 79 were collected from outside the plots. Although Sele-Nono forest is characterized by large number of families (108 families), the top fifteen families (Table 11) were the most important ones that contribute about half of the total species composition. Moreover, out of the total species recorded in this study 59 of them (14%) were new records to Illubabur (IL) floristic region in the flora of Ethiopia and Eritrea (Appendix 16).

Table 11. Top fifteen species rich families recorded in Sele-Nono forest

Family name	Species No.	Percent contribution of families to the total number of species in Sele-Nono forest (%)
Asteraceae	30	7.17
Fabaceae	25	5.98
Acanthaceae	21	5.02
Poaceae	16	3.82
Euphorbiaceae	13	3.11
Lamiaceae	13	3.11
Rubiaceae	13	3.11
Aspleniaceae	12	2.87
Moraceae	10	2.39
Orchidaceae	10	2.39

Celastraceae	9	2.15
Cyperaceae	9	2.15
Amaranthaceae	7	1.67
Malvaceae	7	1.67
Solanaceae	7	1.67
Total	202	48

Among the total plant species documented from the forest, 225 (54%) of them were herbs (including ferns & climbers), 117 (28%) were trees, 25 (6%) were lianas and 47 (11%) were shrubs (Figure 23). Field observation in the study area also revealed virtually plentiful lianas throughout the forest although their species richness accounts only for 6% of the total floristic composition of the area (Figure 23). Of the total plant species compiled in this study, about 25 (6%) of them were endemics to Ethiopia (Ensermu Kelbessa *et al.*, 1992), and some of these are with some level of IUCN threat category (Vivero *et al.*, 2005, 2006) (Appendix 17).

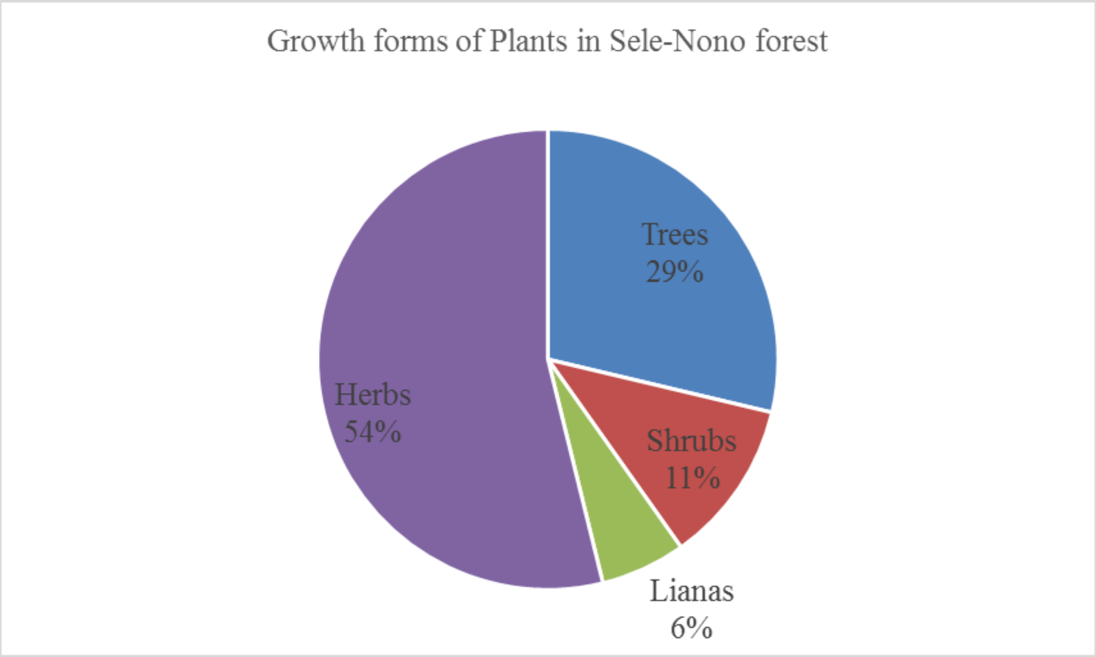


Figure 23. Growth forms of plant species collected in Sele-Nono forest

4.1.2. Plant community types in Sele-Nono forest

Outlier analysis excluded eight species leaving 327 species for the analysis (Appendix 18). Using agglomerative clustering we were able to visualise 7 clusters in the dendrogram corresponding to 7 plant community types or “associations” that are expected to be naturally occurring in the study area (Figure 24). The dendrogram was proved to include more homogenous plots (i.e., plots of high internal similarity with respect to species) in the same cluster (Cophentic correlation coefficient = 0.785).

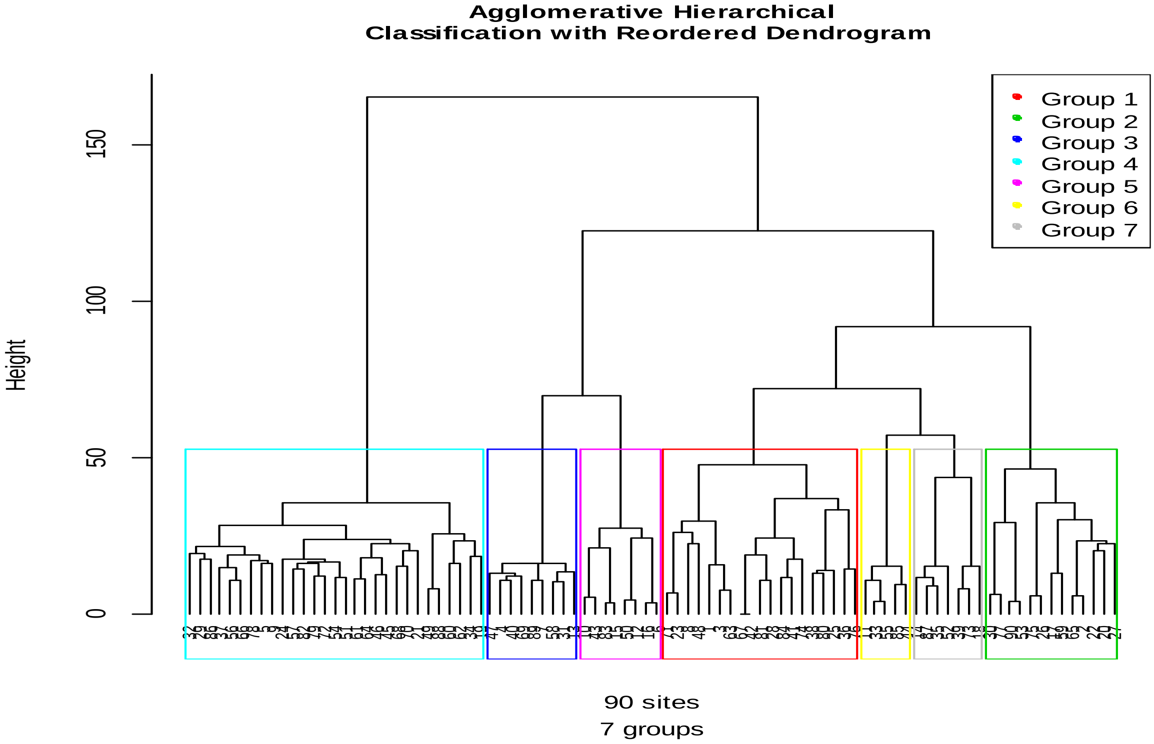


Figure 24. Dendrogram of the vegetation data obtained from hierarchical cluster analysis of Sele-Nono forest using Ward’s method and Euclidean distance (the term ‘Group’ on the legend is synonymous to clusters or plant community types established for the study area).

The seven plant community types described in Sele-Nono forest were named using two diagnostic species identified from synoptic table analysis (Appendix 19).

Community type one is named as *Elaeodendron buchananii - Olea welwitschii*, and mainly includes the vegetation within the elevations of 1600 -1900 m asl in Sele-Nono forest. This community type is often located on steep topographies and spatially mosaic localities such as MOLAYE, YEBECHA, WANGES (all in Onose Kebele), GAGO (in Gemechesa Kebele), QETO (in Bontu-Korma Kebele); KIMO & NONO-BERBERSA Kebele forests; and river lines of CHETA, GURACHA and SEJA. Representative woody species in this community includes *Bersama abyssinica*, *Celtis africana*, *Clausena anisata*, *Cordia africana*, *Dracaena steudneri*, *Embelia schimperi*, *Hallea rubrostipulata*, *Macaranga capensis*, *Maytenus gracilipes*, *Millettia ferruginea*, *Pittosporum viridiflorum*, *Rubus steudneri*, *Rytignia neglecta*, *Sapium ellipticum*, *Teclea noblis*, *Vepris dainellii*, *Isoglossa somalensis*, *Acanthus eminens*, *Lobelia giberroa*, *Maesa lanceolata*, *Erythrococca trichogyne*. Herbaceous species in this community includes *Salvia nilotica*, *Isoglossa puncata*, *Achyranthes aspera*, *Hypoestes forskaolii*, *Tiliacora troupinii*, *Aframomum corrorima*, *Panicum spp*, *Paullina pinnata*, *Piper capensis*, *Desmodium repandum*, *Hypoestes triflora*, *Hypoestes forskaolii*.

Community two is *Alstonia boonei – Manilkara butugi* community type, and often found between an altitudinal ranges of 840 - 1250 m asl. This community type is often located on gentle slopes of WAKA, ARBE, KOPI, YAKEMA, GEMECHESA and WELKKETESA Kebele forests on their lowland extremes. Common woody species in this community type include *Acalypha ornata*, *Anthocleista schweinfurthii*, *Allophylus macrobotrys*, *Alstonia boonei*, *Argomuellera macrophylla*, *Baphia abyssinica*, *Celtis toka*, *Celtis zenkeri*, *Dracaena fragrans*, *Ficus sycomorus*, *Garcinia buchananii*, *Garcinia ovalifolia*, *Lecaniodiscus fraxinifolius*, *Manilkara butugi*, *Metarungia pubinervia*, *Milicia excelsa*, *Pouteria alnifolia*, *Pouteria altissima*, *Saba comorensis*, *Whitfieldia elongata*, *Bridelia scleroneura*. Some of the herbaceous species common in this plant community type includes *Ageratum conyzoides, Stictocardia beraviensis, Achyrospermum schimperi, Isoglossa somalensis, Phaulopsis imbricata, Panicum atrosanguineum, Monothecium glandulosum, Isodon schimperi, Plantago palmata, Crassocephalum vtellium, Guizotia scabra* subsp *schimperi, impatiens rothii, impatiens hochstetteri.* Field observation also revealed that this community type is disturbed prevalently by the conversion of forest land to cropland (Maize, *Ensete ventricosum*, *Colocasea esculenta*) through anthropogenic fire. Moreover, it was evident that these areas were heavily disturbed by anthropogenic activities such as charcoaling, logging, the gathering of *Dioscorea* roots and the likes. Oral communication with elder people, who were born and lived in the area told that the size of the forest became highly diminished than before.

Community type three is *Arundinaria alpina* community type, and it is found in the uppermost altitudes of the study sites between an altitudes of 2300- 2448 m asl. It covers the uplands of TUPI and KOMBOLCHA Kebele forest in the study area. Though it is mainly dominated by one species, *Arundinaria alpina*, it still contains some dominant species, which includes *Maytenus adat*, *Polyscias fulva, Schefflera myriantha, Schefflera volkensii, Dracaena afromontana, Galiniera saxifraga, Ekebergia capensis, Bersama abyssinica, Syzygium guineense* subsp. *Guineense, Prunus africana,* and *Allophylus abyssinicus.* Herbaceous species includes *Blotiella glabra, Amauropelta bergiana, Athyrium schimperi, Veronica abyssinica, Ajuga integrifolia, Thunbergia alata, Cyathula polycephala, Asplenium elliottii, Asplenium friesiorum.*

Community type four is *Pouteria adolfi-friederici – Dracaena afromontana,* and mainly observed between altitude ranges of 1850-2300 m asl in the study area. It covers most parts of the study area such as the forests of DECHA, SOCHOSO, SELASE, DERBETA and the highlands of WAKA, HARO, KOPI, YAKEMA, BONTU KORMA AND GOROSO forest.

Common species in this community includes *Pouteria adolfi-friederici, Syzygium guineense, Albizia gummifera, Olea capensis* subsp. *macrocarpa, Schefflera abyssinica, Allophylus abyssinicus, Clausena anisata, Cyathea manniana, Deinbollia kilimandischarica, Galiniera saxifraga, Lepidotrichilia volkensii, Oxyanthus speciosus, Pittosporum viridiflorum, Rothmannia urcelliformis, Ilex mitis, Brillantaisia madagascariensis, Teclea nobilis, Vepris dainellii, Maytenus* adat., *Combretum paniculatum, Embelia schimperi, Dalbergia lactea, Hippocratea africana, Rytignia neglecta, Ruellia prostrata, Acanthopale ethio-germanica, Asystasia gangetica, Dyschoriste nagchana, Plectranthus sylvestris, Barleria ventricosa*. Common herbaceous species included in this community types include *Canarina abyssinica, Scadox nutans, Peperomia tetraphylla, Asplenium sandersonii, Loxogramme lanceolata, Aerangis luteoalba, Arthropteris monocarpa, Asplenium aethiopicum, Asplenium spp., Lycopodium c1avatum, Bulbophyllum josephi, Habenaria quartiniana, Aerangis thomsonii, Oplismenus hirtellus, Desmodium repandum, Dissotis canescens, Dorstenia sorensenii, Elatostemma monticolum, Tristemma mauritianum, Impatiens ethiopica, Thalictrum rhynchocarpum, Celosia argentea, Crassocephalum macropappurn* and many others. Interview with District leaders and key informants reveal that these highland forest have been called KOBO forests for honey production by the local people. The Kobo system is a traditional forest management practices in the study area that gives the local people a sense of ownerships for a certain block of forests demarcated by big trees and/or other physical features like rivers and small streams and exclusively used for hanging beehives and hunting to sustain their livelihoods.

Community type five is *Cyperus longibracteatus - Cyperus dereilema,* and it referred to the vegetation predominantly found on wetlands and other pocket swamp bodies. These are permanently or seasonally flooded areas dominated by grasses and/or sedges between 1640-1850 m asl. This community type is mainly found in the wetlands (and/or grassland during the dry season) of GOROSO, KIMO, QOTI, ASENDABO, TUPI, GEMECHESA, WELKETESA and the like. Although the primarily vegetation in this community are tall grasses, sedges and ferns, scattered woody species were also notable. The major vascular plant species that characterize the wetland habitat include *Cyperus latifolus, Cyperus dereilema, Panicum hymeniochilum, Floscopa glomerata, Pennisetum macroururn, Pennisetum trachyphyllum, Snowdenia polystachya, Sporobolus pyramidalis, Persicaria setosula, Rumex natalensis*. The grasses grown in this community type are common source of livestock feed & thatches; and field observation also manifested free grazing on these habitats particularly during the dry seasons.

Community type six is *Coffea arabica* - *Trichilia dregeana*, and mainly found within the elevation range of 1600-1800 m asl. It is dominantly observed in ASENDABO, KIMO, DERBA, GEMECHISA, WELKETESA, YAKEMA, KOPI. The main plants included in this community are *Brucea antidysnterica, Croton macrostachyus, Euphorbia ampliphylla, Pavonia urens, Apodytes dimidiata, Bothriocline schimperi, Sapium ellipticum, Polysicas fulva, Ehretia cymosa, Trema orientallis, Kosteletzkya begoniifolia, Triumfetta rhomboidea, Ritchiea albersii, Hippocratea goetzei, Oncinotis tenuiloba, Tiliacora troupinii, Hippocratea africana, Oncinotis tenuiloba, Paullinia pinnata, Cassipourea malosana, Ficus exasperate, Ficus thonningii, Ficus vasta, Ficus ovata, Ficus sur, Psidium guajava, Trichilia dregeana, Coffea arabica, Ehertia cymosa, Bridelia micranta, Dracaena steudneri, Erythrococca trichogyne, Senna petersiana, Nuxia congesta, Pavonia urens*. Field observation showed that this community type is more vulnerable due to forest management (thinning the understory shrubs, logging canopy trees, etc.) for increasing the production of coffee beans for the purpose of household consumption. Moreover, Informal interview with local elders revealed that most local people prefer this area for the expansion of smallholder coffee agriculture as these areas are average between the highland (where there is no much natural coffee plants) and lowlands (where there is much coffee but unconducive area for living). As a result, many of them have coffee plots in the forests where they collect coffee beans for selling to subsidize their livelihood. On top of this, expansion of settlements and recent development in road construction in this community type is major threat to the diversity and richness of plants. As a result, the physiognomy of vegetation in this community are not characterized by continuous cover spacing; rather plants are widely spaced out.

Plant community seven is *Morus mesozygia - Trilepisium madagascariense* community type and is found at altitudes between 1200-1500 m, asl along the courses of BARO, GENJI, and GURACHA rivers. Common woody species in this community types includes *Acalypha ornate, Argomuellera macrophylla, Baphia abyssinica, Dioscorea praehensilis, Diospyros abyssinica, Dracaena fragrans, Gouania longispicata, Turraea holstii, Cissampelos mucronata, Alblzia schimperiana, Albizia grandibractiata, Mimosopes kummel, Justicia ladanoides, Justicia bizuneshiae, Anthocleista schweinfurthii, Celtis philippensis, Celtis gomphophylla, Dracaena fragrans, Eugenia bukobensis, Ficus exasperata, Morus mesozygia, Ficus mucuso, Ficus sycomorus, Phoenix reclinata, Strychnos mitis, Trichilia dregeana, Trilepisium madagascariense and Vepris dainellii.* Common herbaceous species includes *Ceropegia cufodontis, Eulophia guineensis, Setaria megaphylla, Oryra latifolia, Marantochloa leucantha*

4.1.3. Species diversity, richness and evenness in Sele-Nono forest

Diversity analysis such as Shannon species diversity, richness and evenness for each clusters were computed in R as shown in Table 12. Moreover, Whittaker's alpha (α) and beta (β_w) diversity were also computed for each clusters (Whittaker, 1972; Magurran 1988) so as to measure the degree of heterogeneity of species composition. Whittaker's alpha diversity (α-diversity) was computed as the average species richness per plot (i.e., species density); and beta diversity (β_w-diversity) was computed on the basis of the ratio of the total number of species to the average number of species in R software.

Table 12. Diversity analysis for each of the seven plant community types in Sele-Nono Forest

				Shannon diversity		**Whittaker's diversity**	
Cluster number	**Elevation Range (m, asl)**	**No. of plots**	**Species richness (S)**	Species diversity (H)	Species evenness (J)	α-diversity	β_w-diversity
1	1600-1900	19	101	4.096238	0.887569	24.11	4.18
2	840-1250	13	71	3.82028	0.896216	19.69	3.60
3	2300-2448	9	58	3.6214	0.891873	14.00	4.14
4	1850-2300	29	186	4.362704	0.834848	29.20	6.36
5	1640-1850	8	55	3.640168	0.908377	16.25	3.38
6	1600-1800	5	46	3.538256	0.924154	24.40	1.88
7	1200-1500	7	91	4.161504	0.922552	30.66	2.96

Based on the result of the data (Table 12), it can be said that cluster 4 is a cluster with high Shannon diversity (H=4.36) of plant species and are found on the uppermost elevations of the study area before reaching the bamboo zone. The higher the values of Shannon evenness (J), the more even the plant species are in their distribution within the cluster. Thus, cluster 5, 6 & 7 have more even distribution of individuals among various species in each clusters (J>0.90) than the other clusters. On the basis of species richness, cluster 4 (*Pouteria adolfi-friederici – Dracaena afromontana* community type) and cluster 1 (*Elaeodendron buchananii - Olea welwitschii* community type) contain large number of species (S > 100) than the other clusters. Actual field observation during the study period revealed that community type 6 is major coffee growing areas and most local people prefer it for settlements so as to subsidize their livings; whereas community 5 (pocket wet lands/flooded grasslands) mainly served as grazing land for animals particularly during the dry season. Community 3 (the bamboo zone) was the peak and wettest places in the study area.

From the above Whittaker beta diversity analysis (Table 12), it can be seen that the degree of variation of vegetation turnover along the plots in each cluster is not so high ($\beta_w < 5$) except for cluster 4 ($\beta_w > 5$); whereas too low beta diversity was obtained for cluster 6, which is the species poor plant community type. Whittaker's beta diversity index was also calculated in R to assess the overall heterogeneity of plant species in the study area. The result indicated that there is high beta diversity ($\beta_w = 12.04 \text{ which is} > 5$) of plant species across the community types in Sele-Nono forest, which may lead to the conclusion that each plant community types has a heterogeneous species composition or high species turnover.

4.1.4. Statistical test on the variation of plant diversity in Sele-Nono forest

Initial analysis of variance (ANOVA) using "aov" approach in R showed that there were significant differences in diversity such as in species diversity (F=10.89, $P < 0.05$), richness (F=9.83, $P < 0.05$) and evenness (F=3.46, $P < 0.05$) between the plant community types (Figure 25). ANOVA was performed after checking the assumptions of linearity using Shapiro-Wilk normality test ($P > 0.05$) and homogeneity of variances using Levene statistic ($P > 0.05$).

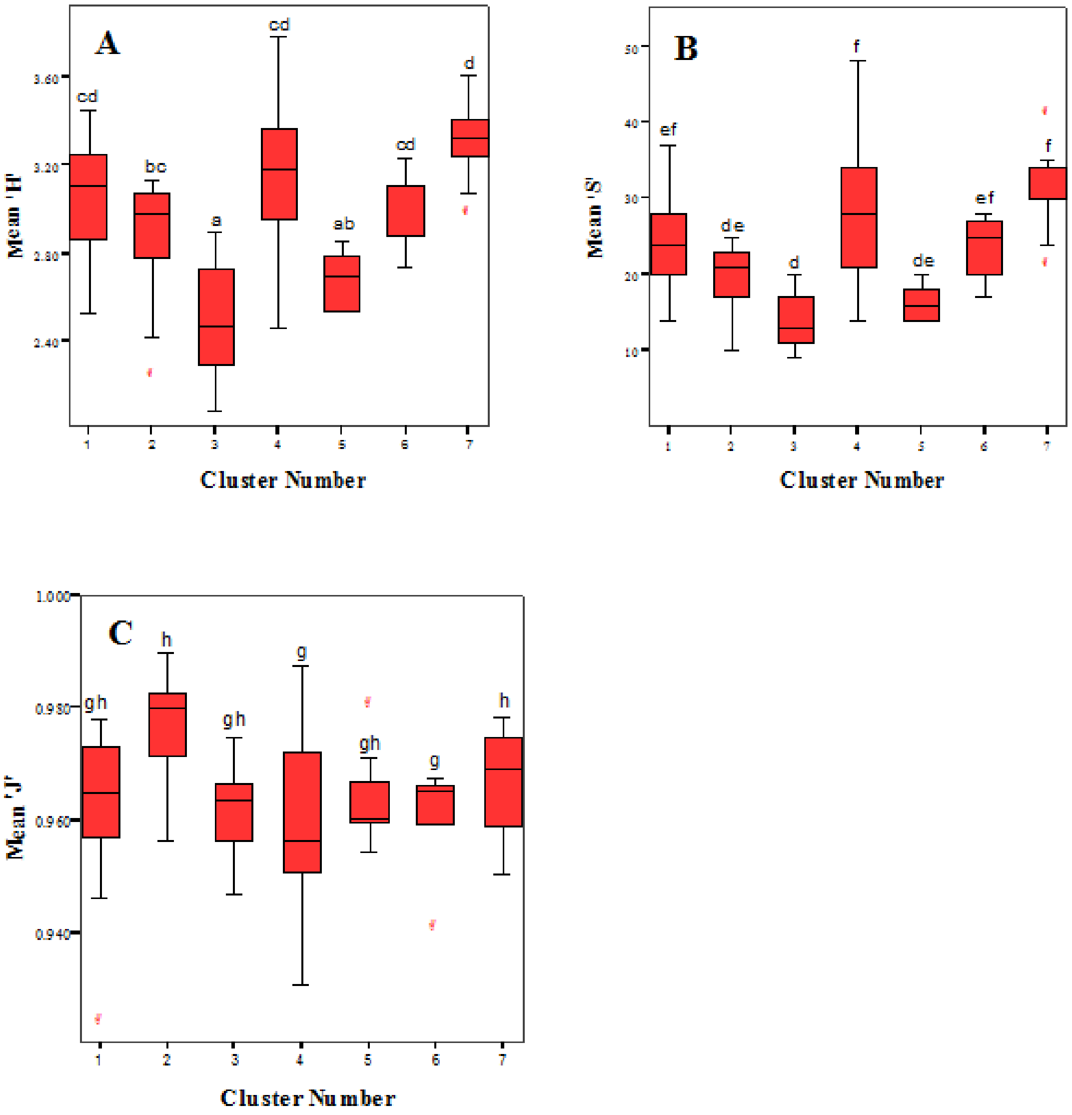


Figure 25. Mean values of plant diversity per plot for the different clusters in the study area (A) Variation of mean species diversity (B) Variation of mean species richness (C) Variation of mean species evenness between the clusters. Boxes represented by the same letters are not significantly different (P >0.05).

From the above figures (Figure 25), it can be revealed that mean species diversity was significantly higher at cluster 1, 4 & 7; and lower at cluster 3 (the community with the alpine bamboo thicket) and cluster 5 (the community with high level of grazing intensity). Similarly, significantly large number of species per plot were found in cluster 4 and 7; and cluster 3 and 5 has significantly less number of species. Regarding species evenness, significantly high species evenness per plot was revealed at cluster 2 while significantly low evenness was observed at cluster 4.

4.1.5. Influence of environmental factors on the distribution of plants in Sele-Nono forest

Result in this study shows that there is a significant correlation between the species composition and environmental variables (Mantel statistic: $r=0.74$, $P< 0.05$). From the environmental data collected for this study (Appendix 20), a forward selection procedure (Monte Carlo permutation tests, n = 999) screened out the following environmental variables (Table 13) to be more responsible ($P< 0.05$) for the distribution of plants and structuring their community composition in the study area.

Table 13. Most influential environmental factors that affect the distribution of plants in Sele-Nono Forest.

Environmental factors	Df	Chisq	F	N.Perm	Pr(>F)
Altitude	1	0.4002	3.4289	999	0.001^{***}
Disturbance	1	0.3736	3.2007	999	0.001^{***}
Slope	1	0.2502	2.1434	999	0.001^{***}
OM	1	0.2177	1.8648	999	0.001^{**}
N	1	0.1679	1.4388	999	0.013^{*}
Residual	84	9.8049			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

The correlation of these environmental factors with themselves and their influence on the distribution of vegetation in the study area was projected as follow using Canonical Correspondence Analysis (CCA) technique (Figure 26).

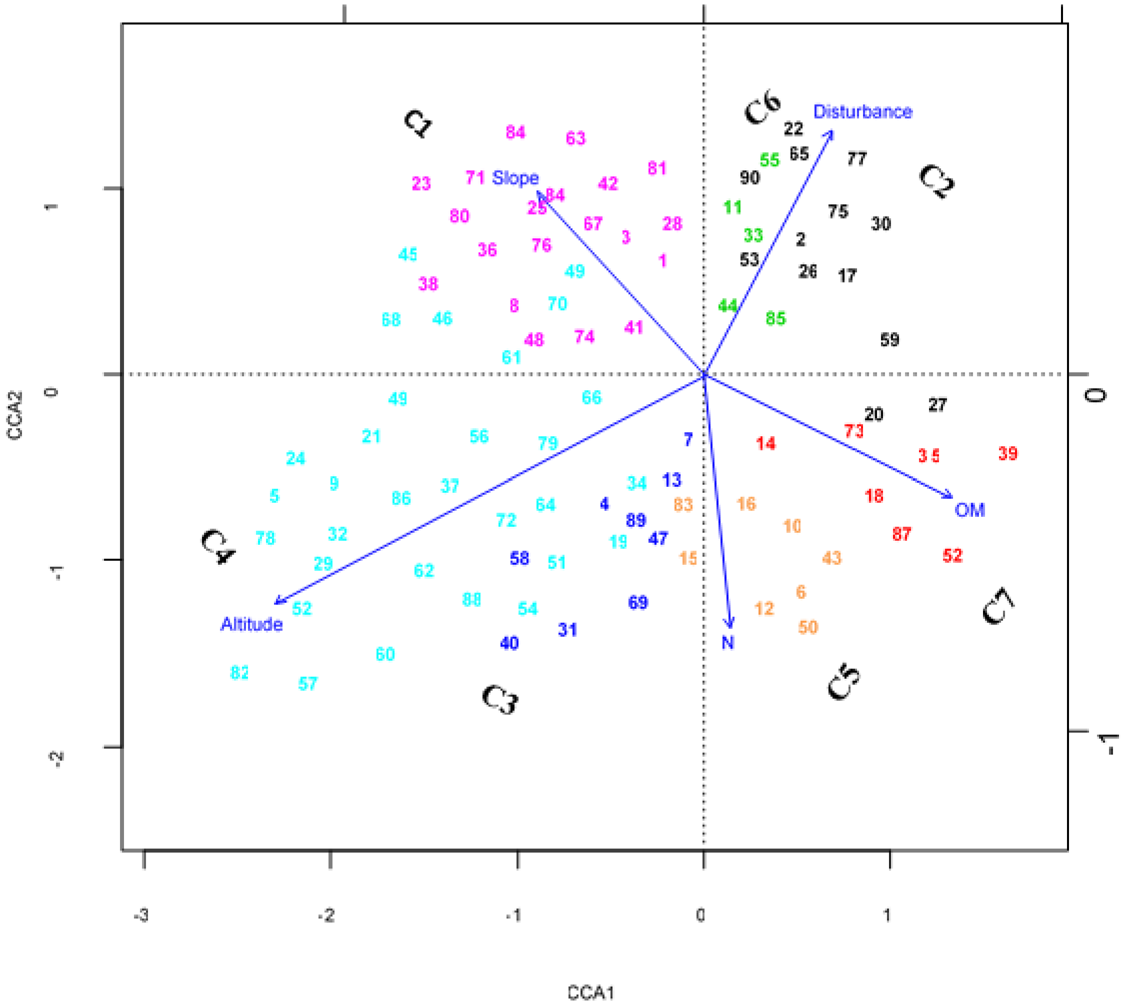


Figure 26. CCA showing the relationship of the environmental factors among themselves and on the distribution of plants in the study area (Numbers inside the ordination diagrams represents plot numbers; and C denotes community number; arrows representing environmental variables; and arrow length shows the strength of the environmental variable).

The first and second ordination axis of the CCA explained 35.51% and 26.08% of the total variation respectively, leading to capture a cumulative of 61.59% of variability in the dataset. From the above ordination diagram (Figure 26) it can be seen that altitude was strongly associated with species composition as indicated by the long arrow in ordination diagram indicating that it is the main environmental factor responsible for the spatial variation of vegetation in the study area. Plant communities that are distributed in the higher elevation of the study area (C1, C3 & C4), which all together form part of Moist Afromontane Forest (MAF) were ordinated to the left side of the diagram; whereas the clusters that are distributed in the lower elevations (C2 and C7), which forms part of the Transitional Rainforest (TRF) were ordinated at the positive end of axis 1. The diagram also demonstrates a positive correlation between slope and altitude as the arrow for slope points in the same direction as the altitude arrow. On the contrary a negative correlation between altitude and disturbance was also evident from the ordination diagram. Vegetation of the swampy areas (C5) have direct relationship with nitrogen content of the soil, whereas *Morus mesozygia* - *Trilepisium madagascariense* community type (C7) mainly enriched by the high organic matter content of the soil in the area.

4.1.6. Threat to vegetation of Sele-Nono forest

Results of the semi structured interview conducted with the informants revealed that the forest vegetation of the study area is depleting from time to time basically due to the following reasons.

- Expansion of Agricultural lands (conversion of forest land to farming land);
- Expansion of settlements/urban boundaries due to population growth;
- Fire (causing a wide distraction of vegetation and affect the regeneration. It is often set deliberately either for farm clearing, or driving out bees during honey collection from the traditional bee hives. Sometimes it may result by smokers leaving butts of cigarettes unextinguished in the forest);
- Over-grazing particularly for herbaceous plants (because it hinders regenerations, decrease species diversity and if it is heavily grazed it paves ways for erosion by wind, water etc.);

- Clearing of forests for wide and far reaching road constructions;

- Thinning of understorey shrubs other than Coffee for improving coffee bean productivity (i.e., conversion of a “forest-coffee systems” into “semi-forest coffee systems” as defined by Tadesse Woldemariam, 2003);

- Selective removal of trees and/shrubs for construction purposes, timbering, charcoal production, harvesting of fuel wood, etc. Some of the species frequently preferred for logging by the local people includes *Pouteria adolfi-friederici, Apodytes dimidiata, Celtis africana, Cordia africana, Croton macrostachyus, Ekebergia capensis, Prunus africana, Olea welwitschii, Polyscias fulva and Syzygium guineense*. These logging practices have been reported to exist in the study forest since the time that dates back beyond the knowledge of the local people. The current participatory forest management (PFM) approach practicing in the study area was appreciated by clan leaders at least in limiting the uncontrolled logging.

Moreover, actual field observation (Figure 27) supported the interview result.

Figure 27. Common threat to the vegetation of Sele-Nono forest

To indicate the above listing of environmental degradation in order of their impact, priority ranking was applied by taking ten key informants following Martin (1995) (Table 14).

Table 14. Results of priority ranking values from ten respondents (A-J) on priority of seven threats to the vegetation of Sele-Nono forest (based on their degree of causing damage: 1 = least damaging, 7= most damaging).

Lists of major threats to Sele-Nono forest	Key informants (coded A-J)											Rank
	A	B	C	D	E	F	G	H	I	J	Total	
Agricultural land expansion	7	6	7	7	7	5	7	7	6	7	66	1st
Settlements boundry expansion	4	4	4	6	5	3	4	5	3	4	42	4th
Fire	1	2	3	1	2	1	2	1	2	2	17	7th
Over-grazing	2	3	1	2	3	4	1	2	1	3	22	6th
Selective removals	6	7	5	3	6	6	6	6	7	5	57	2nd
Road development	3	1	2	4	1	2	3	3	4	1	24	5th
Forest thinning	5	5	6	5	4	7	5	4	5	6	52	3rd

From the above table (Table 14) it can be seen that the study forest is primarily threatened by forest clearing for agriculture purpose and forest degradation through selective removals of woody species and forest thinning practices for optimizing coffee bean production. Moreover, settlement expansion or population increment and road projects are also notable threats to Sele-Nono forest. Overgrazing and fire were found to be the least serious threat to the plant biodiversity of Sele-Nono forest.

4.2. Vegetation structure of Sele-Nono forest

4.2.1. Size class distribution of woody plants in Sele-Nono forest

A general pattern about the size of woody plants in Sele-Nono forest was displayed using DBH and height (H) class distribution as shown below (Figure 28). About 71% of the individuals of woody species were found below a DBH size of 5 cm (Figure 28, Left). Moreover, about 40% of the individuals were lower than a height of 5 m (Figure 28, right).

Only some portion of the individuals were represented by the largest DBH and Height classes.

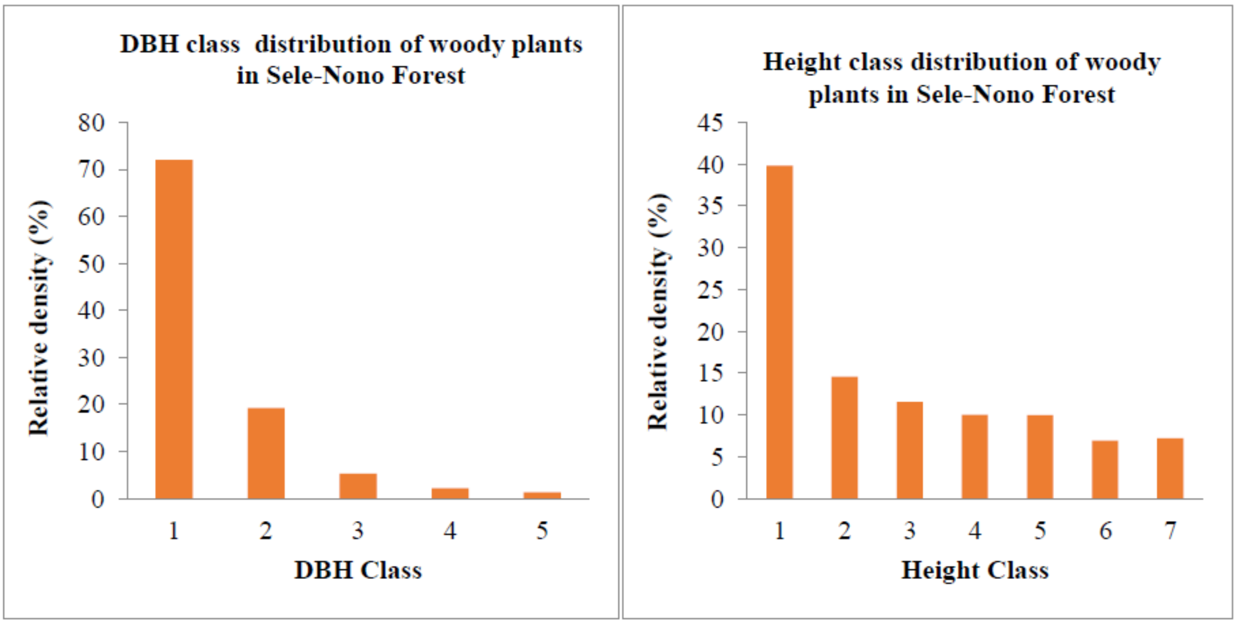


Figure 28. Size class distribution of woody plants in Sele-Nono forest. DBH class (Left): 1=2.5-5 cm, 2=5.1-11 cm, 3=11.1-23 cm, 4=23.1-47 cm, 5>47 cm. Height class (right): 1=1.5-5 m, 2= 5.1-10 m, 3=10.1-15 m, 4=15.1-20 m, 5=20.1-25 m, 6=25.1-30 m, 7>30 m high.

4.2.2. Population structure of woody plants in Sele-Nono forest

Result on population structure revealed eight general patterns and they were represented by eight dominant species which we think are better for demonstrating the result (Figure 29).

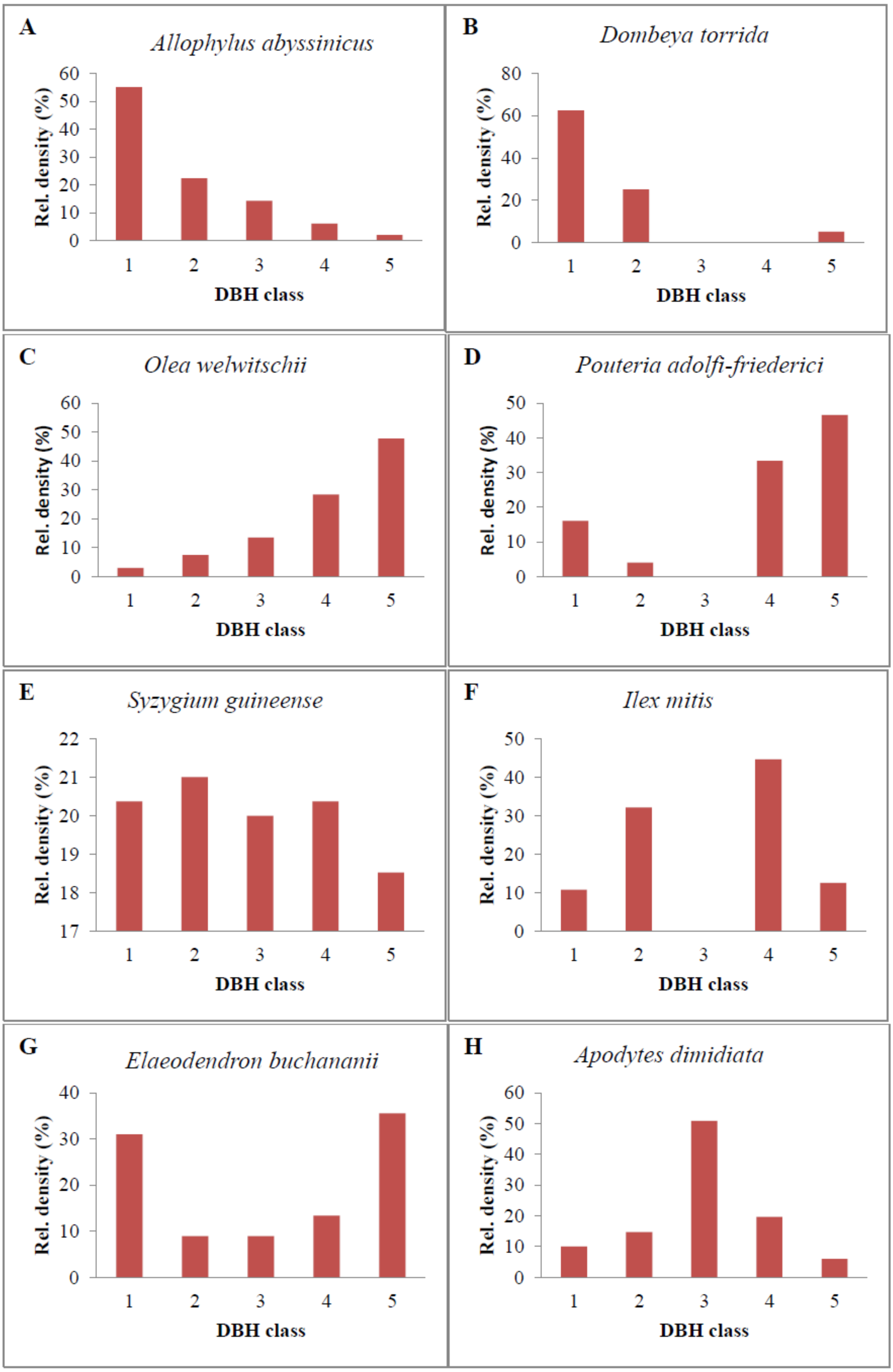


Figure 29. Population structure of woody species in Sele-Nono forest; patterns as shown by 8 representative species.

The first pattern was represented by *Allophyllus abyssinicus* (Figure 29A), which reveals inverted "J" curve, or positively skewed structure. Species in this group have high density of individuals in the lower DBH class that gradually decreases with increasing DBH. Species in this pattern indicates good reproduction and recruitment processes. Species that falls in this category of population structure includes *Albizia grandibracteata, Bersama abyssinica, Dracaena afromontana, Rothmannia urcelliformis, Olea capensis* subsp. *macrocarpa, Oxyanthus speciosus, Pittosporum viridiflorum, Strychnos mitis, Syzygium guineense, Teclea noblis, Trema orientalis, Vepris dainellii*. The second pattern was represented by *Dombeya torrida* (Figure 29B). This pattern shows a high density of individuals at lower class and missed individuals in the middle followed by fewer density of individuals in the higher DBH classes. Such pattern roughly forms a kind of broken inverted J curve which would characterizes the high reproduction and discontinuous recruitments in its population structure. Species that falls under this category includes *Allophylus macrobotrys, Anthocleista schweinfurthii, Brucea antidysenterica, Cassipourea malosana*.

The third kind of population structure is revealed by *Olea welwitschii* (Figure 29C) where they had fewer densities of individuals in the smaller DBH classes and the density increases with increasing DBH forming J shape patterns. Species included in this pattern are *Ficus sur, Garcinia ovalifolia, Garcinia buchananii, Hallea rubrostipulata*. The fourth pattern was represented by *Pouteria adolfi-friederici* (Figure 29D). In this kind of population structure species at lower DBH class have fewer densities of individuals, but missed somewhere in the middle and then density increases with increasing DBH forming a broken J shape curves. Such pattern is characteristics of poorly reproducing and recruiting species. Species that falls in this category includes *Cordia africana*, *Deinbollia kilimandscharica*, *Morus mesozygia, Pouteria altissima, Trichilia dregeana, Trilepisium madagascariense*.

The fifth pattern was represented by *Syzygium guineense* (Figure 29E). In this pattern the density of individuals is more or less regularly represented in all the DBH classes. Species in this patterns may include *Ficus exasperata, Lepidotrichilia volkensii, Macaranga capensis, Millettia ferruginea, Mimusops kummel, Schefflera volkensii*. The sixth pattern was represented by *Ilex mitis* (Figure 29F). The species included in this group are *Diospyros abyssinica, Manilkara butugi, Sapium ellipticum*. They show lower density of individuals at the beginning and then increase up to some limits and then decrease up to some points and finally increase, and form a kind of undulating pattern. This indicates irregular or Zigzag pattern as DBH increases.

The seventh pattern of population structure was represented by *Elaeodendron buchananii* (Figure 29G). In this pattern larger density of individuals are found both at lower and higher DBH classes, but low number of individuals in the intermediate classes forming a kind of U-shape curves. Species characterized by this kinds of pattern includes *Alstonia boonei, Croton macrostachyus, Polyscias fulva, Ekebergia capensis, Celtis africana*. The last population structure was represented by *Apodytes dimidiate* (Figure 29H), which is resulted when a species is represented by low number of individuals in both the lowest and highest DBH classes, but by high number of individuals in the intermediate classes. Such pattern forms Gaussian kind of curve or Bell shapes. Species in this group includes *Dracaena steudenerii, Euphorbia ampliphyla, Fagaropsis angolensis and Phoenix reclinata*.

Deeper analysis on the population structure of the studied species summarizes the species to fall into three basic groups based on their current status of reproduction and recruitment so as to utilize this concept of population structure for the purpose of forest management. These are group 1 that includes species whose reproduction and recruitment is severely limited; group 2 includes species which show discontinuous or irregular recruitments which is a signal for bad recruitments; and group 3 includes species which had good reproduction and good recruitment. With regard to this, the result indicates that out of the studied woody species, 33% of them categorized in to group 1, 24% in to group 2 and 43% in to group 3. The species list for the three groups is presented in Appendix 21.

4.2.3. Density of woody plants in Sele-Nono forest

The total density of woody plants with DBH >2.5 cm and height >1. 5 m was 20939.38 ha^{-1}. Large part of this density (91.23%) was contributed by the species with DBH <10 cm. In this forest, the highest density of species was recorded for *Coffea arabica, Rytigynia neglecta, Canthium oligocarpum*, *Acalypha acrogyna* and *Vangueria madagascariensis* with a density of 3928.89, 2337.78, 1564.44, 1128.89 & 826.67 individuals per hectare respectively (Appendix 22). The density of woody plants with DBH 10 to 20 cm (let say this 'a') was 1145.38 individuals' ha^{-1}. Density of woody plants with DBH greater than 20 cm (let say this 'b') was 690.99 individuals' ha^{-1} (Table 15). The ratio defined as a/b is taken as the measure of size class distribution; and it was found 1.66.

Table 15. Density of woody plants by DBH class in Sele-Nono forest

DBH (cm)	**No. of individuals (ha^{-1})**	**Percentage (%)**	**a/b ratio**
2.5-10.0	19,102	91.23	
10.1-20.0	1145	5.47	
>20.0	691	3.30	1.66
Total	20, 939	100	

4.2.4. Dominance

The total dominance or basal area of woody plants in Sele-Nono forest was 131.05 m^{2}ha^{-1} (Appendix 22). However, larger portion of this basal area (50.66%) was accounted by few species that belongs to larger DBH class which had smaller contribution (about 1.32%) to the total density of woody plants in the forest (Figure 30). Some of these species includes *Schefflera abyssinica, Pouteria adolfi-friederici, Olea welwitschii, Manilkara butugi, Morus mesozygia, Trilepisium madagascariense, Albizia gummifera* (Appendix 22). On the contrary, although majority of the individuals in the study forest (71. 98%) were with DBH less than 5 cm, they contributed little share (about 8%) to the total basal area of woody species in the forest (Figure 30).

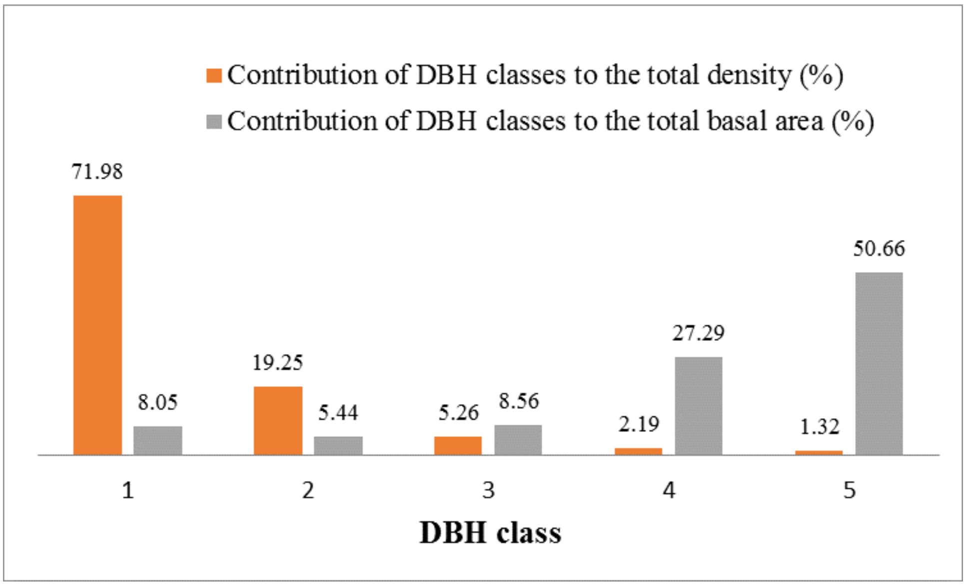


Figure 30. Contribution of different DBH classes to the total density and basal area of woody plants in Sele-Nono forest

4.2.5. Frequency

Computation of absolute frequency of woody species in Sele-Nono forest resulted the presence of two constantly occurring species (*Coffea arabica, Acanthus eminens*) (Frequency > 81%) and seven mostly occurring species (*Oxyanthus speciosus, Dracaena fragrans, Vepris dainellii, Teclea noblis, Psychotria orophila, Landolphia buchananii, Bersama abyssinica*) (Frequency=61-80%) as revealed from the Raunkiaer percentage frequency classes. About half of the woody species in the study area were rarely occurring species as they were recorded in less than 20% of the studied plots (Figure 31; Appendix 23A). Most of the frequent species are low canopy individuals (Appendix 23B).

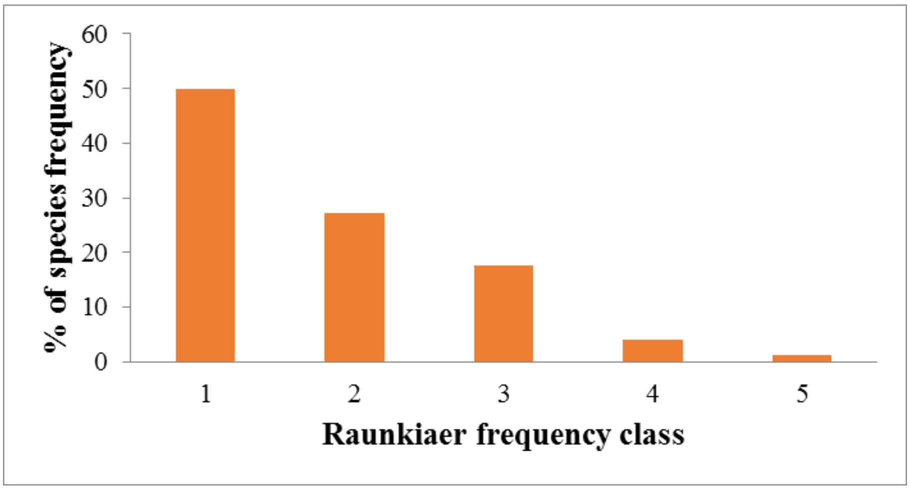


Figure 31. Occurrence of woody plants in Sele-Nono forest as computed from Raunkiaer frequency class (frequency class 1=rarely occurring species, 2=seldom occurring species, 3=often occurring species, 4=mostly occurring species, 5= constantly occurring species).

From the above figure (Figure 31) it can be noted that there were higher number of species in the lower frequency class; and low number of species in the higher frequency classes.

4.2.6. Important value index

Important value (IV) of the woody species in the study forest were computed from the three parameters, namely relative density (RD), relative frequency (RF) and relative dominance (RDo) (Appendix 22); and a summary of the result is depicted as follow (Table 16).

Table 16. Important value (IV) of the 15 most common species in Sele-Nono forest (RD-relative density; RF-relative frequency; RDo-relative dominance).

Species Name	**RD (%)**	**RF (%)**	**RDo (%)**	**IVI (%)**	**Percent IV (%)**	**IV Rank**
Coffea arabica	18.76	2.03	2.70	23.50	7.83	1
Schefflera abyssinica	0.06	0.76	20.99	21.80	7.27	2
Rytigynia neglecta	11.16	1.25	1.01	13.43	4.48	3
Pouteria adolfi-friederici	0.19	0.54	10.19	10.91	3.64	4
Olea welwitschii	0.20	0.49	9.61	10.30	3.43	5
Trilepisium madagascariense	0.14	0.88	7.72	8.74	2.91	6
Canthium oligocarpum	7.47	0.34	0.58	8.40	2.80	7

Manilkara butugi	0.14	0.46	7.19	7.80	2.60	8
Elaeodendron buchananii	0.14	1.27	4.98	6.39	2.13	9
Acalypha acrogyna	5.39	0.32	0.65	6.35	2.12	10
Acanthus eminens	3.37	1.98	0.33	5.68	1.89	11
Morus mesozygia	0.13	0.86	4.05	5.04	1.68	12
Vangueria madagascariensis	3.95	0.42	0.50	4.87	1.62	13
Embelia schimperi	3.44	0.56	0.29	4.29	1.43	14
Albizia gummifera	0.18	1.08	2.74	4.00	1.33	15
Total other species (161)	45.27	86..77	26.47	158.51	52.84	
Total	100.00	100.00	100.00	300.00	100.00	

4.2.7. Vertical structure

In Sele-Nono forest the tallest tree species were *Pouteria adolfi-friederici*, *Olea welwitschii* and *Trilepisium madagascariense*; and their height was recorded 45 m. With this reference of maximum tree height, the vertical structure of trees in the forest was stratified into three layers, namely upper storey, middle storey and lower storeys following the IUFRO scheme of classification (Figure 32). The result demonstrated that the upper storey with the height of 30-45 m accounted only for 7% of the total trees in the studied forest; whereas the middle storey trees with the height of 15-30 m contributed for 27% of vertically stratified trees in Sele-Nono forest. Trees that range from 1.5-15 m tall forms the lower storey and comprised of the largest percentage (66%) of trees in Sele-Nono forest.

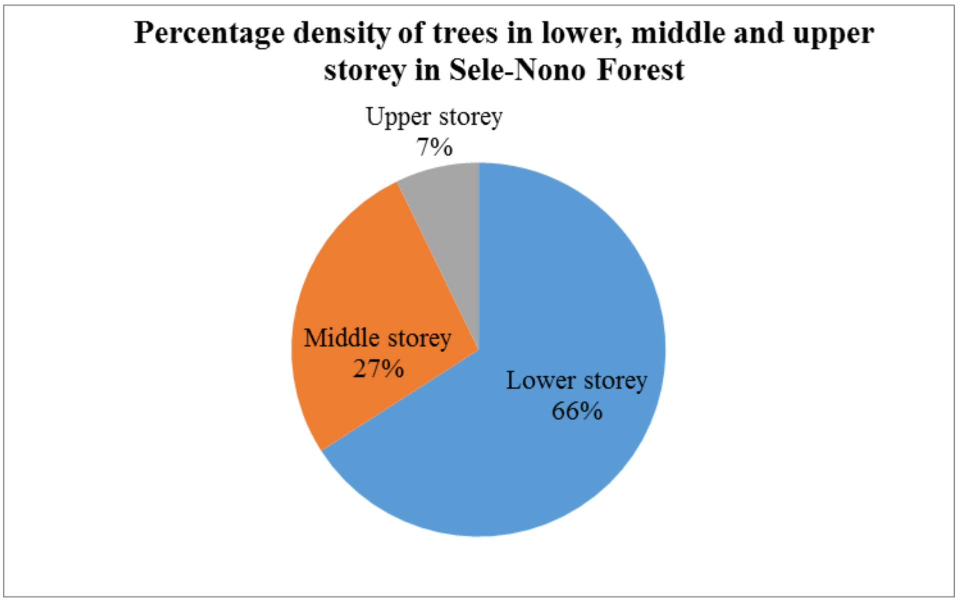


Figure 32. Percentage density of trees in the lower, middle and upper storey of Sele-Nono forest

4.2.8. Profile diagram of plant communities in Sele-Nono forest

The profile diagram of Sele-Nono forest at 1830 m a.s.l in the study forest (Figure 33) shows a closed and compact upper canopy stands of *Olea welwitschii* and *Elaeodendron buchananii*. The middle canopy occupied by 15-30 m high trees is relatively dense and continuous as compared to the lower layers, and is composed of species like *Bersama abyssinica, Celtis africana, Deinbollia kilimandischarica, Macaranga capensis, Millettia ferruginea, Prunus africana, Sapium ellipticum, Syzygium guineense*, and others. The lower tree layer is occupied by *Albizia gummifera, Canthium oligocarpium, Dracaena afromontana, Dracaena steudneri, Galiniera saxifraga, Lepidotrichilia volkensii, Maytenus gracilipes, Millettia ferruginea, Vepris dainellii*. This layer is also dominated by shrub species such as *Coffea arabica, Rytignia neglecta*. The forest floor is generally very dark and consists of sparse seedlings and herbaceous vegetation. This stand is characterized by sloppy terrain and human impacts on the structure of the vegetation is not common. However, a natural disturbance of tree falls were visible. This profile is more prominent in plant community type 1.

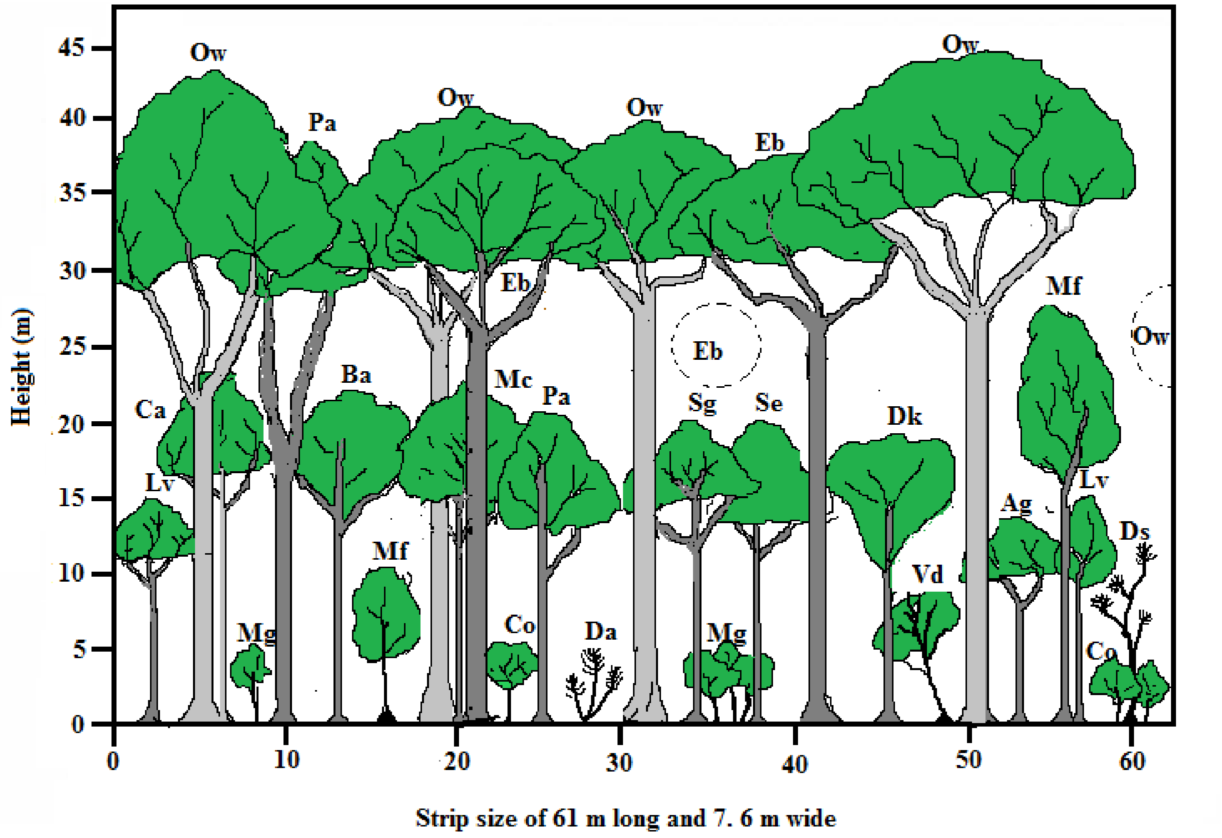


Figure 33. Profile diagram of an *Olea welwitschii* stand (61 m x 7.6 m) in the Sele-Nono forest at 1830 m a.s.l. Ag = *Albizia gummifera;* Ba = *Bersama abyssinica;* Ca = *Celtis Africana;* Co = *Canthium oligocarpium;* Da = *Dracaena afromontana;* De = *Deinbollia kilimandischarica;* Ds = *Dracaena steudneri;* Eb = *Elaeodendron buchananii;* Gs = *Galiniera saxifraga;* Lv = *Lepidotrichilia volkensii;* Mc = *Macaranga capensis;* Mg = *Maytenus gracilipes;* Mf = *Millettia ferruginea;* Ow = *Olea welwitschii;* Pa = *Prunus africana;* Se = *Sapium ellipticum;* Sg = *Syzygium guineense;* Tn = *Teclea nobilis;* Vd = *Vepris dainellii;* Interrupted lines=canopy extension from outside the strip.

The profile diagram of Sele-Nono forest at elevation of 1050 m a. s. l. (Figure 34) shows scattered trees of *Alstonia boonei* and *Manilkara butugi* in the upper canopy of the stand. The foliage canopies of these upper storey were open to the space and *Alstonia boonei* is emergent in this stand. The middle stratum consists of few individuals of trees when compared with trees of the lower stratum. Species common to this stratum includes *Baphia abyssinica, Milicia excelsa, Pouteria alnifolia, Pouteria altissima*. The lower storey trees are denser as compared to the middle and upper storey trees. Species in this layer includes *Acalypha ornata, Allophylus macrobotrys, Argomuellera macrophylla, Celtis toka, Celtis* *zenkeri, Garcinia buchananii, Garcinia ovalifolia, Saba comorensis, Whitfieldia elongate*. The shrub and saplings occupied in the lower layer are *Rytignia neglecta*, *Whitfieldia elongata*, *Dracaena fragrans*, *Coffea arabica* and others. Seedlings and herbaceous layers are generally denser. This stand is more prominent in plant community type 2 of the studied forest.

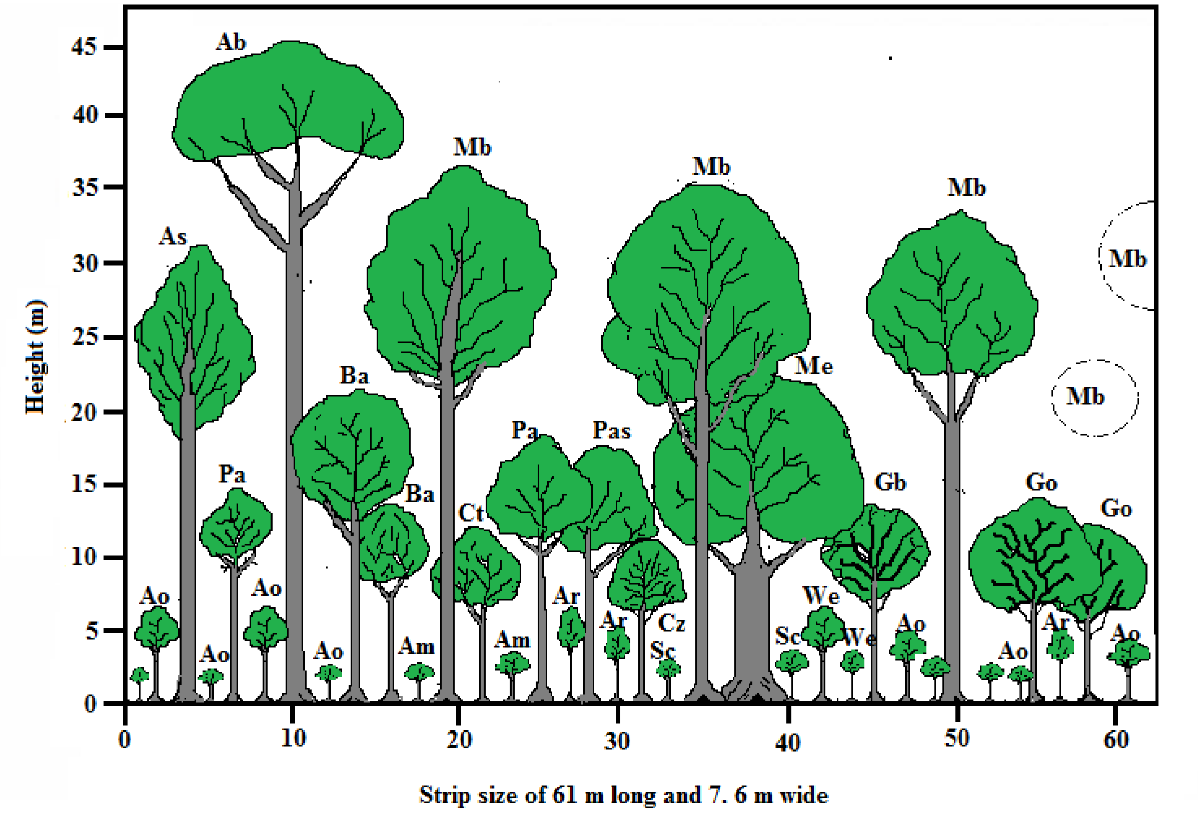


Figure 34. Profile diagram of a *Manilkara butugi* stand (61 m x 7.6 m) in the Sele-Nono forest at 1050 m a.s.l. Ab = *Alstonia boonei;* Ao = *Acalypha ornate;* As = *Anthocleista schweinfurthii;* Am = *Allophylus macrobotrys;* Ar = *Argomuellera macrophylla;* Ba = *Baphia abyssinica;* Ct = *Celtis toka;* Cz = *Celtis zenkeri;* Gb = *Garcinia buchananii;* Go = *Garcinia ovalifolia;* Mb = *Manilkara butugi;* Me = *Milicia excelsa;* Pa = *Pouteria alnifolia;* Pas = *Pouteria altissima;* Sc = *Saba comorensis;* We = *Whitfieldia elongatea;* Interrupted lines=canopy extension from outside the strip.

The profile diagram of the studied forest at an elevation of 2190 m a. s. l. (Figure 35) indicates the dominance of the emergent *Pouteria adolfi-feridericii* in the upper storey of the forest. Other trees such as *Albizia gummifera, Deinbollia kilimandischarica, Polyscias fulva,* and *Syzygium guineense* also forms parts of the upper storey. The middle storey trees with the height ranges of 15-30 m are relatively denser and diverse. Species in this stratum includes *Allophylus abyssinicus, Albizia gummifera, Croton macrostachyus, Ekebergia capensis, Ilex mitis, Pouteria adolfi-friederici, Prunus africana, Syzygium guineense*. Some species such as *Pouteria adolfi-feridericii* forms parts of the middle canopy although it is also an emergent tree in the stand. The lower storey is dark and consists of sparse trees, which includes *Dracaena afromontana, Flacourtia indica, Galiniera saxifraga, Lepidotrichilia volkensii, Olea capensis* subsp. *macrocarpa, Oxyanthus speciosus, Psychotria orophila, Rytignia neglecta, Rothmannia urcelliformis, Sapium ellepticum, Teclea nobilis, Vepris dainellii.* Saplings and shrubs includes *Coffea arabica, Psychotria orophila, Galineria saxifraga* and the likes are very common on forest floor. The herb layer is mainly dominated by various species of ferns. Natural disturbances such as tree falls were visible in the stand. This stand is more reflected in community type 4 of the studied forest.

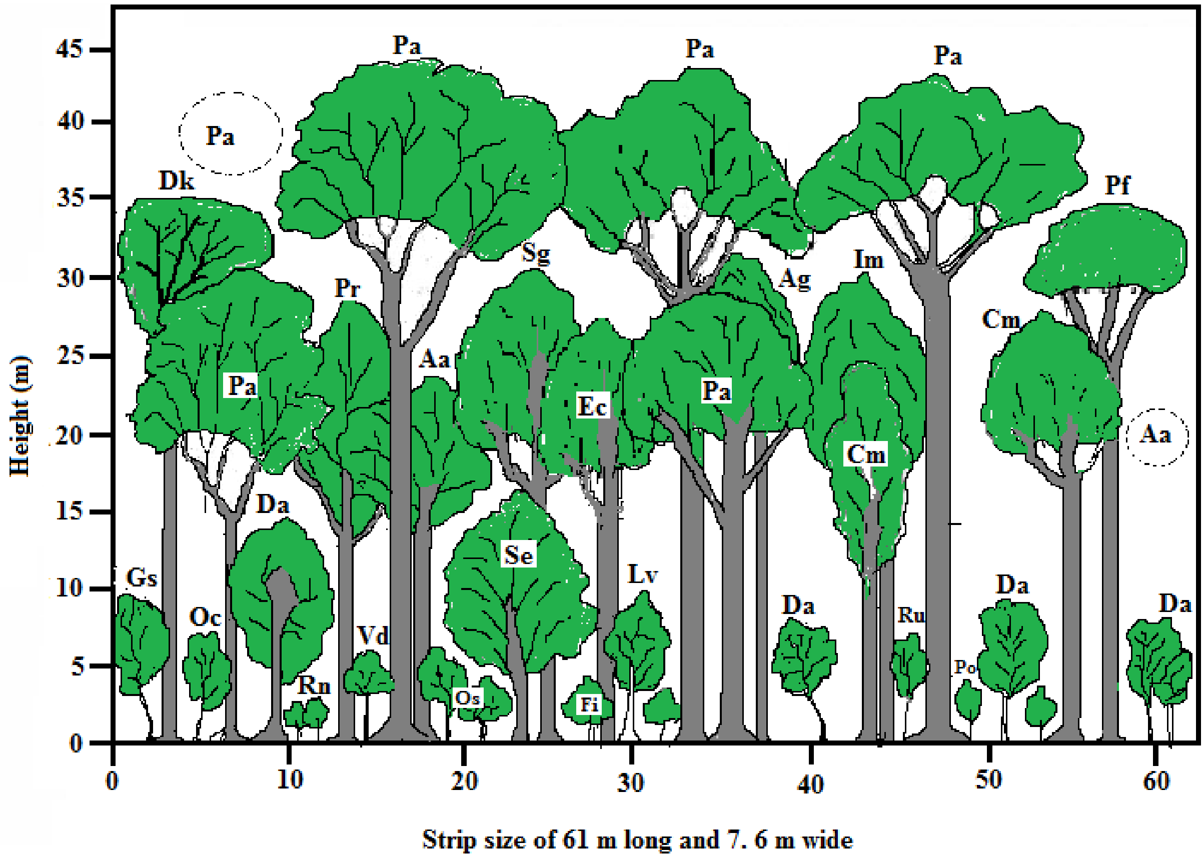


Figure 35. Profile diagram of a *Pouteria adolfi-friederici* stand (61 m x 7.6 m) in the Sele-Nono forest at 2190 m a.s.l. Aa = Allophylus abyssinicus; Ag = *Albizia gummifera;* Cm = *Croton macrostachyus;* Da = *Dracaena afromontana;* Dk = *Deinbollia kilimandischarica;* Ec = *Ekebergia capensis;* Fi = *Flacourtia indica;* Gs = *Galiniera saxifraga;* Lv = *Lepidotrichilia volkensii;* Im = *Ilex mitis;* Oc = *Olea capensis;* Os = *Oxyanthus speciosus;* Pa = *Pouteria adolfi-friederici;* Pf = *Polyscias fulva;* Pr = *Prunus africana;* Po = *Psychotria orophila;* Rn = *Rytignia neglecta;* Ru = *Rothmannia urcelliformis;* Se = *Sapium ellipticum;* Sg = *Syzygium guineense;* Tn = *Teclea nobilis;* Vd = *Vepris dainellii;* Interrupted lines=canopy extension from outside the strip.

The profile diagram of the Sele-Nono forest at 1310 m a. s. l. is shown below in Figure 36. The upper canopy layer is occupied by the discontinuous and scattered tree species of *Trilepisium madagascariense*. Major trees that form the middle storey are *Albizia grandibractiata, Albizia schimperiana, Anthocleista schweinfurthii, Diospyros abyssinica, Mimosopes kummel, Morus mesozygia, Trilepisium madagascariense* and so on. The lower canopy occupied by trees such as *Ficus sycomorus, Pouteria alnifolia, Phoenix reclinata, Strychnos mitis, Whitfieldia elongata*. The shrub and saplings dominating the understory includes *Clausena anisata, Argomuellera macrophylla, Maytenus gracilipes and Dracaena* *fragrans*. The forest floor is mainly covered by herbs such as *Costus afer*, *Costus lucanusianus*, etc. This structure is more revealed in plant community type 7 of Sele-Nono forest.

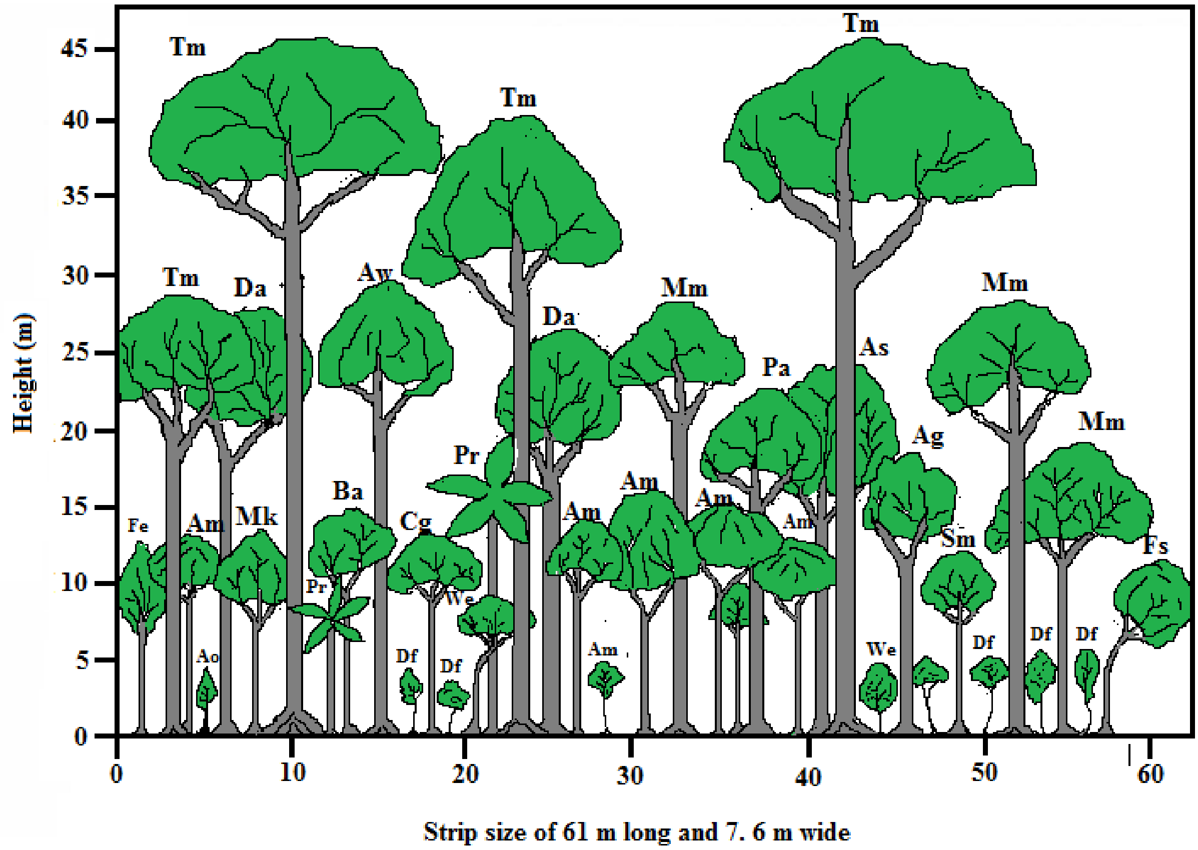


Figure 36. Profile diagram of a *Trilepisium madagascariense* stand (61 m x 7.6 m) in the Sele-Nono forest at 1310 m a.s.l., Ao= *Acalypha ornate;* Ag= *Albizia grandibractiata;* Am= *Argomuellera macrophylla;* As= *Alblzia schimperiana;* Aw= *Anthocleista schweinfurthii;* Ba= *Baphia abyssinica;* Da= *Diospyros abyssinica;* Df= *Dracaena fragrans;* Th= *Turraea holstii;* Mk= *Mimosopes kummel;* Cp= *Celtis philippensis;* Cg= *Celtis gomphophylla;* Fe= *Ficus exasperate;* Mm= *Morus mesozygia;* Fs= *Ficus sycomorus;* Pa= *Pouteria alnifolia;* Pr= *Phoenix reclinata;* Sm= *Strychnos mitis;* Tm= *Trilepisium madagascariense;* We= *Whitfieldia elongata.*

The Profile diagram at stand of 1705 m asl shows the dominancy of Arabica coffee (*Coffea arabica*) in the lower story and *Trichilia dregeana* in the middle storey (Figure 37). This stand looks intact from the air, but it is most affected stand where it is poorly represented by fewer specie as compared to the other stands studied in this paper. Interview with local elders also shows that thinning & over-logging were common practices for better coffee seed/fruit production. This profile diagram is common in community type 6 of the studied forest.

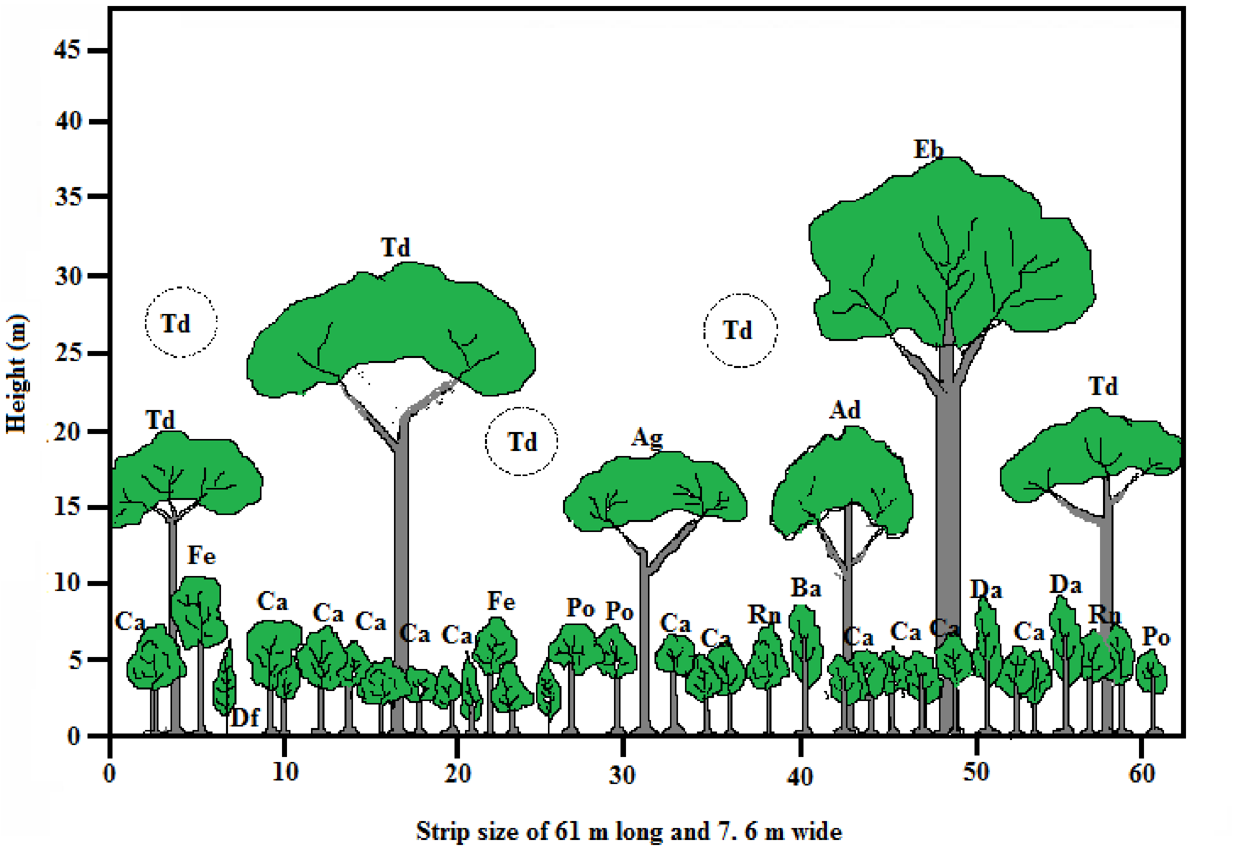


Figure 37. Profile diagram of a *Trichilia dregeana* stand (61 m x 7.6 m) in the Sele-Nono forest at 1705 m a.s.l., Ad = *Apodytes dimidiata*; Ag = *Albizia gummifera*; Ba = *Brucea antidysenterica*; Ca = *Coffea arabica*; Da = *Diospyros abyssinica*; Df = *Dracaena fragrans*; Eb = *Elaeodendron buchananii*; Fe = *Ficus exasperata*; *Psychotria orophila*; Rn = *Rytignia neglecta*; Td= *Trichilia dregeana.*

4.3. Regeneration status of Sele-Nono forest

Field assessment on the regeneration status of woody plants in Sele-Nono forest revealed that 55 out of the total 176 woody species (31.2%) were not represented by seedling stage (SE). Examples are *Antiaris toxicaria, Baphia abyssinica, Cordia africana, Cassipourea malosana, Ekebergia capensis, Euphorbia ampliphylla, Ficus ovata, Ficus thonningii, Hallea rubrostipulata, Ritchiea albersii, Schefflera abyssinica, Schefflera volkensii*. On the other hand, 35 species (19.8%) were not represented by their sapling stages (SA) in the Sele-Nono forest. These species include *Celtis toka*, *Ficus vasta*, *Ficus sycomorus*, *Oncoba* *spinosa*. Based on the comparative density of SE & SA with respect to themselves and their corresponding mature plant, the following eight representative patterns of regeneration structure were noted for the woody species in Sele-Nono forest.

The first pattern demonstrates the absence of SE & SA; and only represented by matured plants. This pattern was exemplified by *Cordia africana* as in Figure 38A. The second pattern exhibited by species such as *Mimusops kummel* that represents the presence of large densities of individuals in all the SE, SA and matured plant stage (Figure 38B). The third pattern was revealed by species such as *Pouteria adolfi-friederici* representing the absence of saplings, and the existence of fewer densities of seedlings as compared to their corresponding matured plants (Figure 38C). The fourth pattern was illustrated by *Deinbollia kilimandscharica* and represents the absence of seedlings and presence of fewer densities of saplings as compared to their corresponding matured plants (Figure 38D). The fifth pattern represents the absence of seedlings; and the occurrence of large density of saplings as compared to the corresponding matured plants (Figure 38E). This pattern was represented by *Gouania longispicta* in Sele-Nono Forest. The six pattern was represented by *Olea welwitschii* (Figure 38F) and illustrates the occurrence of fewer saplings next to seedlings as compared to their matured plants. The seventh pattern was displayed by *Vepris dainellii* showing larger density of seedlings followed by saplings and matured individuals (Figure 38G). The eighth pattern was represented by *Dracaena afromontana* that represents larger density of matured individuals followed by saplings and seedlings (Figure 38H). Field observation revealed that it was common to see species such as *Ficus thonningii* and *Schefflera abyssinica* growing on other plants.

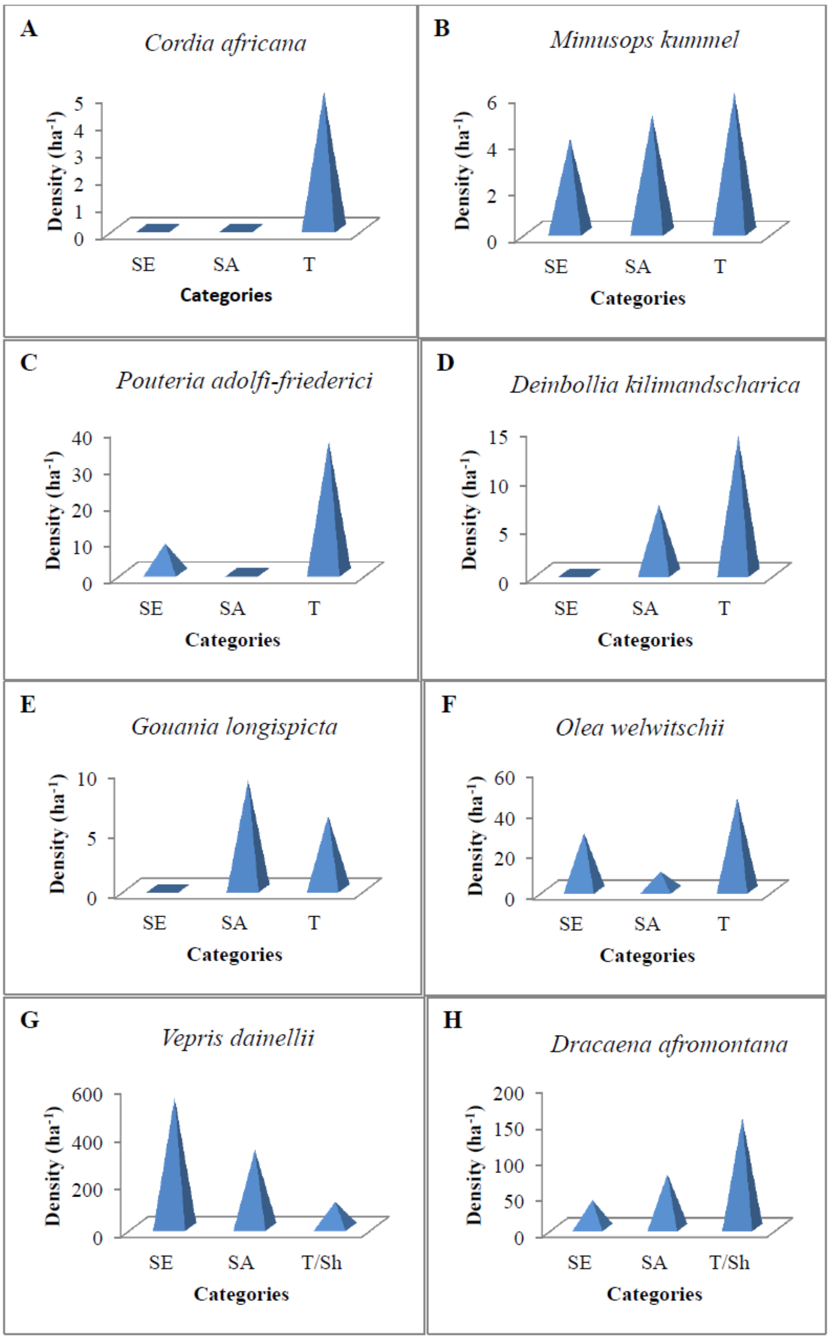


Figure 38. Pattern of regeneration status of woody plants as exemplified by some selected species in Sele-Nono forest

The total regeneration density of Sele-Nono forest was 5894.72 ha^{-1} with a density of 3072.31 seedlings ha^{-1} and 2822.40 saplings ha^{-1}. Based on the analysis of the total regeneration density of the studied woody plants, three priority classes were developed for this study (Figure 39). These are priority class 1 that includes species of no regeneration density (i.e., species of no seedlings and saplings); priority class 2 includes species of poor regeneration (i.e., total density of regeneration ranges between 1-50 ha^{-1}); and priority class 3 includes species with good regeneration status (i.e., when the total density of the regeneration of each woody species exceeds 50 individuals per hectare) (Figure 39). A detail lists of the species in each priority classes are appended on appendix 24.

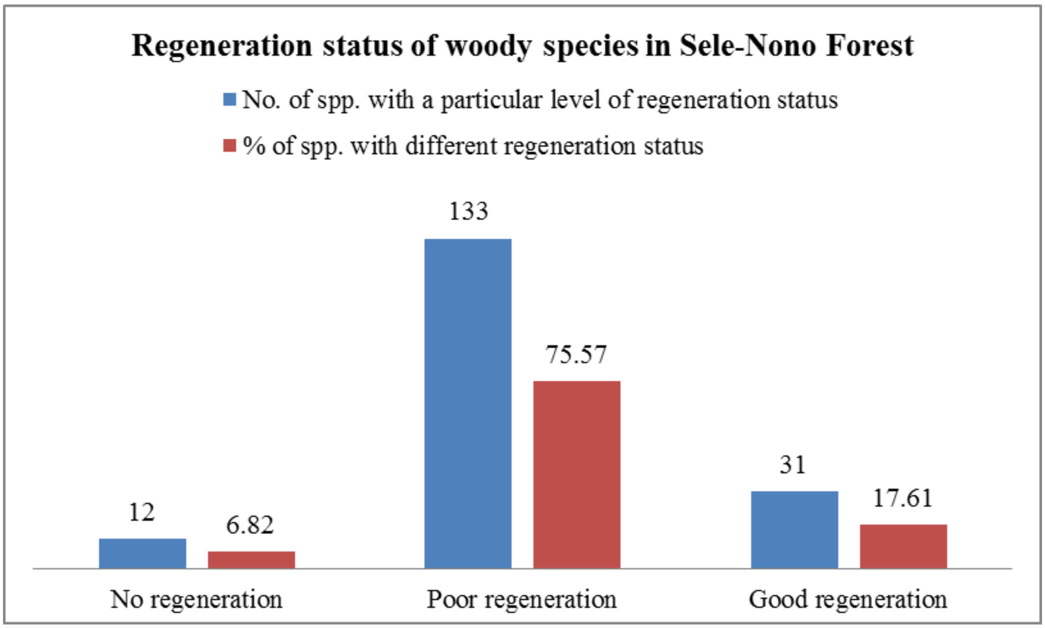


Figure 39. Regeneration status of woody plants in Sele-Nono forest

4.4. Validation of existing allometric equation for Sele-Nono forest

4.4.1. Model validation of trees

Regression graph showed that the pantropical Chave *et al.* (2005) and Chave *et al.* (2014) general allometric equation (referred as Chave 1 and Chave 2 respectively on figure 40) were better estimator of tree biomass in Sele-Nono forest. The pantropic Brown (1997) and the Ethiopian WBISPP (2000) general allometric equation notoriously overestimated the actual biomass of our sample trees; whereas allometric model developed by Djomo *et al.* (2016) extremely under predicted the observed AGB of trees in the study area (Figure 40).

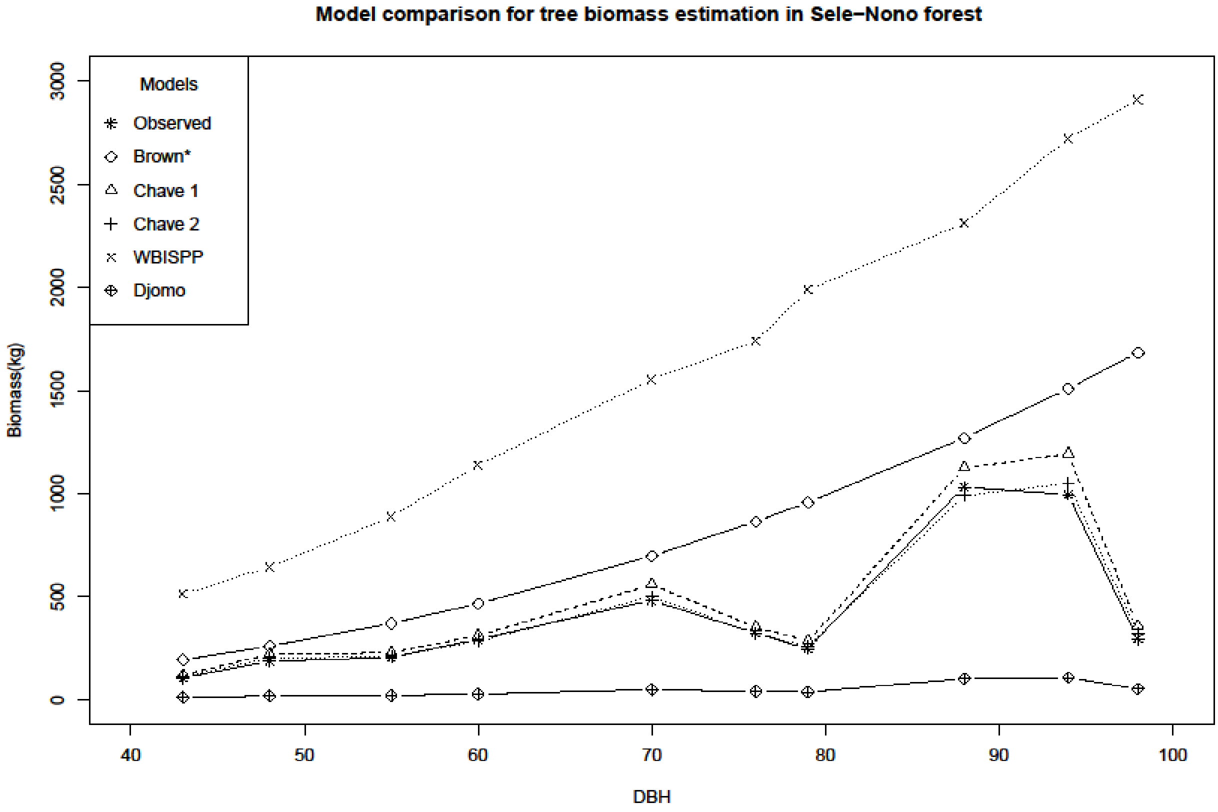


Figure 40. Regression graph for comparing possible models for tree biomass estimation in Sele-Nono forest (Note Brown* line is drawn by dividing its predicted values by 100 to keep it within the limit of the box) (n = 10)

Moreover, the cross validation statistical tests shown below clearly indicates that Chave *et al.* (2014) is the best biomass estimator of trees of Sele-Nono forest with mean relative error of 3.1 % (Table 17), which is in the most acceptable range since bias is less than 10%. On the contrary other models except Chave *et al.* (2005) are inappropriate tool for predicting the AGB of trees as they resulted over 80% bias (calculated as percentage of the mean relative error or average deviation by models).

Table 17. Cross-validation statistics of different biomass models fitted for trees in Sele-Nono forest (n=10). Note that Chave 1 is referring to Chave *et al.*, 2005 and Chave 2 is referring to Chave *et al.*, 2014

Models	ME	RE	MRE	MRE (%)	RMSE	PRESS	Rank
Brown	7849.617	220.48	22.04	2204	9197.92	846018687.5	5
WBISPP	1224.29	37.97	3.797	379.7	1385.68	19201253.16	4

Chave 1	58.56979	1.396	0.139	13.9	78.549	61699.67	2
Chave 2	8.36635	0.312	0.031	3.1	25.16	6333.96	1
Djomo	-369.683	-8.82	-0.882	-88.2	465.28	2164859.577	3

As it can be noted from the above table (Table 17) the error and PRESS for each models were varying across the types of equations. However, prediction bias was found very small for Chave *et al.* (2014), even smaller than the Chave *et al.* (2005).

Paired t-test also indicate that the mean biomass estimation by Chave *et al.* (2014) does not significantly differ from the mean observed biomass of trees of Sele-Nono forest (t=-1.057, df=9, P>0.05); whereas it varies significantly from the biomass predicted by the other models (Table 18).

Table 18. Paired t-test for the mean of the total above-ground biomass (Kg) (n=10).

S/N	Observed & Predicted	N	Observed mean ± SE (Predicted mean ±SE)	t-test	df	p-value
1	Observed & Djomo	10	416.61±104.31 (46.92±10.48)	3.925	9	.003*
2	Observed & Brown	10	416.61±104.31 (8266.22±1662.71)	-4.912	9	.001*
3	Observed & Chave 1	10	416.61±104.31 (475.18±119.55)	-3.357	9	.008*
4	Observed & Chave 2	10	416.61±104.31 (424.97±104.27)	-1.057	9	.318
5	Observed & WBISPP	10	416.61±104.31 (1640.90±267.877)	-5.659	9	.000*

*sig at P<0.05

From all the triangulating analysis of t-test, regression graph and cross validation statistics it can be concluded that Chave *et al.* (2014) is the best fitted model, with lower error of prediction, for estimating the AGB of trees in Sele-Nono forest.

4.4.2. Model validation of Palms

Regression graph for the proposed models of Palm allometric equation indicate that the Brown *et al.* (2000) model is more accurate for Palm biomass estimation of Sele-Nono forest than the model developed by Hughes (1997) and Winrock International (Figure 41).

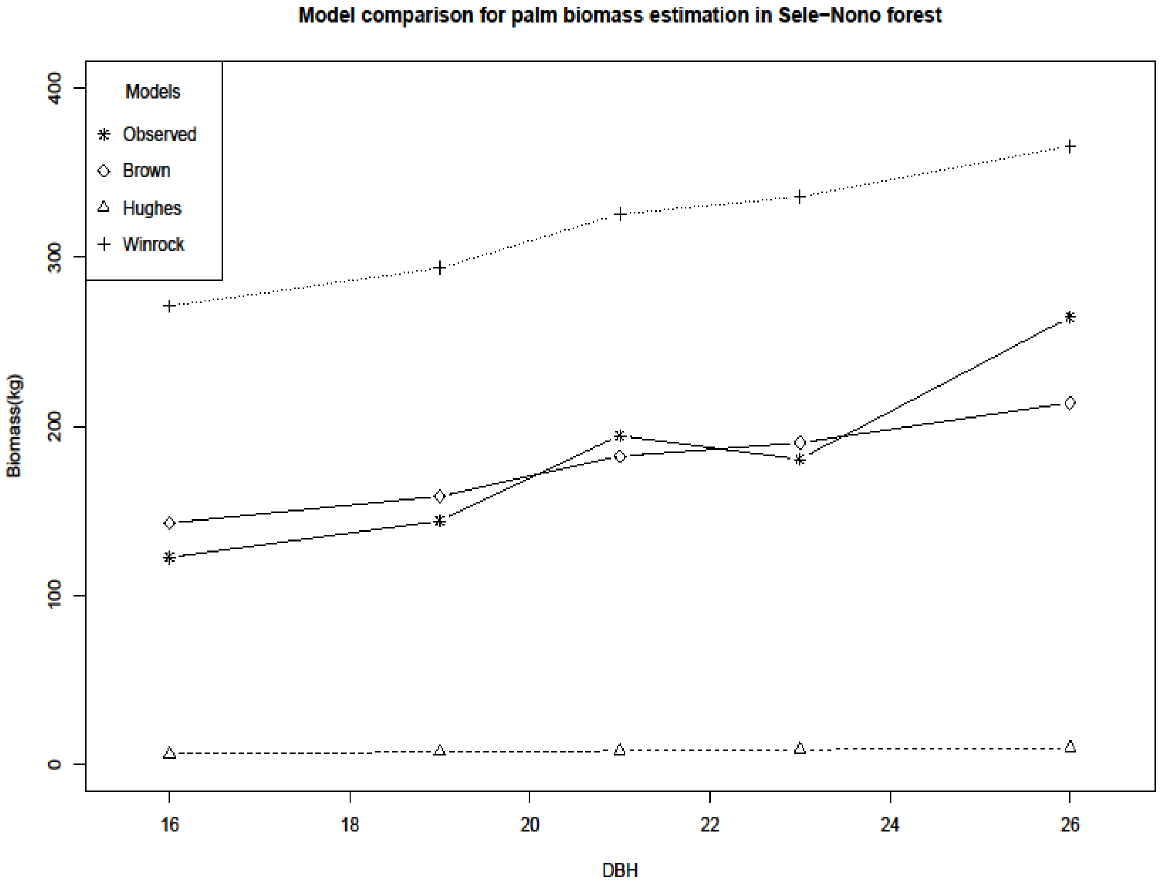


Figure 41. Regression graph showing model comparison for biomass estimation of Palms in Sele-Nono forest **(n = 5)**

The cross validation statistics also assured that the Brown model estimates the AGB of Palms with minimum error input (MRE = 1.35%) than the other suggested models in this study area. Table 19 shows the values of ME, RE, MRE, MRE (%), RMSE, and PRESS.

Table 19. Cross validation statistic for Palms AGB estimation (n=5)

Models	**ME**	**RE**	**MRE**	**MRE (%)**	**RMSE**	**PRESS**	**Rank**
Hughes	-173.22	-4.77	-0.9549	-95.493	179.683	161431.4	3
Brown	-3.6305	0.067	0.01350	1.35	26.2138	3435.829	1

Winrock	137.228	4.173	0.83470	83.4703	138.650	96119.51	2

Paired t-test (Table 20) also indicated that the mean observed biomass does not significantly vary from the predicted biomass of Palms of Sele-Nono forest (t=0.28, df =4, P>0.05) when estimated by Brown *et al.* (2002) than the predicted biomass by other models.

Table 20. Results of paired sample t-test for Palms (n = 5)

S/N	Observed & Predicted	N	Observed mean ± SE (Predicted mean ±SE)	t-test	df	p-value
1	Observed & Brown	5	181.15±24.46 (177.52±12.40)	0.280	4	.794
2	Observed & Hughes	5	181.15±24.46 (7.92±0.63)	7.255	4	.002*
3	Observed & Winrock	5	181.15±24.46 (318.38±16.50)	-13.85	4	.000*

*sig at P<0.05

From both graphical and statistical examination of the analysis, it can be concluded that Brown *et al.* (2002) is the best fitted model for above ground biomass estimation of Palms in Sele-Nono forest.

4.4.3. Model validation of Lianas

Regression graph show that the scatter plot of Schnitzer *et al.* (2006) model is best aliened to the scatter plot for the observed biomass of liana ramet in the study area as compare to Putz (1984), Gerwing and Farias (2000), and Gehring *et al.* (2006) models (Figure 42).

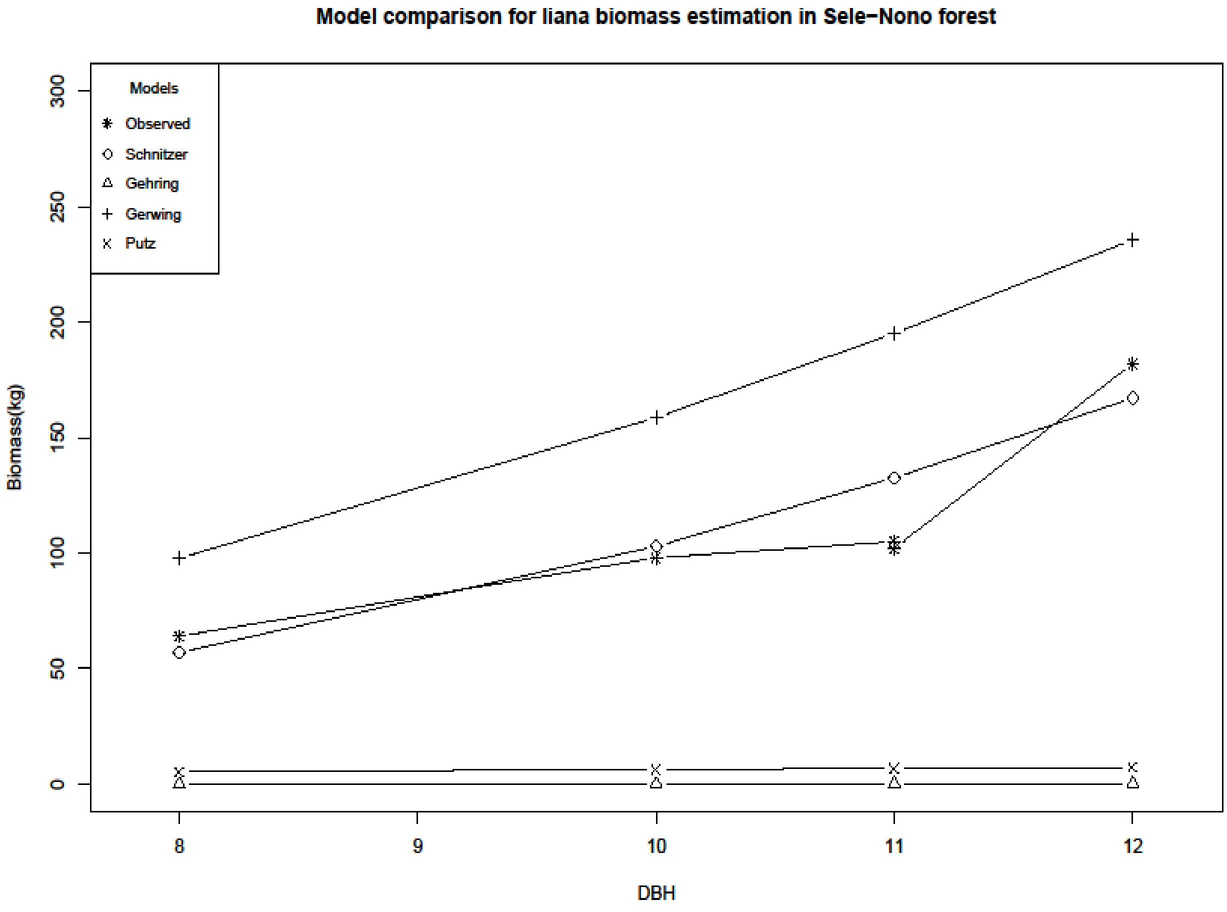


Figure 42. Regression graph showing model comparison for biomass estimation of lianas in Sele-Nono forest (n = 5)

Moreover, Schnitzer *et al.* (2006) were considered to have relatively low bias (Table 21) with mean relative error less than 10% (MRE = 8.39%) for AGB estimation of larger lianas (DBH>5cm) in Sele-Nono forest (values of ME, RE, MRE, RMSE, and PRESS are presented in Table 30).

Table 21. Cross validation statistic for Lianas AGB estimation in Sele-Nono forest (n=5)

Model	**ME**	**RE**	**MRE**	**MRE (%)**	**RMSE**	**PRESS**	**Rank**
Schnitzer	8.20845	0.419567	0.0839	8.39	19.9695	1993.91	1
Gehring	-110.02	-4.9920	-0.99840	-99.8404	116.659	68047.54	4
Gerwing	66.2356	3.211226	0.642245	64.22453	69.9589	24471.3	2
Putz	-103.68	-4.68071	-0.93614	-93.6143	110.514	61067.75	3

Paired t-test (Table 22) also indicates that the predicted biomass by Schnitzer does not significantly vary from the mean actual biomass of lianas in Sele-Nono forest (t=-0.902, df=4, P>0.05); whereas the other predicted biomass varies considerably from the observed biomass of the lianas.

Table 22. Results of paired sample t-test for Lianas in Sele-Nono forest (n=5)

S/N	Observed & Predicted	N	Observed mean ± SE (Predicted mean ±SE)	t-test	df	p-value
1	Observed & Schnitzer	5	110.20±19.40 (118.41±18.43)	-0.902	4	.418
2	Observed & Gehring	5	110.20±19.40 (0.17±0.024)	5.675	4	.005*
3	Observed & Gerwing	5	110.20±19.40 (176.44±23.14)	-5.883	4	.004*
4	Observed & Putz	5	110.20±19.40 (6.51±0.34)	5.422	4	.006*

*sig at P<0.05

From both the graphical and statistical analysis of existed liana models, it can be revealed that the Schnitzer *et al.* (2006) model is the best fitted model for biomass estimation of lianas in Sele-Nono forest.

4.4.4. Model validation of highland bamboo (*Arundinaria alpina*)

Cross validation statistical analysis (Table 23) indicate that the predicted biomass was a bit over estimated from the observed biomass with tolerable bias (MRE= 10.05%)

Table 23. Table Cross validation statistic for *Arundinaria alpina* bamboo AGB estimation (n=5)

Model	**ME**	**RE**	**MRE**	**MRE (%)**	**RMSE**	**PRESS**
Yigardu	1.361	0.502	0.1005	10.05	1.7416	15.1662

However, statistical t-test (Table 24) on the mean difference between the observed biomass of highland bamboo in Sele-Nono forest and its predicted biomass using Yigardu Mulat & Maseresha Fetene (2013) found not to differ significantly (t=-2.50, df=4, P>0.05). This indicate that the predictive model developed by Yigardu Mulat & Maseresha Fetene (2013) is sufficiently accurate (Vieilledent *et al.*, 2010) to estimate the highland bamboo biomass in Sele-Nono forest.

Table 24. Results of paired sample t-test for Bamboo biomass in Sele-Nono forest (n=5)

S/N	Observed & Predicted	N	Observed mean ± SE (Predicted mean ±SE)	t-test	df	p-value
1	Observed & Yigardu		9.6180±2.26525 (10.9798±2.68583)	-2.50	4	.066

*sig at $P<0.05$

4.4.5. Model validation of fern trees (*Cyathea manniana*)

The result of regression line (Table 43) show that the biomass estimated by Stanlay *et al.* (2003) model is best aliened to the scatter plot for the observed biomass of fern trees (*Cyathea manniana*) in the study area as compared to Brown *et al.* (2000) and Beets *et al.* (2012).

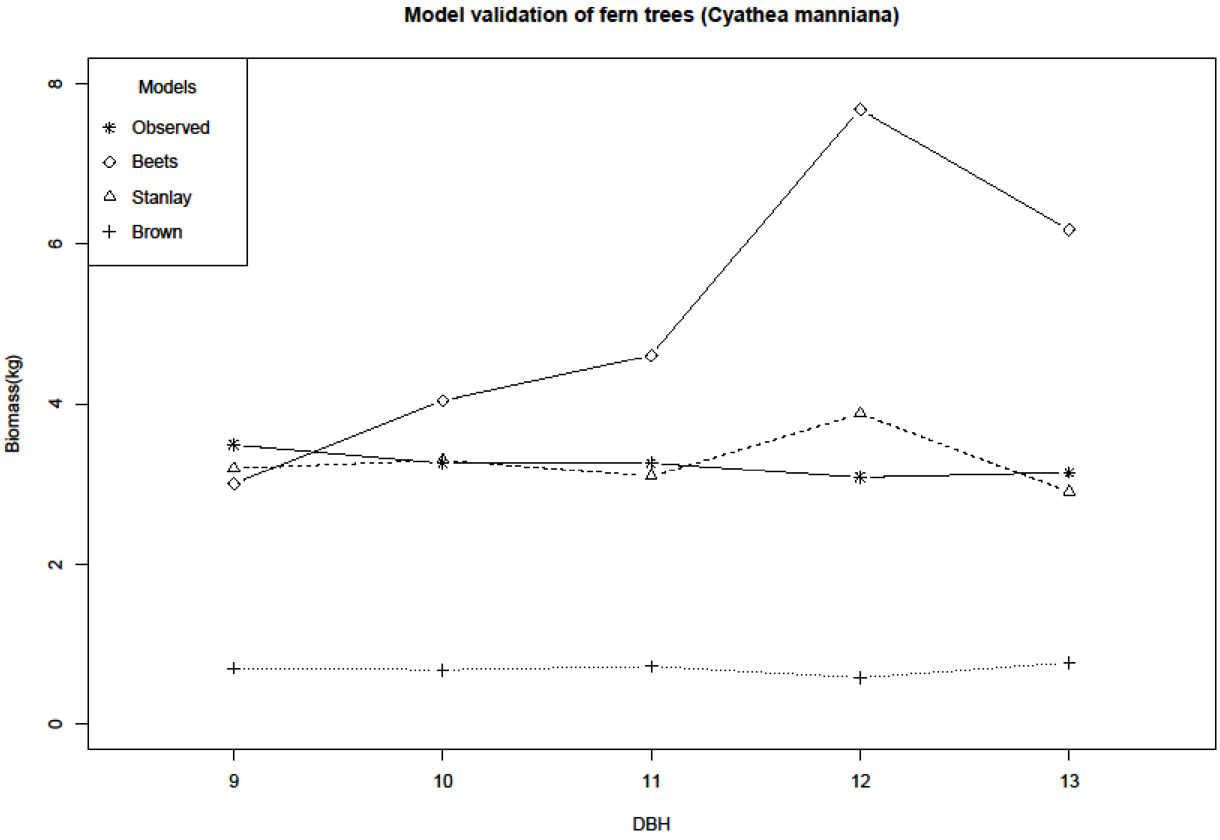


Figure 43. Regression graph showing model comparison for biomass estimation of fern trees in Sele-Nono forest (n = 5)

Cross validation test also shows that the model developed by Stanlay *et al.* (2003) properly estimated the actual biomass of our fern trees with very little bias (MRE = ~1%). On the contrary, the model developed by Beets *et al.* (2000) and Brown *et al.* (2000) respectively overestimated and underestimated the actual biomass of fern trees in the study area to unacceptable level (Bias greater than 50%), which is unjustifiable (Table 25).

Table 25. Cross validation statistic for AGB estimation of fern trees in Sele-Nono forest (n=5)

Model	**ME**	**RE**	**MRE**	**MRE (%)**	**RMSE**	**PRESS**	**Rank**
Beets	1.855	2.974	0.5948	59.48	2.572	33.1	2
Stanlay	0.026	0.058	0.0116	1.16	0.402	0.811	1
Brown	-2.558	-3.94	-0.788	-78.80	2.562	32.824	3

The t-test (Table 26) also shows that the deviation of the predicted biomass by Stanlay does not significantly vary from the mean observed biomass of fern trees in Sele-Nono forest (t=-0.132, df=4, P>0.05); whereas the prediction by any of the other models significantly vary from the mean AGB of tree ferns in Sele-Nono forest and the statistics are presented below in Table 35.

Table 26. Results of paired sample t-test for tree ferns (n=5)

S/N	Observed & Predicted	N	Observed mean ± SE (Predicted mean ±SE)	t-test	df	p-value
1	Observed & Beets	5	3.25±0.07 (5.10±.825)	-2.083	4	.006*
2	Observed & Stanlay	5	3.25±0.07 (3.27±0.16)	-0.132	4	.902
3	Observed & Brown	5	3.25±0.07 (0.69±0.03)	37.506	4	.000*

*sig at P<0.05

From the analysis of both graphical and statistical examination, it can be claimed that Stanlay *et al.* (2003) is the best fitted model for biomass estimation of fern trees in Sele-Nono forest.

4.5. Validation of tree height estimation methods

The Bland-Altman (BA) plot shows the relationship between estimated height of trees using different methods and the actual tree heights. The 45-degree diagonal line is a reference line that shows perfect equality between the estimated and actual heights. BA plot demonstrate that the predicted heights of sample trees (shown by blue scatter points) by Feldpausch2 model better alien to the actual (or reference) height of sample trees. On the other hand, the Brown and Niklas models underestimated the actual height of trees; whereas visual estimation overestimate it like that of Feldpausch1 model (Figure 44).

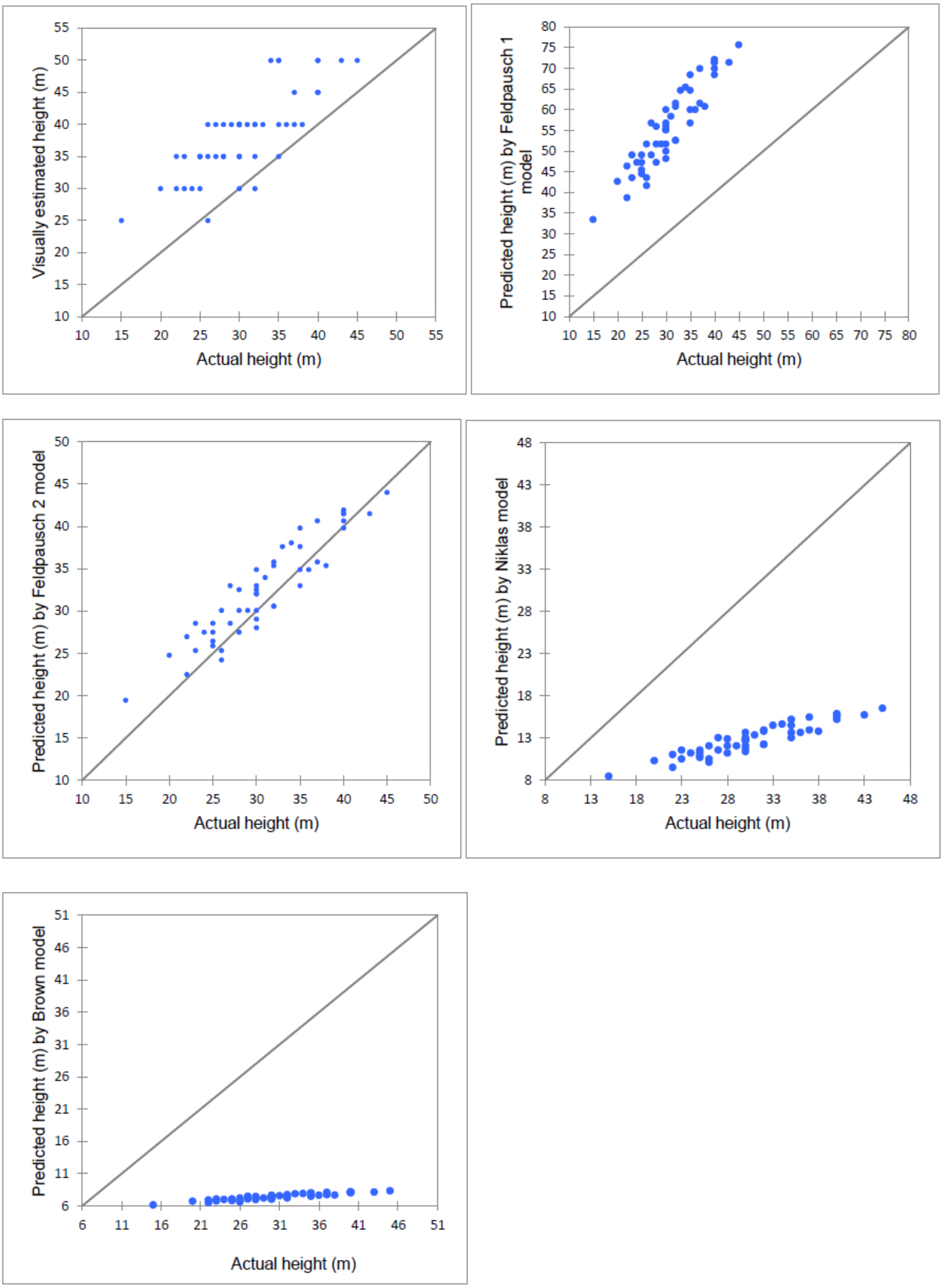


Figure 44. BA plot techniques for comparison of height estimation of trees in Sele-Nono forest (n = 50)

Moreover, cross validation statistics presented below (Table 27) reveals that the estimation of tree heights by Feldpausch2 model in Sele-Nono forest causes small error (Bias=6.54%), whereas the other estimation method were unreliable as they induced large error (Bias >10%) when compared to the reference values (or measured heights) (Appendix 12).

Table 27. Bias to the choice of the methods for tree height estimation in Sele-Nono forest (n=50)

Models	**Bias (%)**
Visual height estimation method	26.95
Feldpausch1 DBH-H allometry	83.12
Feldpausch2 DBH-H allometry	6.54
Brown *et al.* (1989) DBH-H allometry	-75.19
Niklas (1993) DBH-H allometry	-57.63

4.6. Biomass and carbon stock density of Sele-Nono Forest

4.6.1. Wood density of lying dead woods in Sele-Nono forest

This study came up with wood densities of the different forms of lying dead woods (Table 28) (Detail result is on Appendix 25).

Table 28. Wood density values for the three classes of lying dead woods in Sele-Nono forest (n = 90)

Lying dead wood density classes	Wood density result (g/cm^3)
Sound	0.56
Intermediate	0.38
Rotten	0.26

4.6.2. Biomass density of Sele-Nono forest

Result indicated that the mean total biomass (mean ± SD) of the forest was estimated at 259.82±122.59 t ha^{-1} (Appendix 26). This is the cumulative result of the mean above ground biomass (AGB), below ground biomass (BGB), litter biomass (LB), Herb biomass (HB) and lying dead wood biomass (LDWB) that were estimated at 189.20±91.62, 37.84±18.32, 8.50±3.76, 2.92±1.03, 21.36±13.52 t ha^{-1} respectively (Figure 45).

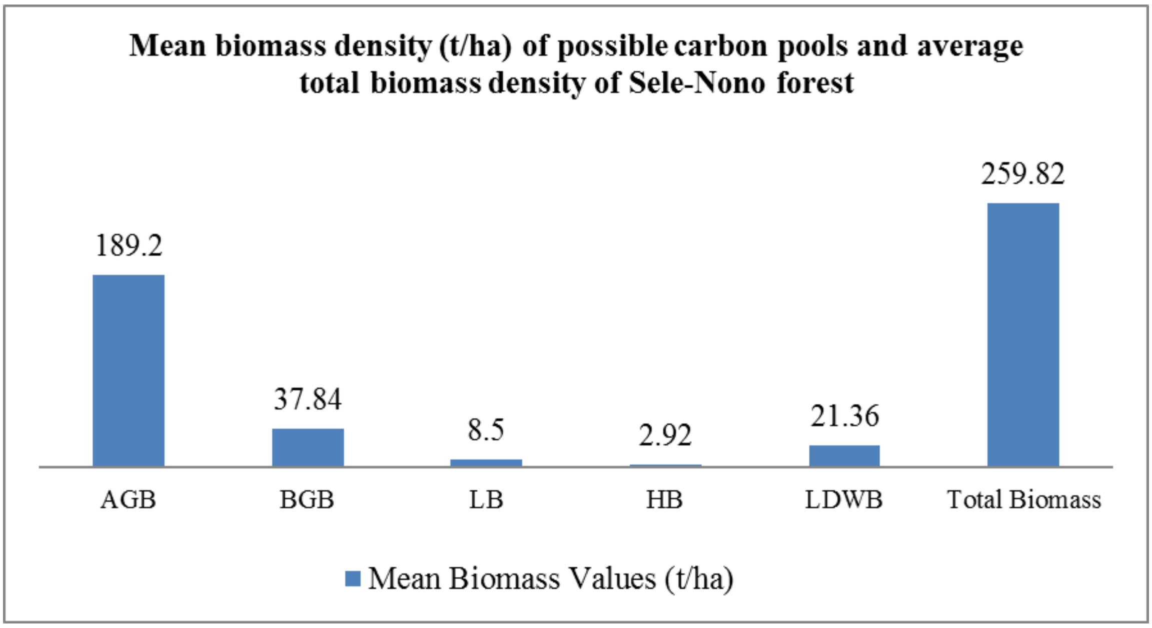


Figure 45. Mean biomass density of possible carbon pools and mean total biomass density of Sele-Nono forest

The total minimum and maximum AGB per plot was 30.6 and 382.73 t ha^{-1} respectively whereas the minimum and maximum BGB of the study site was 6.12 and 76.54 t ha^{-1} respectively (Appendix 26). The litter biomass density found in this study ranged from a minimum of 0.88 t ha^{-1} to a maximum of 16.28 t ha^{-1}. The herbaceous vegetation produced a minimum and maximum biomass density of 1.03 and 5.88 t ha^{-1} respectively. Moreover, the lying dead woods ranged from a null to a maximum of 45.03 t ha^{-1} (Appendix 26).

4.6.3. Comparison among the biomass components of Sele-Nono forest

Above ground biomass was found to be the largest biomass that contributes primarily (72.82%) to the total biomass density of the forest followed by below ground biomass (14.56%), lying dead woods (8.22%) and litters (3.27%). Herbaceous vegetation contributes little to the total biomass of the forest (1.12%) (Figure 46).

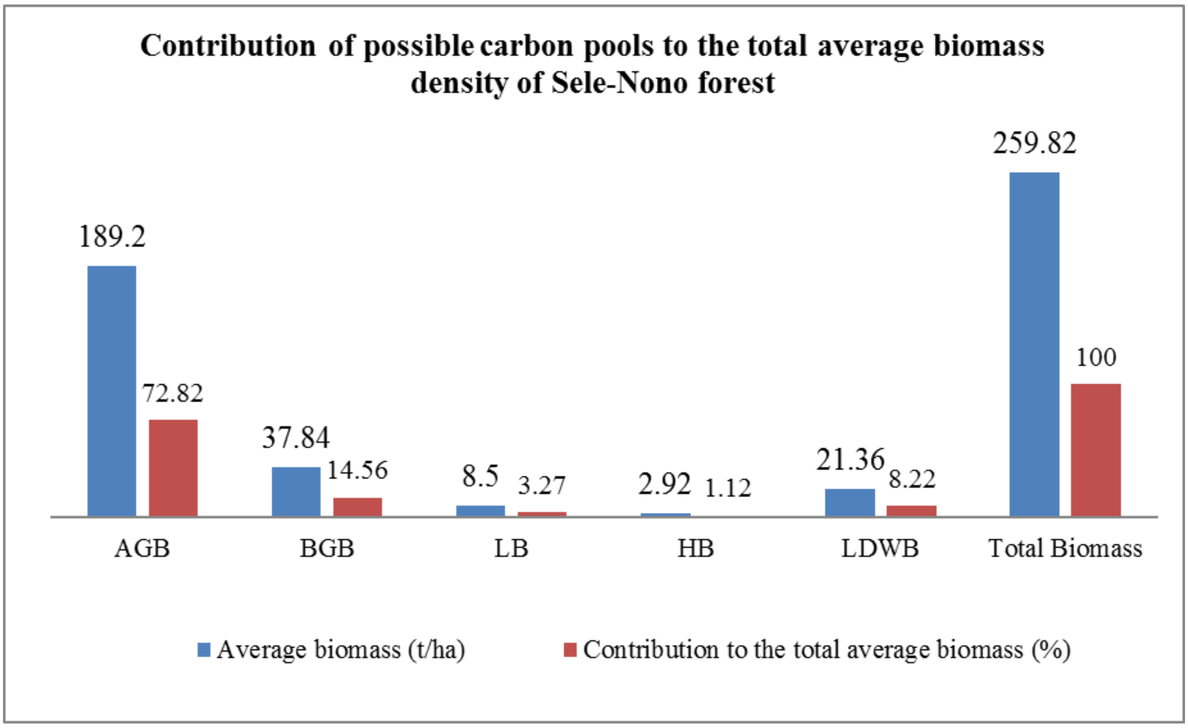


Figure 46. Contribution of possible carbon pools to the total average biomass density of the study forest

4.6.4. Carbon stock density in Sele-Nono forest

The aboveground biomass carbon stock density (AGC) of the study site was calculated by adding all values of AGC obtained in each plot. Result shows that the mean (mean ± SD) AGC of the study forest was 88.92 ± 43.06 t ha^{-1} (Table 29) with the minimum and maximum AGC per plot of 14.38 and 179.88 t ha^{-1} respectively (Appendix 26). Similarly, the mean (mean ± SD) BGC of the study forest was 17.78±8.61 t ha^{-1} (Table 29) with a maximum and minimum BGC of 35.98 t ha^{-1} and 2.88 t ha^{-1} (Appendix 26).

Result also showed that litters contain a minimum and maximum carbon stock (LC) of 0.41 t ha^{-1} and 7.65 t ha^{-1} respectively (Appendix 26) with a mean (mean ± SD) LC of 4.01 ± 1.76 t ha^{-1} (Table 29). The carbon stock in herbaceous vegetation (HC) was estimated from 0.48 t ha^{-1} to 2.76 t ha^{-1} (Appendix 26) yielding a mean (mean ± SD) HC of 1.37 ± 0.48 t ha^{-1} (Table 29). Result also indicates that the forest has stored carbon in its lying dead woods

(LDWC) to a range of 21.16 t ha^{-1}(Appendix 26); and with a mean value of 10.04 ± 6.35 t ha^{-1}(Table 29).

The outcome in this study also revealed that Sele-Nono forest harbours carbon in its soil with a range of 36.38 t ha^{-1} to 356.49 t ha^{-1}(Appendix 27); and the mean amount of carbon stored in the soil (SOC) was 162.69 ± 78.73 t ha^{-1}(Table 29).

The total carbon stock density (TC) of the study forest was performed by summing all the carbon stock densities of each pool (AGC, BGC, LC, HC, LDWC and SOC) for all plot samples of the study area. Accordingly, the total carbon stock density of the study forest ranged from 90.99 to 484.88 t ha^{-1} (Appendix 26) with a mean carbon stock density of 284.81 ± 107.81 t ha^{-1}.

Table 29. Mean carbon stock of each carbon pools in Sele-Nono Forest

Possible carbon pools in Sele-Nono forest	Reference of carbon stock in each C-pools	Mean carbon stock density (t ha^{-1})
Above ground biomass (AGB)	AGC	88.92±43.06
Below ground biomass (BGB)	BGC	17.78±8.61
Litter biomass (LB)	LC	4.01±1.76
Herb biomass (HB)	HC	1.37±0.48
Lying dead wood biomass (LDWB)	LDWC	10.04±6.35
Soil	SOC	162.69±78.73
Total Mean carbon stock		**284.81±107.81**

4.6.5. Comparison of carbon stock density in the different carbon pools of Sele-Nono forest

The contribution of each carbon pools of Sele-Nono forest to the total carbon stocks density varied markedly among themselves. Figure 47 presents the percentage contribution of each carbon pools to the total average carbon stock density of Sele-Nono forest. Accordingly, 31.22% of the carbon stock was contained in AGB while 6.24% was contained in BGB. The litter, herb, lying dead wood and soil accounted for 1.41%, 0.48%, 3.53%, and 57.12% of the total carbon stock of the forest respectively (Figure 47).

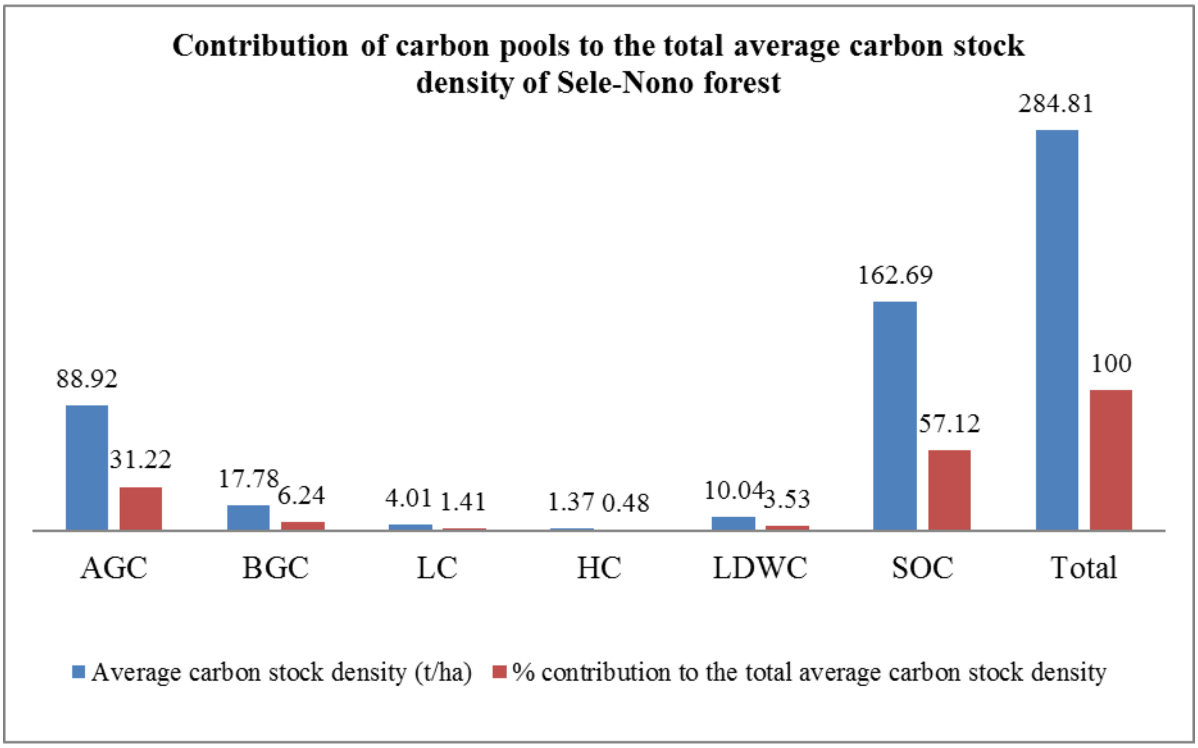


Figure 47. Contribution of carbon pools to the total average carbon stock of Sele-Nono Forest

4.6.6. Overall carbon stock of Sele-Nono forest and its economic valuation for sustainable forest management and climate change mitigation

The total carbon stock of Sele-Nono forest in each strata is dipicted as follow (Table 30).

Table 30. Total current carbon stock of Sele-Nono forest in each stratum (S refers to strata number, ∑denotes summation)

Strata code	Number of plots (n_{plot})	Sum of carbon stock ($\sum C_{plot}$) (t/ha)	Area of stratum (ha)	Carbon stock of each stratum ($C_{stratum}$)	
				ton	Mega ton (Mt)
S-1	11	1801.78894	18373.08	3009492.031	3.01
S-2	22	6969.49664	36746.17	11641014.02	11.64
S-3	22	6761.13918	36746.17	11292998.62	11.29
S-4	20	7552.67612	33405.61	12615087.65	12.62
S-5	14	2420.74466	23383.93	4043323.12	4.03
S-6	1	127.19008	1670.28	212443.0468	0.21
Total	**90**	**25633.03562**	**150325.27**	**42814366.67**	**42.81**

The overall carbon stock estimate of the forest ($C_{whole\ forest}$) was obtained by summing all the carbon stocks in each stratum as $C_{whole\ forest} = \sum C_{stratum}$. So the carbon stock of Sele-Nono Forest was found 42, 814, 366.67 tons (or 42.81 Mt) of carbon; and the estimated atmospheric CO_2e reduced due to the present stand of the forest is $CO_2e = carbon\ stock\ of\ the\ forest \times 3.67$, which equals to 157, 128, 725.68 tCO_2e (or 157.12 Mt of CO_2). If this amount of gas is sold for individuals, communities, companies and/ or governments by an average price of 11 dollars per tCO_2 e (Pelletier *et al.*, 2010; Hamrick, 2017) then the expected financial reward for the local people as benefit of CO_2 mitigation will be more than one billion dollars, and is calculated as follow.

$$Economic\ benefit\ of\ the\ study\ forest = \frac{157,128,725.68\ tone\ of\ CO_2e\ X\ 11\ USD}{1\ tone\ of\ CO_2e}$$

$$= 1.72\ X\ 10^9 = 1.72\ \text{Billion USD}$$

Thus, this monetary benefit of CO_2 mitigation from concerned organizations like UN-REDD+ would help further for sustainable conservation of the study forest by allotting the payment to a wide variety of conservation and sustainable forest management projects.

4.7. Formulation of species specific allometric models in Sele-Nono forest

4.7.1. Model development of trees

Using regression analyses for the data collected for this purpose (Appendix 28) the following eleven candidate models were developed to estimate the AGB of *Albizia gummifera* (Table 31), *Mimusops kummel* (Table 32), *Syzygium guineense* subsp. a*fromontanum* (Table 33) using the various combinations of the input variables. Based on RSE, Adj.R^2 and AIC statistics the 11th model for *Albizia gummifera* and *Mimusops kummel* (Table 31 and 32) and the 7th model (Table 33) for *Syzygium guineense* were determined as the best performing models for predicting their AGB in Sele-Nono forest.

However, since growth by organisms is typically "multiplicative by nature" (Kerkhoff and Enquist, 2009; Packard, 2014), the best performing models derived as 'ln expression' in Table 31, 32 and 33 were back transformed and reported on their original scales as shown beneath each tables.

Table 31. Allometric model developed for biomass estimation of *Albizia gummifera* in Sele-Nono forest (n = 30)

Model	β_o	β_1	β_2	β_3	**df**	**RSE**	**Adj.R^2**	**AIC**	**Rank**
1) $\ln(AGB)= \beta o + \beta_1 \ln(DBH)$	-3.8205	1.9073	-	-	28	0.2536	0.8353	6.7370	8
2) $\ln(AGB)= \beta o + \beta_1 \ln(H)$	-8.8976	4.2156	-	-	28	0.2704	0.8128	10.5868	9
3) $\ln(AGB)= \beta o + \beta_1 \ln(\rho)$	4.8686	1.3865	-	-	28	0.6168	0.0256	60.0739	11
4) $\ln(AGB)= \beta o + \beta_1 \ln(H) + \beta_2 \ln(DBH)$	-6.0034	1.6511	1.2089	-	27	0.2475	0.8431	6.1997	7
5) $\ln(AGB)= \beta o + \beta_1 \ln(DBH) + \beta_2 \ln(\rho)$	-7.8943	4.1700	1.1364	-	27	0.2432	0.8485	5.1486	6
6) $\ln(AGB)= \beta o + \beta_1 \ln(H) + \beta_2 \ln(\rho)$	-2.8418	1.8917	1.2023	-	27	0.2191	0.8770	-1.1088	3
7) $\ln(AGB)= \beta o + \beta_1 \ln(DBH) + \beta_2 \ln(\rho) + \beta_3 \ln(H)$	1.2544	1.1740	1.5074	-	26	0.2126	0.8842	-2.0584	2
8) $\ln(AGB)= \beta o + \beta_1 \ln(DBH*H)$	-5.6144	1.3434	-	-	28	0.2434	0.8482	4.2924	5
9) $\ln(AGB)= \beta o + \beta_1 \ln(DBH* \rho)$	-2.0347	1.8048	-	-	28	0.2267	0.8683	0.0269	4
10) $\ln(AGB)= \beta o + \beta_1 \ln(H* \rho)$	-2.8135	2.9410	-	-	28	0.3499	0.6864	26.0682	10
11) $\ln(AGB)= \beta o + \beta_1 \ln(\rho*DBH*H)$	-4.44808	1.32066	-	-	28	0.2057	0.8917	-5.8216	1

$\ln(AGB)= \beta o + \beta 1\ln(\rho*DBH*H) =\ln (AGB) = -4.44808 + 1.32066*\ln (\rho*DBH*H)$

- ⇨ $AGB = \ln (-4.44808 + 1.32066*\ln (\rho*DBH*H))$
- ⇨ $AGB=\exp (-4.44808* (\rho*DBH*H)^{1.32066}$
- ⇨ $AGB = 0.0117 (\rho*DBH*H)^{1.32066}$ ……………………………………………..(Eq.1)

Table 32. Allometric model developed for biomass estimation of *Mimusops kummel* in Sele-Nono forest (n = 30)

Model	**β_o**	**β_1**	**β_2**	**β_3**	**df**	**RSE**	**Adj.R^2**	**AIC**	**Rank**
1) $\ln(AGB)= \beta o + \beta_1\ln(DBH)$	1.2861	1.4863	-	-	28	0.3033	0.8072	17.48365	6
2) $\ln(AGB)= \beta o + \beta_1\ln(H)$	3.2977	1.2121	-	-	28	0.3353	0.7643	23.50106	8
3) $\ln(AGB)= \beta o + \beta_1\ln(\rho)$	6.43908	-0.01796			28	0.7029	-0.0357	67.91467	11
4) $\ln(AGB)= \beta o + \beta_1\ln(H) + \beta_2\ln(DBH)$	1.8352	0.4710	0.9758	-	27	0.2913	0.8222	15.96586	4
5) $\ln(AGB)= \beta o + \beta_1\ln(DBH) + \beta_2\ln(\rho)$	1.7600	1.5082	1.1274	-	27	0.2989	0.8127	17.51999	7
6) $\ln(AGB)= \beta o + \beta_1\ln(H) +\beta_2\ln(\rho)$	3.27589	1.21209	-0.04466	-	27	0.3414	0.7556	25.49858	10
7) $\ln(AGB)= \beta o + \beta_1\ln(DBH) + \beta_2\ln(\rho) + \beta_3\ln(H)$	2.0854	1.0635	0.7807	0.4040	26	0.2921	0.8212	17.00084	5
8) $\ln(AGB)= \beta o + \beta_1\ln(DBH*H)$	2.19824	0.69989	-	-	28	0.2904	0.8232	14.88470	2
9) $\ln(AGB)= \beta o + \beta_1\ln(DBH* \rho)$	1.9529	1.5058	-	-	28	0.2947	0.818	15.75379	3
10) $\ln(AGB)= \beta o + \beta_1\ln(H* \rho)$	3.9367	1.1895	-	-	28	0.3459	0.7492	25.36517	9
11) $\ln(AGB)= \beta o + \beta_1\ln(\rho *DBH*H)$	2.52988	0.70164	-	-	28	0.2888	0.8252	14.53847	1

$\ln(AGB)= \beta o + \beta 1\ln (\rho *DBH*H) = \ln(AGB)= 2.52988 + 0.70164*\ln(\rho *DBH*H)$

⇨ $AGB = \exp (2.52988 + 0.70164*\ln (\rho *DBH*H)$
⇨ $AGB = \exp (2.52988* (\rho*DBH*H)^{0.70164}$
⇨ $AGB = 12.5519 (\rho*DBH*H)^{0.70164}$ ……………………………………………….(Eq. 2)

Table 33. Allometric model developed for biomass estimation of *Syzygium guineense* subsp. *afromontanum* in Sele-Nono forest (n = 30)

Model	β_o	β_1	β_2	β_3	**df**	**RSE**	**Adj.R^2**	**AIC**	**Rank**
1) $\ln(AGB)=\beta o+\beta_1\ln(DBH)$	-0.1871	2.0108	-	-	28	0.2971	0.771	16.23996	3
2) $\ln(AGB)=\beta o+\beta_1\ln(H)$	3.5860	1.4269	-	-	28	0.3981	0.5889	33.79715	10
3) $\ln(AGB)=\beta o+\beta_1\ln(\rho)$	7.6271	-0.1167	-	-	28	0.6316	-0.0351	61.50007	11
4) $\ln(AGB)=\beta o+\beta_1\ln(H)+\beta_2\ln(DBH)$	-0.173321	0.009944	1.999982	-	27	0.3025	0.7626	18.23906	6
5) $\ln(AGB)=\beta o+\beta_1\ln(DBH)+\beta_2\ln(\rho)$	-0.1045	2.1376	1.0009	-	27	0.276	0.8024	33.25213	9
6) $\ln(AGB)=\beta o+\beta_1\ln(H)+\beta_2\ln(\rho)$	3.8324	1.5144	0.8604	-	27	0.3885	0.6084	11.63957	2
7) $\ln(AGB)=\beta o+\beta_1\ln(DBH)+\beta_2\ln(\rho)+\beta_3\ln(H)$	-0.01717	2.07016	1.00601	0.06249	26	0.271	0.8095	13.59509	1
8) $\ln(AGB)=\beta o+\beta_1\ln(DBH*H)$	1.6330	0.8915	-	-	28	0.333	0.7123	23.09534	7
9) $\ln(AGB)=\beta o+\beta_1\ln(DBH*\rho)$	0.9975	2.0047	-	-	28	0.3059	0.7573	17.98886	4
10) $\ln(AGB)=\beta o+\beta_1\ln(H*\rho)$	4.2991	1.4761	-	-	28	0.3916	0.6021	32.81830	8
11) $\ln(AGB)=\beta o+\beta_1\ln(\rho*DBH*H)$	1.78060	0.95080	-	-	28	0.3063	0.7566	18.07323	5

$$\ln(AGB)=\beta o+\beta 1\ln(DBH)+\beta 2\ln(\rho)+\beta 3\ln(H)=\ln(AGB)=-0.01717+2.07016*\ln(DBH)+1.00601*\ln(\rho)+0.06249*\ln(H)$$

⇨ $AGB=\exp(-0.01717+2.07016*\ln(DBH)+1.00601*\ln(\rho)+0.06249*\ln(H))$

⇨ $AGB=\exp(-0.01717)*(DBH)^{2.07016}*(\rho)^{1.00601}*(H)^{0.06249}$

⇨ $AGB=0.98297*(DBH)^{2.07016}*(\rho)^{1.00601}*(H)^{0.06249}$ …………..…………… (Eq. 3)

4.7.2. Model validation

Visual comparison on the efficiency of the proposed models using scatter plots indicate that the newly formulated models are more precise for estimating the biomass of *Albizia gummifera* (Figure 48), *Mimusops kummel* (Figure 49) and *Syzygium guineense* subsp. *afromontanum* (Figure 50) in Sele-Nono forest. Comparison of our new equation with some widely used generic allometric equation such as Brown and WBISPP indicate that these generic equations overestimate the observed biomass; whereas the Djomo model underestimate the observed biomass of the trees (Appendix 29).

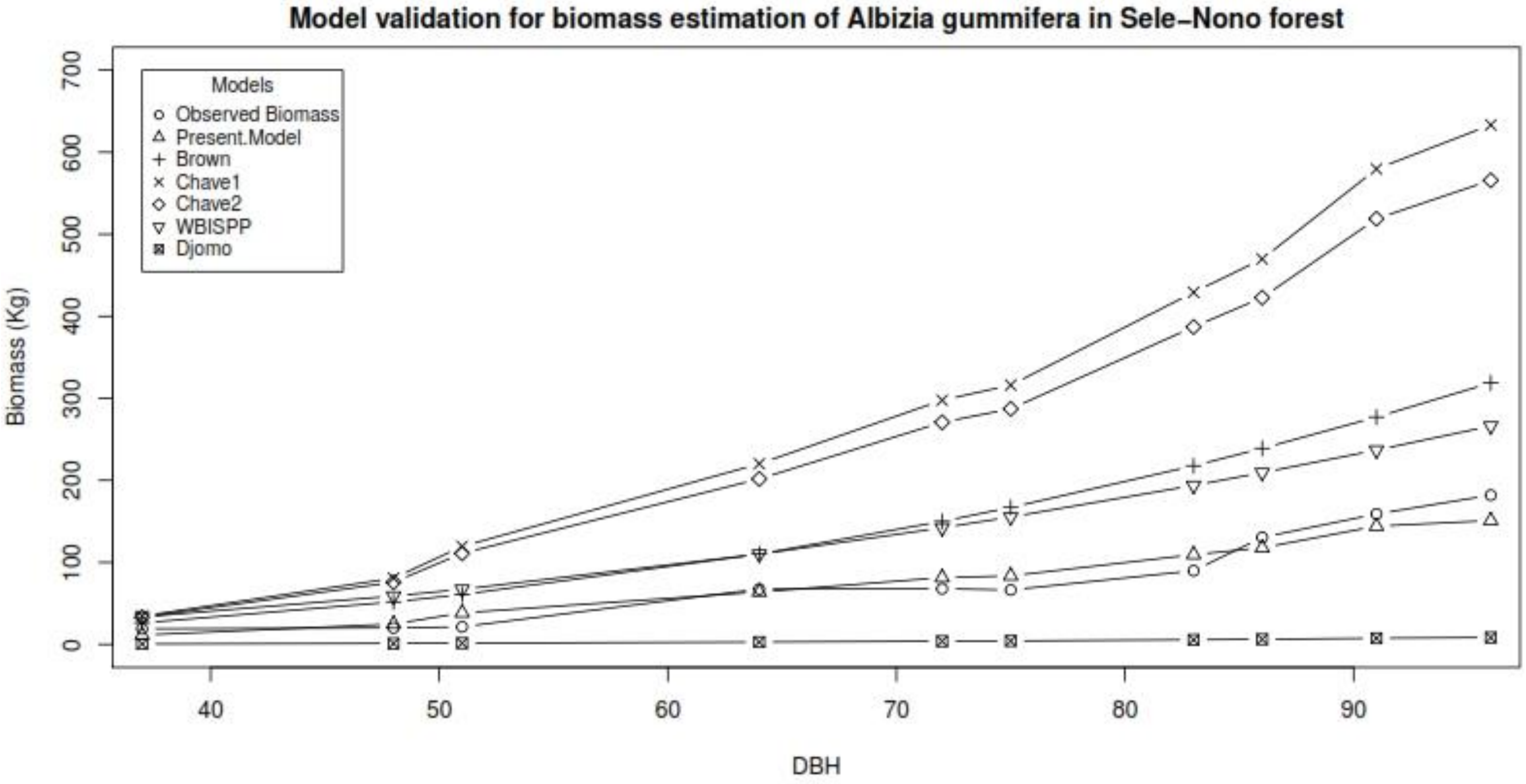


Figure 48. Model validation for biomass estimation of *Albizia gummifera* in Sele-Nono forest (n =1 0)

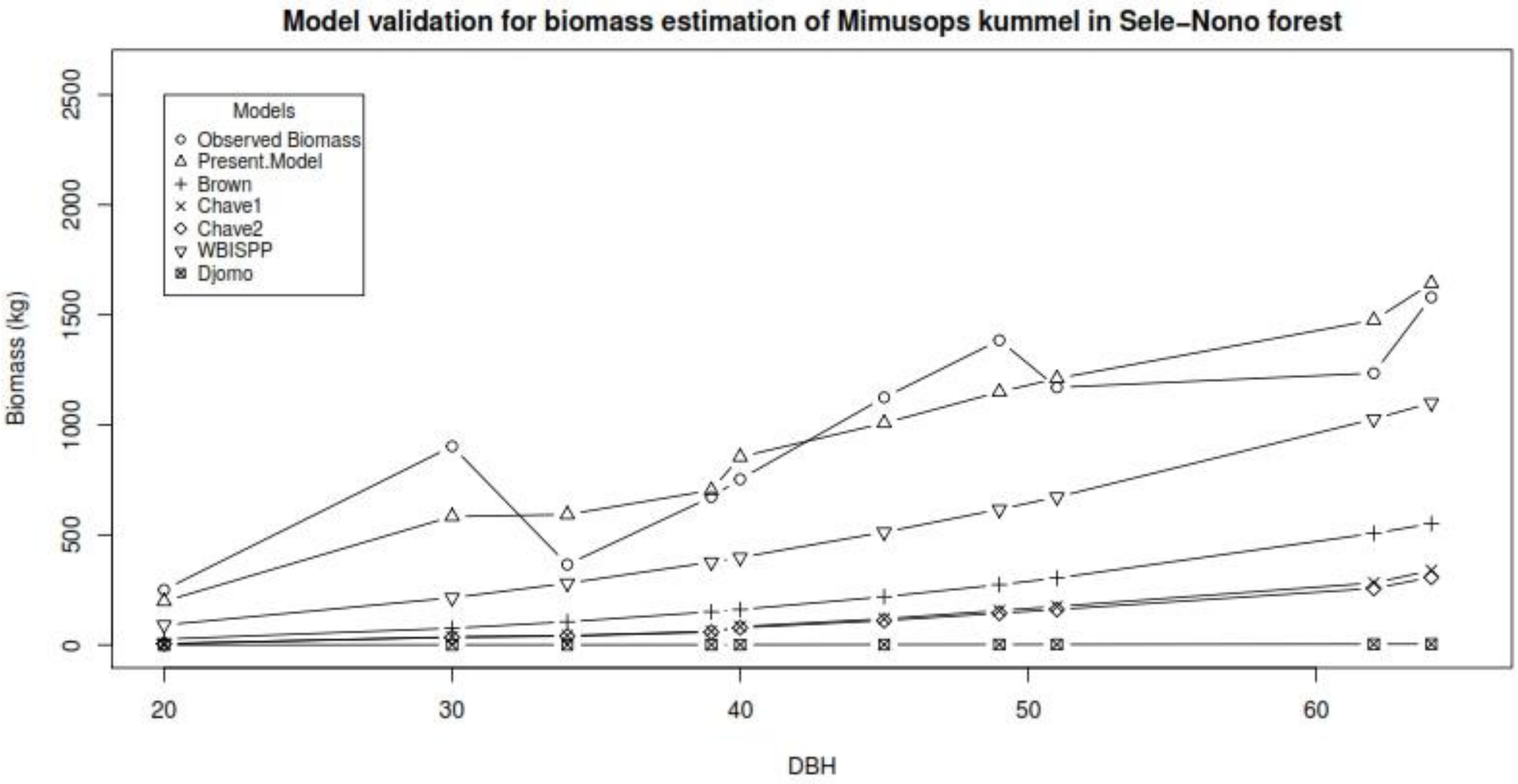


Figure 49. Model validation for biomass estimation of *Mimusops kummel* in Sele-Nono forest (n = 10)

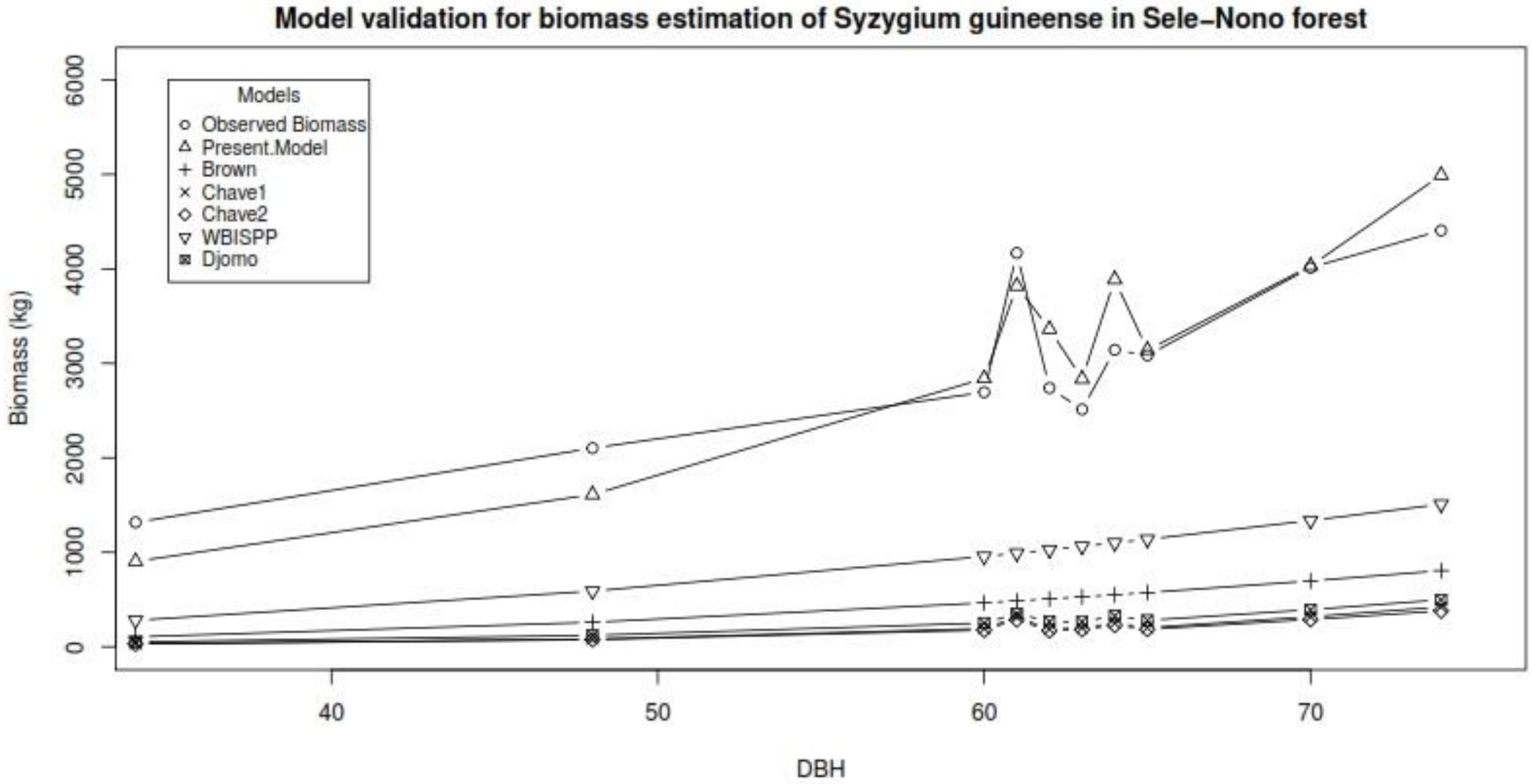


Figure 50. Model validation for biomass estimation of *Syzygium guineense* in Sele-Nono forest (n = 10)

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. DISCUSSION

5.1.1. Floristic composition and community types in Sele-Nono forest

5.1.1.1. Floristic composition in Sele-Nono forest

Realizing the floristic composition of a given area is the first step to understand and plan for the management of a given forest (Kneeshaw *et al.*, 2000; Simberloff, 2001; Sanjit and Bhatt, 2005; Ssegawa and Nkuutu, 2006). With this sentiment in Sele-Nono forest a large number of vascular plant species (414) in diverse plant families (108) and considerable growth forms (herbs, shrubs, lianas and trees) were documented. The number of species reported in this study exceeds the number of species reported for some other southwest forests such as the Bonga forest (220 species) as reported by Schmitt *et al.* (2010), Gura Ferda forest (196) by Dereje Denu (2006), Masha forest (130) by Abereham Assefa *et al.* (2013), Yayu forest (220) by Tadesse Woldemariam *et al.* (2008), Sheko forest (374) by Feyera Senbeta *et al.* (2007). This might indicate that the current study area is one of the richest forest ecosystem in southwest forest of Ethiopia. This presumably attributed with the large elevation range (840 – 2448 m asl) accompanied by the occurance of different vegetation types (MAF, TRF and Riverine) in the study area. Moreover, the presence of relatively less anthropogenic pressure on the forest due to low population number, ca 22,000 (CSA, 2007) & poor road access for long time in the past might have contributed the area to haven large number of plant species

In Sele-Nono forest Asteraceae, Fabaceae, Acanthaceae, Euphorbiaceae, Rubiaceae, are among the richest plant families in the current study. These plant families have also been reported as top plant families in the flora of Ethiopia and Eritrea (Ensermu Kelbessa and Sebsebe Demissew, 2014) in general and in the different patches of the moist southwest forests in particular (Kumelachew Yeshitela and Tamrat Bekele, 2002; Tadesse Weldemariam, 2003; Kumelachew Yeshitela and Taye Bekele, 2003; Feyera Sebeta *et al*., 2005; Ensermu Kelbessa and Teshome Soromessa, 2008). The prevalence of the family Asteraceae in the present study may indicate that the forest might have been under a certain level of disturbance as plants of Asteraceae are often ruderal (early colonizers); and normally prefer open and disturbed lands to grow (Friis, 1992; Malcolm, 1994; Turner, 1996; Mesfin Tadesse, 2004).

This study also reported the presence of a large number of herbs followed by trees and shrubs. The higher floristic composition of herbs could be a consequence of low grazing impact in the forest (Feyera Senbeta and Demel Teketay, 2003; Onaindia *et al.*, 2004; Lapaix *et al.*, 2009). It could also be associated with the moist climate of the area (due to high precipitation) and prescence of abundant trees and shrubs that shade herbs from lethal temperature due to radiation (Ellum *et al.*, 2010). Large proportion of herbs have been also noted in other moist forests of Ethiopia (Admassu Addi *et al.*, 2016; Feyera Senbeta *et al.*, 2007). The prescence of large number of trees and shrubs, next to herbs, could suggeste that there might have been less selective utilization of tree species in the study area. Moreover, the prescence of plenty lianas (25 species) in the present study could be associated to the occurance of large trees that provide support to lianas to ascend to the heights of the canopy to reach the light rich environment (Putz, 1984; Villagra *et al.*, 2013). The presence of high numbers of lianas has also been noted elsewhere in the moist southwest forests of Ethiopia (Feyera Senbeta *et al.*, 2005) and elsewhere in moist forests of Africa (Adane Girma, 2011; Addo-Fordjour *et al.*, 2013).

The finding in this study also reported that about 6% of the total plant species compiled for Sele-Nono forest, are endemics to Ethiopia. The restriction of these taxa is probably a consequence of limited dispersal ability. The low endemicity of plants is a common phenomenon for the vegetation of the moist SW forest of Ethiopia in particular (Friis, 2009) and for the vegetation of the country at large (Ensermu Kelbessa and Sebsebe Demissew, 2014).

5.1.1.2. Community types and diversity of plants in Sele-Nono forest

In the study area seven plant community types were recognized. None of these community types were poor with respect to their plant diversity as revealed from their Shannon indices (H in all community types >1.5). According to Kent and Coker (1994) the optimal value of the Shannon diversity index (H) for areas with higher plant diversity lays between 1.5 and 3.5, and some times to 4.5. The diversity of plant species in this study is comparable with the diversity in other forests of Ethiopia, such as Harenna Forest (Lisanework Nigatu and Mesfin Tadesse, 1989), Mana Angetu Forest (Ermias Lulekal *et al.*, 2008), Komto Forest (Fekadu Gurmessa *et al.*, 2013), Wondo Genet Forest (Mamo Kebede *et al.*, 2013). This may be becouse these forests are similar in that they all belongs to Moist montane Forest (Friis *et al.*, 2011)

Among the community types described in this study community type 1 & 4, which are mainly representing the Moist Afromontane forest (MAF) parts of the study area, have a relatively high species diversity and richness of plants (H >4, S >100). The high diversity and richness of plants in moist evergreen Afromontane forest of Ethiopia were also reported by Friis (Friis *et al.*, 2011). One possible reason for having high richness and diversity of plants for these community types could be a consequence of the large sample size employed in the study forest. Another possibility may be the altitude gradient since these community types were found at reasonably high altitudes that provide optimal environmental conditions required for their physiological needs and favors vegetation growth (Rosenzwieg, 1995). Moreover, the tradition of the local people named as KOBO system might have contributed for the higher richness and diversity of plants in these plant community types as this culture emphasizes on the use of the forest for traditional apicultural practices and other non-timber forest products. The same observations were made in the previous study on the area (Bekalu Tamene, 2010). This communal culture (KOBO system) have also been reported elsewhere to have conservation value in other southwest forests of Ethiopia (Dereje Tadesse and Tadesse Woldemariam, 2007; Tadesse Woldemariam and Fite Getaneh, 2011). On the contrary, lower richness and diversity of plants were found in the second community type (C2) which was found in the lower elevation of the study area (840-1200 m, asl). Possible reason could be a relatively high level of disturbance and effect of local climatic variation. Moreover, geographical isolation might also have contributed to the low diversity of plants in this forest since this community type is bordered by large tracts of dry and lowland vegetation of Gambella Regional State (Friis, 1992).

The findings of this study also revealed that community type 3, 5 and 6 are with relatively low species richness and diversity of plants (H = 3.5-3.6; S = 46-58) compare to community type 1 and 4. The low diversity and richness of species in community type 3 (*Arundinaria alpine-Oplismenus hirtellus*), which was mainly represented on the peak of mount TUPI (in Tupi Kebele) at an elevation of 2300-2448 m asl of the study area, might be the influence of the chilly local climate that may be harsh enough to permit other plants to grow well except few species such as the highland bamboos. Moreover, the low richness and diversity of plants in this community type may be attributed to its smaller size as this community type is only concentrated on the top of Tupi, which is an inverted conical shaped mountain. In line with this view Rahbek (1997) claimed that areas on uppermost of a mountain is not only cooler but they are also smaller in size and carries only limited species. The low richness and diversity of species in community type 5 (*Cyperus longibracteatus* - *Cyperus dereilema*) may be due to the absence of a number of woody plants as this community type is mainly characterized by patches of swampy places whose stagnant water restricts root growth of woody plants due to poor soil aeration. Lower diversity of plant species in this community type could also be attributed to the anthropogenic influences such as over-harvesting of grasses & sedges important for beautifying floors in the culture of the local people mainly for holydays; and for making roof of the huts in the rural areas. Moreover, this plant community type is the sole places for grazing; and consequently these places over-grazed by livestocks. Similar observation on the wetlands of southwest forests of Ethiopia were noted in previous studies (Zerihun Woldu, 1999; Afework Hailu, 2003; Zerihun Woldu and Kumelachew Yeshitela, 2003). The low diversity and richness of plant species in community type 6 (*Coffea arabica* – *Trichilia dregeana*) might also be attributed to their occurrence close to settlements that was mainly situated at 1600-1800 m asl. Studies elsewhere also suggested that areas close to settlements are often prone to poor diversity of plants (Fahrig, 2003; Somashekar *et al.*, 2003; Specht *et al.*, 2015). The preference of the local people to form settlements at this elevation zone (or community type) since long years before is perhaps due to the occurrence of rich coffee plant resources, which is an important cash crop in the study area. Given this community type is more abundant in wild coffee (*Coffea arabica*), which is a flagship species at the international level, it would help ecologist to consider this matter under any possible conservation activities. This elevation zone is also reported to be a dominant habitat for naturally growing coffee (*C. arabica*) population in other Afromontane rainforests of Ethiopia (Demel Teketay, 1999; Tadesse Woldemariam *et al.*, 2002; Feyera Senbeta and Denich, 2006; Schmitt *et al.*, 2009).

Moreover, the finding in this study demonstrates that Sele-Nono forest contain Moist Afromontane characterstic species in plant community types 1 and 4; and transitional rainforest characteristic species in community types 2 and 7 suggesting that Sele-Nono forest belongs to both the Afromontane and Transitional rainforest (Friis, 1992; Kindt *et al*., 2011).

5.1.1.3. Influence of environmental factors on the spatial distribution of plants in Sele-Nono forest

It is well-known that the vegetation cover of a given area is developed due to its interactions with biotic and abiotic factors. The finding of this study tells that the existing plant species composition and diversity is mainly influenced by environmental factors such as altitude & slopes, edaphic variables such as total nitrogen (N) & organic matter (OM) and disturbance factors.

From this study it could be said that elevation is a substantial factor for the high species richness and diversity of plants on highland forests, particularly in community type 4; and for the low richness and diversity of plants in community type 3. The elevation is suggested to build favorable microclimates (temperature and moisture) at the elevation range between 1850-2300 m asl (Community type 4) for optimal growth of plants; and unfavourable microclimates on the extreme elevation between 2300-2448 m asl (Community type 3) that limits plant growth (Richardson and Friedland, 2007). Similar explanation was given about vegetation variation along elevation gradient in moist afromontane forests of Ethiopian (Zerihun Woldu *et al.*, 1999; Sisay Nune, 2005; Schmitt *et al.*, 2010; Friis *et al.*, 2011; Schmitt *et al.*, 2013) and elsewhere (Lovett, 1993; Eilu *et al.*, 2004; Kabrick *et al.*, 2008; Fonge *et al.*, 2013).

Slope could also be traced as an important environmental factor contributing for high species richness and diversity of plants in community type 1 (C1), which lies between an elevation of 1600-1900 m asl (H = 4.09, S = 101). This may be attributed with the improperness of these areas (plant community type) due to its sloppy terrain to access for use such as for ploughing and crop cultivation, which are often regarded as serious threat to forests (MoEFCC, 2011). Moreover, it could be linked with the fact that steeper terrains would accelerate the circulation of soil water down the slope which is an advantage to vegetation in moist forests to support plant growth through avoiding water accumulation and consequently providing soil aeration and ease of root penetration (Osano, 2012; Nawaz *et al.*, 2013). The occurrence of diverse plant species on sloppy terrains of moist forests have been also reported elsewhere (Tadesse Woldemariam, 2003; Desalegn Tadele *et al.*, 2014).

High level of disturbance is one of a chief factors for the plant communities below the elevation of 1800 m asl (C2 and C6). Clearing of forests and their conversion into croplands; and selective removal of trees were the main disturbance factors in Community type 2 (C2) and Community type 6 (C6) respectively. These factors are thought to effect the decline in richness and diversity of plant species in these community types. This could be associated with the fact that clearing of forests and conversion of these into croplands in C2 could reduce litter production, increase soil erosion rates and decomposition of organic matters (OMs) by oxidation (Lawton *et al.*, 2001; Fahrig, 2003). All these factors in effect reduce species diversity and richness. Likewise, forest disturbance through selective exploitation of canopies certainly create vegetation openings in C6. This further might have altered the local microclimate in the community type that would dry out the soil rapidly and cause loss of nutrients through run-off (Berry *et al.*, 2008; Ruger *et al.*, 2008; Muscolo *et al.*, 2014). These effects ultimately cause decline in plant diversities. In both community types it could be summarized that disturbance have reduced their natural stability which subsequently might impede recovery of trees and shrubs. Results of many other studies in Ethiopia (MOA, 1990) and elsewhere (Lovett, 1999; Aubert *et al.*, 2003; Onaindia *et al.*, 2004) also shows similar findings in that anthropogenic disturbance leads low species richness.

Edaphic factors also influence the diversity of plants. In this study soil organic matter (OM), and total nitrogen contents (N) were the most significant edaphic factors for the distribution of plants. Among the plant community types described in the lower elevation of the study area (<1500 m asl) community type 7 was found with high diversity of species. This might be related to the high organic matters (OM) content of the area, which could give the soil a buffering capacity by resupplying the soil solution when important nutrients are removed by uptake or leaching (Cole, 1995; McCauley *et al.*, 2017) and hence contribute for the rapid growth of plants. The high temperature (due to low elevation) that favour decomposition of forest litters might have resulted to have high-level of soil organic matter (OM) in in this community type (community type 7). On the contrary, total nitrogen content of the soil is thought to be a more responsible edaphic factor for the vegetation pattern in community type 3, which was mainly represented by swamp vegetation. This may be partly because of the wetland areas are often presented as symmetric cup shaped curve circumscribed by hilly slopes; and flooded with the runoff rains washed down the slopes that might lead to nitrogen deposition. These conditions may form nitrate pollutions especially when mixed with animal dugs leftover during the dry season while they were grazing. Similar observation was found in Bonga forest by Sisay Nune (2005). It is also claimed that nitrogen in its nature is easily leachable from soil along sloppy terrains that are exposed to high precipitation (Batjes and Dijkshoorn, 1998; Infante-Mata *et al.*, 2011).

5.1.1.4. Threats to Sele-Nono forests

It is true that disturbance influences species composition and diversity of a forest ecosystem. However, not all aspect of disturbances is equally threatening to the composition of a forest vegetation. Thus, it is essential to know which disturbance factors are critical to a particular forest to bring meaningful changes in the conservation aspect (Simberloff, 2001; Onaindia *et al.*, 2004). In this study clearing of forests for cropland expansion by the local people followed by selective removal of trees were relatively the most threat factors. Clearing of forests for agricultural expansion is also reported as the main threating factor accounting for the loss of 60% of tropical moist forests (Wright, 2010; Chakravarty, 2012). However, this finding contradicts with previous reports for other forests in southwest Ethiopia (e.g. Sheka and Bonga forest) where the conversion of forest land into commercial tea plantation were considered as the leading threat of the forest (Zerihun Woldu, 1999; Tadesse Woldemariam and Fite Getaneh, 2011; Feyera Senbeta *et al.*, 2013). This is due to the fact that unlike the forests in Sheka and Bonga, conversion of forest land into other commercial investments such as tea plantations in Sele-Nono is prohibited by the rules of the District administration office.

The uncontrolled selective removal of trees was reported in this study as the second main threat, which is also regarded as a substantial threat factor in other southwest forests of Ethiopia (Mateos Ersado, 2001; Tarekegn Abebe, 2003). The presence of abundant number of disturbance-associated plant species such as members of the Asteraceae and lianas in the current study may indicate that the area might have faced selective logging. Similar assertions were reported in other moist forests of Ethiopia (Lisanework Nigatu and Mesfin Tadesse, 1989; Getachew Berhan and Yoseph Assefa, 2004; Feyera Senbeta *et al.*, 2005; Ermias Lulekal *et al.*, 2008) and elsewhere in tropical forests (Putz, 1984; Gerwing, 2002) who described the abundance of vines and/or Asteraceae plants in openings of a disturbed forest through selective logging. This findings also goes with the report by Chaffey (1979) who reported the presence of extensive uncontrolled forest exploitations in the SW forests of Ethiopia presumably as of the 1950s in the past.

Most of the species preferred for timber and timber related purposes by the local people in this study have also been mentioned in other forests in the southwest (Chaffey, 1979; EFAP, 1994; Schmitt *et al.*, 2010; Getachew Desalegn *et al.*, 2012). Some of these species are *Pouteria adolfi-friederici, Apodytes dimidiata, Celtis africana, Cordia africana, Croton macrostachyus, Ekebergia capensis, Prunus africana, Olea welwitschii, Polyscias fulva* and *Syzygium guineense*. However, the current Participatory Forest Management (PFM) system in the study area is well accepted in at least controlling the uncontrolled logging practices that have been prevailing in the forest. Moreover, thinning of forest for optimizing coffee bean productivity is a substantial factor for degradation of forests in Sele-Nono Forest. This threat is also a common phenomenon in other southwest forests of Ethiopia (Friis, 1979; Demel Teketay, 1999; Tadesse Woldemariam *et al.*, 2002; Senbeta Feyera and Denich, 2006; Schmitt *et al.*, 2009).

In addition, clearing of forests for settlement expansion due to growing population is another source of threat to the forest. Reusing (2000) indicated that settlement and population growth are the main causes for forest degradation (decline of forest quality) and deforestation in the forests of southwest Ethiopia. On top of this the recent wide-spreading new road construction projects in the study forest is an emerging threat to plant biodiversity as it involves clearing of trees and fragment habitats. Similar observations were reported elsewhere (Olander *et al.*, 1998; Ledec and Posas, 2003; Bera *et al.*, 2006; Caliskan, 2013). On the other hand, over-grazing and fire are among the least notorious threats to the current study area. This could be attributed to the moist nature of the forest that could extinguish fire incidences; and presence of rainy season that permits to rehab the grazed lands. These are also reported as the least damaging threat in other moist forests elsewhere (Chakravarty, 2012; Tranquilli *et al.*, 2014).

5.1.2. Structural description

5.1.2.1. Diameter and height profile of woody plants

This study assessed the size class distribution of woody plants using the frequency histograms of diameter (DBH) and height (H) classes. This technique has been regarded as standard method for generalizing the spatial distribution of woody plants of a forest ecosystem against certain structural characteristics like DBH and Height classes (Bongers *et al.* 1988; Vester & Cleef 1998). Accordingly, the findings of this study suggest that the forest is largely dominated by small sized plants of DBH less than 10 cm (91. 23%) and height less than 15 m (65%) signifying the importance of the small-sized woody species to the structure of woody plants. The high proportion of small sized woody plants is a common feature to the moist forests of the southwest (Chaffey, 1979; Tadesse Woldemariam, 2003; Feyera Senbeta *et al.*, 2007; Fekadu Gurmessa *et al.*, 2012; Feyera Senbeta *et al.*, 2014) and elsewhere in other tropical moist forests (Dale and Beyeler, 2001; Dale *et al.*, 2002; Memiaghe *et al.*, 2016). The abundance of small sized woody species (91. 23%) in the current study might indicate that the forest is in a stage of ecological succession (Quesada *et al.*, 2009). On the contrary, few proportion of the species in the study area (about 1. 32% of the total woody species) were recorded with larger DBH (DBH > 47 cm) suggesting the existence of only few old grown trees left in the forest (Kent and Coker, 1992).

The overall size class distribution of woody plants in the forest forms an inverted J-shape pattern suggesting that the studied forest looks healthy. This might indicate Sele-Nono forest seems in a position of maintaining its component species to ensure sustainability & stability

(Franklin, 1993; Cairns, 2002) as though it has never been perturbed. Previous studies conducted in Ethiopia (Tamrat Bekele, 1993; Demel Teketay, 1997; 2005; Feyera Senbeta, 2006; Tsegaye Gobeze *et al.*, 2009; Young *et al.*, 2017; Solomon Tadesse *et al.*, 2018) and elsewhere in the tropics (Richards, 1952; Campbell *et al.*, 1992; Mwavu & Witkowski, 2009) also reported inverted J-shaped size class profile when portraying the frequency distribution of all individuals of all species against DBH or height classes. However, the in depth analysis on the population structure of woody species in the study forest indicated variation in the pattern of the population dynamics, which might be a reflection of previous logging history on the desirable size of the species to satisfy the need for fuel, construction material and all sorts of tools. This undoubtedly reveals the presence of unhealthy population structures (Condit *et al.*, 1998; Tsheboeng, 2016); which may suggest that the overall-size class distribution for Sele-Nono forest only gives the general impression about the forest and hardly tells the true healthiness of every species in it. In this regard, the lesson from this study could tell that effective forest management effort must focus on the health of each woody species at population level than focusing on the gross profile of the forest structure.

5.1.2.2. Population structure

Population structure for each woody species using histogram technique have been recommended as a standard procedure for describing and analyzing patterns in their recruitment processes (Condit *et al.*, 1998; Silvertown and Charlesworth, 2001). Accordingly, this study produced eight different patterns of population structure for woody species in Sele-Nono forest.

The first pattern recognized in this study forms an inverted J shape pattern. Such pattern has been reported to be an indication of stable or healthy population structure of species under consideration (Teshome Soromessa and Ensermu Kelbessa, 2014; Neelo *et al.*, 2015; Corey and Craig, 2017). The finding of such structural pattern of species in the current study forest could be linked to their exploitation in the past above an intermediate classes or due to bad recruitment of species not to attain large diameter. The second pattern observed in this study area is similar to the first pattern but the species show hampered recruitment somewhere in the intermediate DBH classes forming a broken inverted J-shape. This could be a result of selective cutting of desirable sizes of trees, for instance pole size for different purpose. Such pattern has been reported for some species in Southwest forests (Feyera Senbeta, 2006; Ensermu Kelbessa and Teshome Soromessa, 2008; Kifle Kidane *et al.*, 2015) and elsewhere in Ethiopia (Motuma Didita *et al.*, 2010; Gebremicael Fisaha *et al.*, 2013; Tesfaye Burji *et al.*, 2013; Tulu Tolla *et al.*, 2017).

The third pattern of population structure noted in this study was a J-shape pattern indicating that species of this pattern are not well represented by the young individuals; and hence revealing poor reproduction. The low number of individuals in this pattern may be a consequence of selective logging at the lower class due to their economic importance and easier logging for various purposes; whereas the good representation of higher diameter classes could be a result of difficulty for logging. Such pattern of species population has been evident in other forests in the southwest (Feyera Senbeta, 2006; Yohannes Mulugeta *et al.*, 2015) and elsewhere (Ermias Lulekal *et al.*, 2008; Mamo Kebede *et al.*, 2013; Tulu Tolla *et al.*, 2017). The fourth pattern of population structure that was noted was a broken J-shape pattern, which is similar to the third pattern but with some individuals hindered to recruit in the middle classes. This might be attributed to selective logging of desirable size in the intermediate class.

The fifth pattern in the population structure reveals a regular pattern where individuals show more or less even distribution in all DBH classes. Species of such a pattern clearly show that they have good reproduction and recruitment potential in the forest. This could be attributed either the species are from protected sites of the forest, or they may not be in high demand by the local people. The sixth pattern was irregular pattern which shows zigzag type of distribution. This may indicate that individuals of species that reveal this pattern might be removed from different classes by natural or human-related factors. The occurrence of regular and irregular patterns for some plants is a phenomenon in southwest forests (Kumlachew Yeshitela and Taye Bekele, 2003; Getachew Berhanu and Yoseph Assefa, 2004; Feyera Senbeta *et al.*, 2007; Ensermu Kelbessa and Teshome Soromessa, 2008; Kflay Gebrehiwot and Kitessa Hundera, 2014) and elsewhere in tropical forests (Kellner, 2008; Rayburn, 2011).

The seventh pattern of population structure in the study area was a U-shape pattern. This finding vividly shows that selective logging has been confined to the medium sized individuals of the species under consideration. This might be because species showing such pattern are probably having high demand for timber value and hence the medium sized individuals are preferred due to their easiness to cut than the thicker individuals with high diameter. Similar pattern of population structure have been reported for species that were thought to have high timber values in Ethiopia (Getinet Masresha *et al.*, 2015; Markos Kuma and Simon Shibru, 2015; Tesfaye Burju *et al.*, 2013; Desalegn Tadele *et al*., 2014; Tesfaye Bogale *et al.*, 2017); and elsewhere (Coomes and Allen, 2007; Lines *et al.*, 2012). The eighth pattern noted in this study was a bell-shape (Gaussean curve) pattern. This might show that species belonging to this pattern have been selectively cut to a confined size of lower and higher DBH classes indicating that these species are locally demanded for various purposes such as house construction, fire wood, etc. (by the lower sized individuals) and for timber & poles (by the higher DBH class). This pattern has also been observed in other forests of Ethiopia (Feyera Senbeta and Demel Teketay, 2003; Mamo Kebede *et al*., 2013;

Melese Bekele and Wendawek Abebe, 2016) for species that were thought to have multiple local purposes.

Ultimately, this study puts the different patterns of population structure discussed so far into three groups so as to use this finding for management decisions. Species categorized under group 1 are those that contain species with no recruitment & reproduction, group 2 containing species that were with good reproduction but bad recruitment; and group 3 containing species that were with good reproduction and recruitment. Accordingly, species in group 1 & 2 should be prioritized first & second respectively under any possible conservation efforts in Sele-Nono forest. Similar approaches have been used in other moist forests of Ethiopia (Getachew Berhan and Yoseph Assefa, 2004).

In a nut shell, the findings on population structure in Sele-Nono forest indicate that the frequency of distribution of individuals in the various diameter classes were not uniform. Moreover, from the same analysis, it could be understood about the previous logging history of each woody species; and to forecast the future fate of the species under the existing threat trends. Of course, logging have been reported to be very selective in Ethiopia and mostly confined to a particular size of woody species based on the demands of the local people who use them (Getachew Tesfaye *et al.*, 2002; Feyera Senbeta and Demel Teketay, 2003; Tarekegn Abebe, 2002; Getachew Tesfaye and Demel Teketay, 2005).

5.1.2.3. Stratification

The vertical differentiation of tree layers (stratification) in the present study was analyzed based on the IUFRO classification scheme as used by Lamprecht (1989) and profile diagrams of trees from a stripe of forest as recommended by Richards (1952) and Baker and Wilson (2000). Accordingly, the finding of this study indicates that trees of the lower storey has higher density of individuals (65%) than the middle and upper storey suggesting that

Sele-Nono forest is characterized by lower stature trees. From this it could be traced that the forest has been under exploitation. The predominance of lower stature individuals is a common features of moist forests in Ethiopia (Getachew Berhan and Yoseph Assefa, 2004; Ermias Lulekal *et al.*, 2008; Tadesse Woldemariam *et al.*, 2008; Feyera Senbeta *et al.*, 2014; Tesfaye Bogale *et al.*, 2017), and elsewhere in tropics (Gentry, 1988; Whitmore, 1997; Condit *et al.*, 1996; Felfili, 1997; Addo-Fordjour *et al.*, 2009). Moreover, the findings on the profile diagram revealed the visualization of 2-3 strata in the forest. These kinds of stratification are a typical features of other moist forests of the southwest (Mateos Ersado and Yoseph Assefa, 2004; Feyera Senbeta, 2006) and elsewhere in the country (Tamrat Bekele, 1994) and other tropical rainforest (Baker and Wilson, 2000). The presence of multiple storeys in the current study area might reveal that the forest trees are at different level of developmental stage or succession. In relation to this temporal variation in the developmental stages of the vegetation lower storeys are associated to younger trees, middle storeys to middle aged trees and upper canopy trees to old aged trees (Felfili, 1997; Dial *et al.*, 2011).

Specific findings on the profile diagram of this study revealed the existence of two layer strata in those stands that can be exemplary to community type 6 (1600 –1800 m asl); where the lower storey is dominated by *Coffea arabica*. The dominance of coffee trees in this stand could be a consequence of forest degradation through selective hunting of large sized trees & thinning of other lower canopy trees for improving the yields of Arabica coffee as this community type is found close to the vicinity of human settlements. Thinning for this purpose is also reported as the most important threat to influence structure of forest between altitudes of 1300-1700 m asl in other moist forests (Feyera Senbeta and Denich, 2006; Schmitt, 2006; Schmitt *et al.*, 2009; Tadesse Woldemariam *et al.*, 2002, 2008; Feyera Senbeta *et al.*, 2014). Two layers in forest stratification is often regarded as indicator of degraded forests or species poor forest patches in Ethiopia (Tamrat Bekele, 1994; Senbeta, 2006) and elsewhere in Borja montane forest in Ecuador (Grubb *et al.*, 1963). Two strata layers were also observed in areas representing community type 2 (840-1250 m asl). This might reveal poor vertical structure; which is indicative of low conservation status of this particular community type. This poor structure for this community type could have resulted from clearing of forests basically for agriculture expansion.

On the contrary, the vertical structure prevalent in community type 1 (1600-1900 m asl) showed stratification with three layers, the upper story being more or less a closed canopy. A number of ecological literature claims multiple layer with closed canopy of trees is a characteristic of intactness of a forest ecosystem (Parker and Brown, 2000; Sagar *et al.*, 2008; Whitmore, 2008; Potapov *et al.*, 2017). Thus, from this existing multiple strata it could be suggested that community type 1 is comparatively in a stage of good conservation status and can be predicted to be biodiversity rich forest patch. This is because each particular storey is expected to enhance a number of species that are capable of occupying the space, as a result of adaptive responses to different light conditions (Terborgh, 1985; Guilherme *et al.*, 2004). In line with this inferences, Proctor (1988) and Hill and Hill (2001) reasoned out multiple layer as a crucial factor for high biodiversity in tropical forests since heterogeneity in forest storey provides more niches and microhabitats for a higher number of specialized species.

All in all, the report on the profile diagram of this study shows variation in the physiognomic representation at the different stands of the studied forest. This might attributed to differences in previous disturbance intensity apart from other possible factors such as elevation differences, and microclimate differences. Thus, it can be realized that the analysis of vertical structure in this study can be regarded as an important tool to infer about the intactness and/or degradation of the forest and to support its management. Studies elsewhere also used results of canopy stratification to sort out the forest community types for setting conservation priorities (Dale and Beyeler, 2001; Pastorella and Paletto, 2013). Accordingly, community type 2 & 6 of the Sele-Nono forest deserves conservation priority as they are poor interms of their vertical structure.

5.1.2.4. Density and occurrence of woody species in Sele-Nono forest

The finding of this study shows that the density and frequency of woody species is not uniform; and varies among the woody species themselves. This might be attributed to differences of species characteristic towards their dispersal nature, site condition, and disturbances (Simon Shibru and Girma Balcha, 2004; Getachew Tesfaye and Demel Teketay, 2005; Kitessa Hundera and Tsegaye Gadissa, 2008).

The finding of this study reveals that the total density of woody species (DBH > 2.5 cm) in the forest was 20939.38 individuals (stems) per ha. This value related to the density of woody species in other moist forests of the southwest Ethiopia; for instance, to the forests of Bonga (19232 ha^{-1}), Berhane Kontir (18981 ha^{-1}), Maji forest (18183 ha^{-1}) as studied by Feyera Senbeta *et al.* (2014) and Sheko forest (16433 ha^{-1}) as reported by Feyera Senbeta *et al.* (2007). This may be due to their phytogeographical proximity and climatic similarity. However, the current study exhibited much lesser density when compared to the Yayu forest (63, 000 ha^{-1}, Tadesse Woldemariam *et al.*, 2008), which could be related with the fact that Yayu is a Biosphere Reserved Forest under UNESCO (Tadesse Woldemariam, 2010).

The finding in this study shows that the density of woody plants of DBH >10 cm was 1836 ha^{-1}. It has been reported that the normal density of woody species over 10 cm DBH for virgin rain forests in Africa is more than 600 ha^{-1} (Richard, 1966, cited in Lamprecht, 1989). Thus, it can be deduced that Sele-Nono forest has a coverage of woody species as those of the virgin rain forest in Africa. However, this does not necessarily mean & guarantee that our study forest is a virgin forest, but it rather means that the area still has woody species of DBH > 10 cm that has not been heavily exploited in the past. This could be attributed to the relatively low disturbance history of the forest. It is known that 91% of Sele-Nono District is covered by natural forest, also called Sele-Nono forest (150,325 ha) and currently only 9% of the District is occupied by settlement (SNDAO, 2015) showing the negligible influence on the forest by the people for many years in the past. The presence of more than 600 woody stems (DBH > 10 cm) per hectare is also characteristics of other moist forests of Ethiopia such as Belete forest, Setema forest, Sigmo forest, Bonga forest, Godere forest, Sheko forest, Yayu forest (Mateos Ersado and Yoseph Assefa, 2004), and Masha forest (Abreham Assefa *et al.*, 2013).

In the study the density of woody plants with DBH of 10-20 cm (a) was greater (a = 1145 ha^{-1}) than those species with DBH > 20 cm (b) (b = 691 ha^{-1}), which is in line with the findings of other natural forests in Ethiopia (Tamrat Bekele, 1994; Tulu Tolla *et al.*, 2017) and elsewhere in other tropical forest (Neelo *et al.*, 2015). Moreover, the a & b densities in the present study were larger than some moist forests in Ethiopia such as Masha forest (a = 633, b = 286; Abreham Assefa *et al.*, 2013), Gura Ferda forest (a= 500, b = 263; Dereje Denu, 2006), Menna Angetu forest (a = 292, b = 139; Ermias Lulekal *et al.*, 2008), Komto forest (a = 330, b = 215; Fekadu Gurmessa *et al.*, 2012), Bonga forest (a = 521, b = 246; Mateos Ersado and Yoseph Assefa, 2004), Godere forest (a = 456, b = 165; Mateos Ersado and Yoseph Assefa, 2004), Sheko forest (a = 461, b = 200; Mateos Ersado and Yoseph Assefa, 2004) indicating that Sele-Nono forest is relatively a better preserved forest. However, Sele-Nono forest has the smallest a/b density ratio (a/b = 1.66) as compared to many of the forests in southwest Ethiopia such as Belete (2.13), Boginda (3.66), Bonga (2.12), Godere (2.76), Setema (2.71), Sigmo (2.32), Sheko Forest (2.31) (Mateos Ersado and Yoseph Assefa, 2004). This may indicate that the study area haven relatively a comparable density of the medium and large sized woody plants. The low proportion of trees (DBH > 20 cm) as compare to trees with DBH 10 to 20 cm in the study forest could indicate that Sele-Nono forest is a secondary forest. Similar assertion was given elsewhere (Dale *et al.*, 2002).

Specific finding on the density of woody species show that *Coffea arabica, Rytigynia neglecta*, *Canthium oligocarpum*, *Acalypha acrogyna* and *Vangueria madagascariensis* are denser species in Sele-Nono forest. This may indicate that these species are relatively most preserved species in-situ. The higher densities of these species might also reveal that these species are likely autochoric (Lopes *et al.*, 2014) which involve falling of fruit and seeds due to gravity and grow under the canopy of the mother plant that might have subsequently enhanced the stocking (density) of these species. Inline to this inferences some researchers elsewhere generalize that stocked trees of lower canopy predominantly dispersed by authochory (Howe and Smallwood, 1982). This features of dispersal might have contributed for the more stocking of small sized trees in Sele-Nono forest.

Result also showed the presence of large number of species in the lower frequency class; and low number of species in the higher frequency class indicating the heterogeneity of the forest in terms of species composition. Specific findings on the occurrence of woody species reveal that some species such as *Balanites aegyptiaca, Combretum adenogonium, Combretum molle, Kigelia africana, Lannea schweinfurthii, Pseudocedrela kotschyi, Zanthoxylum usambarense, Terminalia schimperiana, Sterculia africana* are the rarest species in Sele-Nono forest (Frequency < 5%). These species have not been even listed as characteristic species in the moist forests of Ethiopia (Friis *et al.*, 2011). The occurrence of these species in the current study area may be a consequence of ecological connectivity (Metzger, 2000) that promote dispersals of species since the boundary of our study site (Sele-Nono moist forest) has not been physically separated by a barrier from the nearby woodland vegetation of Gambella Region. Most of the remaining ‘rarely occurring species’ in Sele-Nono forest occurred with various level of occurrence (Frequency: 15-20%).

On the contrary, the remaining 50% of the species in Sele-Nono forest often occur in more than 20% of the studied plots, of which (55.8 % of the total density) were lower canopy tree species. The high frequency of lower canopy species (shade tolerant) could be a consequence of long distance dispersal ability that might have been dispersed principally through animals (zoochory). Zoochory has been suggested as an important factor for long dispersal of plants (Gentry, 1988; Cain *et al.*, 1998; Higgins and Richardson, 1999). In this connection, Janzen (1983), Herrera (1989) and Ollerton *et al.* (2011) indicated that about 90% of the dispersals known in flowering plants are effected through Zoochory. In supporting this notion, ecologists suggest that the understory of tropical forests is composed of mainly shade-tolerant, zoochoric, and evergreen species (Terborgh, 1992; Toniato and Oliveira-Filho, 2004). This might be because the lower layers of tropical forests often shielded from wind influence as they are protected by the canopy trees; and dispersed by animals as their activities are more intense in the lower canopies (Roth, 1987; Clark and Poulsen, 2001).

Among the 50% species that occur in more than 20% of the sample plots of this study two species (*Coffea arabica, Acanthus eminens*) were noted as persistently occurring species in (Frequency > 81% of the studied plots); whereas seven species (*Oxyanthus speciosus, Dracaena fragrans, Vepris dainellii, Teclea noblis, Psychotria orophila, Landolphia buchananii, Bersama abyssinica*) as mostly occurring species (Frequency = 61-80% of the studied plots). Hence, these species could be regarded as cosmopolitan species for the study forest due to their occurrence in broader plots. This may indicate that the studied forest is specifically more favorable habitat for these species in particular and/or these species might have potential to withstand unfavorable conditions during their dispersals and upon early arrival.

From this study, it can be realized that most of the frequent & dense species are those of lower storeys that are shade-tolerant species and are probably autochorous and/or zoochorous.

5.1.2.5. Dominant species in Sele-Nono forest

In vegetation ecology, dominance of a species can be explained in terms of its area coverage as measured from basal area per hectare (Barbour *et al.*, 1987); and/or in terms of its ecological significance as measured from IVI values (Curtis and McIntosh, 1951). The total basal area of all woody species > 2.5 cm DBH in Sele-Nono forest was 131.05 m^2ha^{-1}. This value is comparable to Masha forest (141.12 m^2ha^{-1}; Abreham Assefa *et al.*, 2013). This might be attributed to the fact that these two forests are adjacent to each other; and they might have been exposed to similar level of historical disturbances and cultural forest conservation practices.

On the contrary, basal area of woody species in the current study area is higher than the basal area reported for many of the southwest forests of Ethiopia such as Bonga forest (Feyera Senbeta *et al.*, 2014); Komto forest (Fekadu Gurmessa *et al.*, 2012); Masha-Anderacha forest (Kumelachew Yeshitela and Taye Bekele, 2003); Sheko forest (Feyera Senbeta *et al.*, 2007) and Yayu forest (Tadesse Woldemariam *et al.*, 2008). This variation in their basal area could be related to differences in density of the species and intensity of previous logging on the species. This can be elaborated with the fact that these forests have been reported as the more exploited patch forest in southwest forests as they were the most accessible forest patches & susceptible to commercial logging due to their proximity to the main Jimma-Mizan national road for many years in the past (Mateos Ersado, 2001). Hence, it would not be surprising that these forests could have lower basal area when compared with Sele-Nono forest, which has been accessible only very recently and is found at a distance of about 100 Km away from the nearby main national tarmac road. Related results have also been documented in a relatively well conserved forest that had higher basal area than the relatively more exploited forest (Blomley *et al.*, 2008; Tsegaye Gobeze *et al.*, 2009; Aklilu Ameha *et al.*, 2016). Moreover, the findings of this study showed that the basal area in the forest is higher than the basal area suggested for a typical virgin tropical forests in Africa. (Dawkins, 1959 cited in Lamprecht, 1989) which ranges from 23-37 m^2ha^{-1}. The high basal area of trees in Sele-Nono forest could be attributed to the presence of high density of trees in the study forest.

The findings of this study also showed that large portion (50.66%) of the total basal area in Sele-Nono forest was contributed by few large DBH individuals such as *Schefflera abyssinica, Pouteria adolfi-friederici, Olea welwitschii, Manilkara butugi, Morus mesozygia, Trilepisium madagascariense, Albizia gummifera* and the like indicating that few large plants species dominate the study area. Similar findings were reported in other moist forests of Ethiopia (Kumelachew Yeshitela and Taye Bekele, 2003; Kitessa Hundera *et al.*, 2007; Kitessa Hundera and Tsegaye Gadissa, 2008) and elsewhere (Sagar *et al.*, 2003; Wiegand *et al.*, 2007; Clark *et al.*, 2015). The dominance of thicker (larger diameter) trees could be attributed to the fact that these species might have subjugated the competition that might have helped them to be prominent in the study area to have bigger basal area. Moreover, these species might have achieved maximum growth to their height, and consequently allocate their investment to increase their basal area. On top of this, these species could have low demand of timber value contributing for their dominance of area coverage.

The analysis of IVI value was used to sort out ecologically most important woody species in Sele-Nono forest. Similar approaches have been used elsewhere (Abate Ayalew *et al.*, 2006; Haileab Zegeye *et al.*, 2006; Ermias Lulekal *et al.*, 2008). Some of the top 15 ecologically most important species in the forest includes both small sized and large sized species. These species are *Coffea arabica, Schefflera abyssinica, Rytigynia neglecta, Pouteria adolfi-friederici, Olea welwitschii, Trilepisium madagascariense, Canthium oligocarpum, Manilkara butugi, Elaeodendron buchananii, Acalypha acrogyna, Acanthus eminens, Morus mesozygia, Vangueria madagascariensis, Embelia schimperi* and *Albizia gummifera*; and probably indicating that these are immediate successive species of their pioneer (first colonizers) type. Researchers believe that most ecologically important species are pioneer species, which could be pristine or their successive type (Curtis and Mcintosh, 1951; Lamprecht, 1989; Demel Teketay, 2005); and need monitoring management to maintain the authenticity of the forest. In line with this notion, Whitmore (1997) viewed pioneer species (or their successives) of a forest ecosystem into two ways. One is for large sized species which is characterized by long life cycle and low replacement rate such as *Pouteria adolfi-friederici, Olea welwitschii, Trilepisium madagascariense, Manilkara butugi, Elaeodendron buchananii,* which could be a consequence of late succession; whereas small sized species are those that have rapid life cycle and high replacement such as *Coffea arabica, Rytigynia neglecta, Canthium oligocarpum, Acalypha acrogyna, Acanthus eminens, Vangueria madagascariensis, Embelia schimperi*; which could be the result of early succession. It is probably because of this resaons that these species (the above mentioned ones) were often reported as ecologically most important/ typical species in the description of moist southwest forests of Ethiopia (Chaffey, 1979; Friis *et al.*, 2011).

5.1.2.5. Regeneration status of Sele-Nono forest

The finding of this study revealed that the total regeneration density of Sele-Nono forest was 5894.72 ha^{-1} with a seedling and sapling density of 3072.31 and 2822.40 ha^{-1} respectively. The total regeneration density for the current study forest is comparable with the regeneration density of other forests in the southwest such as Bonga forest (5656 ha^{-1}), Masha-Anderacha forest (4878 ha^{-1}), Yayu (6818 ha^{-1}), Sigmo (5225 ha^{-1}), Setema (5528 ha^{-1}), Belete-Gera forest (6630 ha^{-1}), Godere forest (6676 ha^{-1}) as studied by Elias Taye and Getachew Berhan (2004). However, the regeneration status in the current study is lower than the regeneration status reported for the dry montane forests of Ethiopia such as Gara Ades forest (16, 290 ha^{-1}, Demel Teketay, 1997), Menagesha Suba forest (32, 650 ha^{-1}, Demel Teketay, 1997), Wof Washa forest (8796 ha^{-1}, Gebremichael Fisaha *et al.*, 2013). This might be associated with the environmental conditions required such as moisture, light and temperature which are expected to be more optimal in the dry Afromontane forests of Ethiopia than for moist forests (Khaine *et al.*, 2018). This is because optimum temperature is usually a limiting factor for regeneration of woody species in moist forests of southwest Ethiopia (Taye Bekele *et al.*, 2002) which remains cold and rainy for eight to ten month in a year (Daniel Gemechu, 1977; Tafesse Asres, 1996; Friis *et al.*, 2011) and elsewhere in tropical moist forests (Vazquez-Yanes and Orozco-Segovia, 1990).

The finding of this study also indicate that the woody species in Sele-Nono forest follow different patterns of regeneration. About eight different patterns were identified indicating that there is a clear variation in the reproduction and recruitment during the regeneration processes of the woody species in the study area. However, this study has categorized all these different patterns of regeneration status into three basic classes based on their regeneration status so as to apply the finding for the forest management decision. These classes include Group 1 that contain species with no regeneration, group 2 consists of species that has a total regeneration density up to 50 ha^{-1} whereas the third group includes species with total regeneration density of more than 50 ha^{-1}. Classifying the regeneration patterns of woody species into three classes is a usual approach in many research outputs in Ethiopia (Dereje Denu, 2006; Elias Taye and Getachew Berhan, 2003; Fekadu Gurmessa *et al.*, 2012) and elsewhere (Whitmore, 1997). Accordingly, the finding of this study shows that majority of the woody species (75. 57%) in Sele-Nono forests were with poor regeneration status and categorized in group 2; whereas only few species (17.61%) were seen with good regeneration density (Group 3 species). About 6. 82 % of the species were found to be totally absent in the regeneration and were grouped under class 1 which deserves first priority. Providing a generalized suggestion for deficient seedlings and saplings (in priority class 1 & 2) is difficult since several reasons could account for no and/or poor regeneration status of some woody species in the forest. For instance, the hampered regeneration for species in “group 1” could be the results of either most trees are not producing seeds due to age or there could have been losses due to predators after reproduction. Hampered regeneration in the study area might have also resulted due to ineffectiveness arrival of seeds as a result of some factors such as high canopy cover (for seeds of light demanding species), low canopy cover (for seeds of shade demanding species) and/or thick litters and herbaceous layers to prevent seeds not to reach soil. Grazing of seedlings/sapling could also be another reason for the lack of regeneration and/or poor regeneration of some species in the study area. Related suggestions were noted by Dereje Denu (2006); Tarekegn Abebe (2003); Simon Shibru and Girma Balcha (2004), Demel Teketay (2005). In this study, it was also observed that young *Schefflera abyssinica* and *Ficus vasta* were growing on other plants. Thus, it may be one of the reasons why it was not possible to find seedlings of these species on the ground. This is ellaborated by the observation made by Getachew Berhan and Yoseph Assefa (2004) who reported *Schefflera abyssinica* and *Ficus* spp. prefer coppicing as a strategy of survival rather than regeneration.

The present finding of poor regeneration for the majority of woody species (75%) might indicate that the future fate of this forest could be with declined species richness and abundance. Moreover, the complete absence of regeneration for 'group 1 species' might show that the future forest of the study area might lose these species from its floristic list unless proper actions are taken like paying attention to the conservation of coppices of these species.

5.1.3. Validation of existing biomass models for Sele-Nono forest

It is believed that existing allometric models developed elsewhere are sources of uncertainty for biomass and/or carbon stock estimation of forests. Thus, this study has evaluated and compared the level of uncertainty induced due to the utilization of possible allometric equations for making decisions on their prediction accuracy in Sele-Nono forest.

5.1.3.1. Validated tree biomass model for Sele-Nono forest

The finding of this study reveals that Chave *et al.* (2014) equation is more accurate for estimating above ground biomass of trees. This is because the bias induced due to this model was found very small, even smaller than the Chave *et al.* (2005) model. This is more likely due to the fact that Chave *et al.* (2014) model was developed in the moist tropical forests and took data from African Moist Afromontane forests, which is a similar forest type to the Sele-Nono forest and/or the Southwest forests in general (Friis, 1992; Friis *et al.*, 2011) with respect to species composition and structure. Moreover, the 2014 model of Chave used more samples (n = 4004 trees), exceeding by 1594 sample trees from the 2005 model of Chave (n = 2410) which increases the validity of the models (Hanselman *et al.*, 2012; Taylor, 2013; Duncanson *et al.*, 2015).

Although the model of Djomo *et al.* (2016) is developed for tropical African moist forests, it was found less accurate for Sele-Nono forest as it induced large source of error (MRE = -88.2%) to the current data set. This may be attributed to the relatively lower number of sample size (n = 700 trees) used to develop this generic model (Djomo *et al.*, 2016). Moreover, most of the sample species are part of the species composition of lowland rainforests (Guineo-Congolian forest) of West and Central Africa, which does not synchronize to the moist Afromontane forest of Sele-Nono Forest (White, 1983; Dykstra *et al.*, 1996). The lowland rainforests (Guineo-Congolian forests) of West and Central Africa are typically semi-deciduous moist forest, mostly smaller in size (less H and DBH) (Malhi *et al.*, 2013; Bastin *et al.*, 2015); and hence expected to have lower biomass as compared to the typically Moist evergreen Afromontane Forest, which are especially common in the Eastern Africa highlands (> 1000 m elevation) (Lovett, 1993; Feldpausch *et al.*, 2011; Ostertag *et al.*, 2014). Similarly, studies elsewhere also reported forest type as a significant influence on tree allometric models (Brown, 1997; Chave *et al.*, 2005).

The finding of this study also indicates that Chave *et al.* (2005) model is the second more accurate model next to Chave *et al.* (2014) for estimating carbon stock of trees in Sele-Nono Forest. Chave *et al.* (2005) pan-tropical equation has been widely used for carbon stock assessment of moist forest of Atlantic Forest (e.g. Vieira *et al.*, 2008), Africa (e.g. Bastin *et al.*, 2015) and Ethiopian forest (e.g. Vreugdenhil *et al.*, 2011). This model has been validated to be appropriate for moist Madagascar and Ghana forest with mean bias of 4.2% (Vieilledent *et al.*, 2012) and 3.74% (Henry *et al.*, 2010) respectively. These and other researchers also suggested the use of Chave *et al.* (2005) for African moist forests (Henry *et al.*, 2010; Kaonga and Bayliss-Smith, 2010). This may be because this model (Chave *et al.*, 2005) developed from various tropical moist forests based on the compilation of data (n = 2410) since 1950s from 27 study sites in America, Asia and Oceania (Chave *et al.*, 2005).

However, the prime choice of this model by the then time might be because Chave *et al.* (2014) model was not published for use that time and may not know to their attention. This model, however, produced a relatively less accurate estimate of biomass in this study as compared to the recent Chave model (Chave *et al.*, 2014). The inappropriateness of Chave *et al.* (2005) to the Sele-Nono forest when compared to Chave *et al.* (2014) may be due to sampling errors resulting from the exclusion of sample trees from African Moist Afromontane forest.

However, from this study it can be said that both the Chave *et al.* (2005) and Chave *et al.* (2014) are relatively better estimator of trees AGB in comparison to the Brown (1997) pan-tropical model and that of the local model developed for the Ethiopian moist forests by the Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2000). A similar finding was obtained by Vieilledent *et al.* (2005) who found the pan-tropical Chave *et al.* (2005) model as the best equation for the AGB estimation of the Madagascar moist forest than their regional equation. This may be due to the fact that the Brown and woody biomass project models used only single variable that greatly diminish the prediction potential of the models. Studies elsewhere similarly emphasizes the use of models with more predictors (two or more parameters) for a better carbon stock estimation of a forest under interest than models with only one independent variable (Claesson *et al.*, 2001; Clark *et al.*, 2001., Chave *et al.*, 2001; Cummings *et al.*, 2002; Vincent *et al.*, 2015., Kuyah *et al.*, 2016; Imani *et al.*, 2017). On top of this, sampling errors of these models due to the inclusion of samples from different forest types might have contributed for the high disparity of biomass estimation when they are applied to Sele-Nono forest. For instance, the Brown general model (Brown, 1997) was developed from small data sets (n = 169), most of which (>62%) were from Southeast Asian forests which are a different forest types from Sele-Nono forest. Similarly, the local WBISPP (2000) model used limited sample size (n = 70), most of which were collected from woodlands (Henry *et al.*, 2013; Ensermu Kelbessa, Pers. Comm). Moreover, this finding may signify that the use of generic models developed elsewhere but in similar vegetation types would have better predictive capacity than models developed locally but in a different vegetation types.

5.1.3.2. Validated palm biomass model for Sele-Nono forest

The allometric equation developed by Brown *et al.* (2000) is a more accurate estimator of the AGB for Palms (MRE<10%) in Sele-Nono forest than the models developed by Hughes (1997) and Winrock international organization which works on carbon stock. The appropriateness of Brown *et al.* (2000) model may be attributed to the climatic similarity of Bolivia forest (research site of Brown *et al.*, 2000) and Sele-Nono forest as both are moist. On the contrary the improperness of Hughes (1997) model could be associated to the fact that Hughes developed the model for small palms of Mexican tropical rainforest whose DBH ranges 1-10 cm; and floristically very different when compared to Sele-Nono forest. Moreover, the Hughes model solely based on DBH of palm, a parameter which is not well associated with its biomass (Pearson *et al.*, 2005, 2007). Likewise the improperness of the Winrock international model to the current study could be attributed to the fact that this model was developed specifically to palm species in the genera *Asai* & *Pataju*, which are different species types from the Palms (*Phoenix recliniata*) in Sele-Nono forest.

5.1.3.3. Validated liana biomass model for Sele-Nono forest

Schnitzer *et al.* (2006) is a better model for estimating AGB of lianas in Sele-Nono forest than other related models such as Putz (1983), Gerwing and Farias (2000) and Gehring *et al.* (2004). This might be attributed to the fact that Schnitzer used large number of sample sizes (424 liana species) than the other liana models (Gehring *et al.*, 2004, 26 species; Gerwing & Farias, 2000, 19 species; Putz, 92 species). Moreover, the Schnitzer model collected the samples from larger sample places (Brazil, Venezuela, French Guiana & Combodia) than the other models (Gehring, Brazil; Gerwing, Brazil; Putz, Venezuela). Moreover, many of these inappropriate models could be due to range out. In relation to this Aalde *et al.* (2003) underlined that allometric models should not be used out of their domain of validity.

Thus, the Schnitzer *et al.* (2006) model can be used for any liana biomass estimation in Sele-Nono forest irrespective of their species, shoot numbers, or environmental conditions where the lianas grow. This model has also been used to estimate the biomass of lianas in Mount Kilimanjaro forest (Ensslin *et al.*, 2015). This is because liana shoot allometry is believed to be unaffected by environmental conditions over a wide range of vegetation types (Addo-Fordjour and Rahmad, 2013). Moreover, liana allometry has been reported to be workable for both single- and multiple-shooted lianas (Van der Heijden *et al.*, 2015). Findings elsewhere also reported that species-specific equations for lianas slightly corrects the accuracy of the biomass; and recommends the use of general equation for liana biomass estimation (Putz, 1984; Schnitzer *et al.*, 2006).

5.1.3.4. Validated bamboo biomass model for Sele-Nono forest

Allometric equations developed for Bamboo are plenty in literatures (An Ha and My Anh, 2014; Kaushal *et al.*, 2016; Guangyi *et al.*, 2017). However, no equation has been developed so far for *Arundinaria alpina* (highland bamboo from easily measurable parameters except the equation developed by Yigardu Mulat & Maseresha Fetene (2013) at Choke Mountain, Northwest Ethiopia. Even the biomass predicted by this model when compared with the actual biomass of the validating data sets of *Arundinaria alpina* in Sele-Nono forest found not to be significantly different ($P > 0.05$). Moreover, the variation induced due to the model was found to be tolerable (MRE = ~10%) and negligible when one considers other source of errors (Nascimento and Laurance, 2001; Kozak and Kozak, 2003; Pearson *et al.*, 2005;

Segura and Kanninen, 2005; Colgan *et al.*, 2013; Molto *et al.*, 2013; Mate *et al.*, 2014). The finding of this study indicate that the mean biomass estimation of a bamboo tree in Sele-Nono forest (10.97 Kg ± 2.68 Kg) when predicted by Yigardu Mulat & Maseresha Feten (2013) was equivalent to the mean biomass estimation of *Arundinaria alpine* in Kenya; which was estimated at 10 Kg (Muchiri and Muga, 2013). This current study thus can be a supplementary data source to increase the precision for a mean biomass of a highland bamboo, which is close to 10 Kg.

5.1.3.5. Validated fern tree biomass model for Sele-Nono forest

The model developed by Stanlay *et al.* (2003) best estimates the above ground biomass of fern trees in Sele-Nono forest. This model is a height dependent model and therefore it may indicate that the biomass of fern trees is more correlated with its height than its DBH. The best estimation of the tree fern by Stanlay model may be due to similar morphology (height, DBH and branches) of the fern trees in the current study with the *Cyathea* spp. of Belize forest, Central American moist tropical forest, a research site from which Stanlay model was developed (Stanlay *et al.*, 2003). A photographic illustration of *Cyathea* spp. on the other documents of Stanlay *et al.* (https://www.netl.doe.gov), which is the other version of Stanlay *et al.* (2003) document and prepared for conference presentation resembles quite the fern trees in Sele-Nono forest (https://www.netl.doe.gov).

The study also finds that the Brown *et al.* (2000) model developed for fern trees (*Cyathea* spp.) of the Brazil’s Atlantic forest has underestimated the biomass of the fern trees in Sele-Nono forest. This could be due to the fact that the Brown *et al.* (2000) model was developed from highly degraded forests with poor soil nutrient (Brown *et al.*, 2000) that might have resulted in the lower biomass. Studies conducted elsewhere have shown similar association of soil and forest stand biomass (Miyamoto *et al.*, 2013; Ahmad and Nizami, 2015).

Although Brown *et al.* (2000) is inappropriate for our study site, it has been applied for fern trees of Jimma moist forest, which is part of the Southwest forest of Ethiopia (Vanderhaegen *et al.*, 2015; De Beenhouwer *et al.*, 2016). This may be because these authors might have applied this model without checking the validation to trust it. Moreover, this study has also shown that the overestimation of the fern tree biomass when Beets *et al.* (2012) model was applied. This may be associated with the methodology when Beets *et al.* (2012) developed the model. Beets got his observed biomass from the volume and wood density data where the volume was calculated using truncated cones formula. However, many studies suggest that using truncated volume would be appropriate for woody plants having solid volume; whereas it overestimates non-woody plants like fern trees whose trunks are hollow due to the lack of secondary cambium (Dean, 2003; Large and Braggins, 2004; Ough and Murphy, 2004; Dudani *et al.*, 2014). Moreover, the Beets model was developed for fern trees including different genera such as *Dicksonia* spp, Silver fern apart from *Cyathea* spp.

5.1.3.6. Implication of validating existing biomass models

It is known that there are two extreme views arguing on the use of general allometric equation. One extreme opinion suggests to employ general allometric equation since site-specific allometric equations would not significantly improve the accuracy of the estimation (Gibbes *et al.*, 2007; Chave *et al.*, 2004, 2005, 2014); whereas the other extreme view condemns the use of general allometric equations as they lead to significantly a biased estimate (Basuki *et al.*, 2009; Djomo *et al.*, 2016; Nam *et al.*, 2016). However, the finding of this study lays in the middle of the two extreme views as it falsifies either of the hypothesis. According to this study, there were some existing general equations which really significantly bias the actual biomass of our current data sets (e.g. the use of Brown, 1997 model & the use of WBISPP, 2000); and there are also general equations which are reasonably accurate for estimating trees AGB of a forest (e.g. the use of Chave *et al.*, 2014 for trees in Sele-Nono forest). Therefore, the lesson that could be advocated from this study is the advantage of doing validation which involves looking for more appropriate candidate equations, and making comparisons and testing their performance with local data sets before rushing to a decision about what models a researcher has to use for forest biomass estimation work.

5.1.4. Tree height estimation methods in Sele-Nono forest

The study evaluated how precisely one could measure tree height as the uncertainty in tree heights can translate into uncertainty in biomass estimates and/or carbon stock estimation. Heights of some mature trees with relatively smaller height, but bigger DBH (e.g. *Schefflera abyssinica*, *Ficus* spp., *Hallea rubrostipulata*, *Sapium ellipticum*) were not treated in the study as they are visually very notable that their DBH and height were uncorrelated and estimating their height from their DBH definitely produces pronounced errors; and consequently the finding of this research should not be applied for these plant types and the likes. This study evaluated visual estimation and DBH-H allometry for height estimation of trees in Sele-Nono forest, southwest Ethiopia. Accordingly, the results demonstrated clear differences between the methods.

The study revealed that visual estimation method was faster to decide, and the results were more repeatable across samples. The main disadvantage of the visual estimation method for the study site was the higher probability of overestimating the actual height of trees as indicated by higher error (Bias = 26.95%). In line with this finding Chave *et al.* (2005) after his long experience of forestry research claimed that tree height estimation using visual inspections are almost always considerably biased, as it is difficult to assess the size of vertical trees 10-40 m in height. This method might produce good results when used carefully by experienced foresters or vegetation ecologists (Tamrat Bekele, 1994; Teshome Soromessa *et al.*, 2004; Feyera Senbeta *et al.*, 2007; Ensermu Kelbessa and Teshome Soromessa, 2008) although we don't have data on how far they were certain in their estimation.

Similarly, the height estimation found in this study by Feldpausch 1 model notoriously overestimated the true height by 83% (Feldpausch *et al.*, 2011). This may be associated with the fact that this model was developed for the entire east African forests without discriminating forest types and climatic variation; and consequently inappropriate for the current study site. A number of studies goes in agreement to this notion where DBH-H models developed somewhere would be more prone to errors when applied to a different vegetation types (Huang *et al.*, 2000; Wang *et al.*, 2006; Nogueira *et al.*, 2008; Saunders and Wagner, 2008; Feldpausch *et al.*, 2011; Lines *et al.*,2012; Kearsley *et al.*, 2017).

The finding of this study also revealed that the height estimation of trees in Sele-Nono forest was less prone to error when estimated by Feldpausch 2 model (Bias = 6%). This low bias may be attributed to the fact that Feldpausch 2 model (Feldpausch *et al.*, 2011) have been developed for trees of moist east African forests from larger sample sizes (N = 1658 trees), which may include forests like the moist southwest forests of Ethiopia (Feldpausch *et al.*, 2011). Moreover, the moist forests of Uganda and Tanzania (selected moist east African forest to develop Feldpausch 2 DBH-H allometry) are thought to have similar forest stands (Physiognomy) to moist forests of Ethiopia (Kindt *et al.*, 2011), which might have made Feldpausch 2 model to yield less bias when applied to Sele-Nono forest. This further could be related to "Hydraulic limitation theory" which states that tree height is basically limited by water availability; and suggests that tree heights are more or less similar when grown in areas with similar rainfall distribution (Ryan and Yoder, 1997; Ryan *et al.*, 2006).

This study also indicates the underestimation of the actual height of trees when the equation of Brown (Brown *et al.*, 1989) and Niklas (Niklas, 1993) were used to trees of Sele-Nono forest. This may be attributed to the fact that those studies that were conducted in the moist tropical forests of Venezuela, Puerto Rico and Papua Guinea, which are geographically very far from the current study area. Moreover, most of the sample trees were dominated by small trees, and consequently might fail to accurately estimate the heights of large trees in Sele-Nono forest.

All in all, this study demonstrated that compared to Feldpausch 2, the other models have induced substantial errors (Bias > 10%) although the degree of acceptable error has been debated and often set subjectively. For instance, Williams and Schreuder (2000) compared diameter-only allometry to a diameter–height allometry and claimed a height error of up to 40% was acceptable in temperate forests. On the contrary, Molto *et al.* (2012) suggested that a height error of 2–5% is a substantial error; and may significantly influence estimates of aboveground biomass of a tropical forest in French Guiana. However, a 10% error is often regarded as an acceptable level of error in cross validation statistics (Pearson *et al.*, 2005; Walker *et al.*, 2012).

5.1.5. Carbon stock of Sele-Nono forest

5.1.5.1. Current carbon stock density in Sele-Nono forest

The mean (mean±SD) above ground carbon stock (AGC) of the forest was 88.92 ± 43.06 t C/ha. This is the cumulative result of above ground carbon stock density of trees, palms, bamboos, tree ferns, standing dead trees, shrubs, lianas and saplings. Our finding is closer to the value of other moist southwest forests such as Masha, Anderacha and Gesha which estimated their above ground carbon at 76.83 t C/ha (EWNRA, 2013). The inclusion of saplings, lianas and standing dead trees as part of AGC might have made the mean carbon stock density of Sele-Nono forest a bit higher than the value reported for Masha, Aderacha and Gesha forest. This carbon stock density of Sele-Nono Forest is higher than the carbon stock density of Ethiopian high forest which was reported at 101 t C/ha (Brown, 1997; Yetebitu Moges *et al.*, 2010) and the published average Ethiopia-wide data of 37 tC/ha (Brown 1997) and/or 47 t C/ha (FAO, 2000). However, our finding is in agreement with the carbon stock of the African-wide estimates of 30–200 t C/ha (Gibbs *et al.*, 2007) and global forest ranges of 20–400 t C/ha (Hairiah *et al.*, 2001). Our finding is also more comparable with the IPCC (2006) estimation of AGC of tropical mountainous system of Africa and tropical rain forest of Africa which were estimated at 54.1 tC/ha and 145.7 tC/ha respectively. Such large variation between our estimate in Sele-Nono forest and the estimate made for the other studies compared with could be attributed to geographical variation. It may also be attributed to the variation in the methods that were used for the carbon stock estimation in the forests. Moreover, variations in the methods for calculation and sampling techniques could also be another reason for the varying results.

The mean carbon stock in litter pool of the present study was estimated at 4.01±1.76 t/ha. The value of LC is greater than the values reported for other montane forests of Ethiopia such as Gedo forest (0.41±0.008 tC/ha) as reported by Hamere Yohannes *et al.* (2015), Adaba-Dodola community forest (1.06±0.31 tC/ha) as reported by Muluken Nega *et al.* (2015), Forest belt of Simen Mountains National Park (0.019±0.008 tC/ha) as reported by Tibebu Yelemfrhet and Teshome Soromessa (2015). These differences may be attributed to the difference in vegetation type which influences the composition of litter falls and its carbon stock. However, the LC of Sele-Nono forest is less compared to the LC estimated for selected church forests in Addis Ababa (4.95 tC/ha) (Tulu Tolla *et al.*, 2013) and dry montane forests such as Menagesha-Suba State forest (5.26 tC/ha) (Mesfin Sahile, 2011) and Mount Zequalla Monastery (6.5 t C/ha) (Abel Girma *et al.*, 2014). This low LC in Sele-Nono forest may be linked with the high moisture contents of litters in the current study area than those of the dry forests. In relation to this, Fisher and Binkly (2000) have said that geographic and climatic variation has an impact on the differences of litter biomass and their carbon contents in forests.

This study also indicated quite low mean carbon stock density of herbaceous vegetation (HC) (0.96±0.44 tC/ha) when compared with the other carbon pools. This may be associated to the fact that the forest is highly dominated by tall trees and shrubs having bigger canopies which compete for dominancy with herbs even if they are rich in their species composition (Friis *et al.*, 1982). Moreover, the low HC may be related to the fact that herbaceous vegetation donot have lignified tissues which are supposed to harbour more nutrients including carbon (Cornwell *et al.*, 2008). In addition, herbaceous vegetation normally has short life span as many of them are annuals and hence unable to capture and store carbon for long period (Waran and Patwardhan, 2001). It may be due to these factors that many other studies didn't include the herbaceous vegetation in their carbon accounting work (Watson, 2013; Watson *et al.*, 2013; EWNRA, 2013; Vanderhaegen *et al.*, 2015; De Beenhouwer *et al.*, 2016; Hamere Yohannes *et al.*, 2015; Tibebu Yelemfrhat and Teshome Soromessa, 2015) though others included it (Swai *et al.*, 2014; Ensslin *et al.*, 2015).

This study also showed that lying dead wood is the third most important carbon pool that contributes largely to the entire biomass of the forest next to the AGB and BGB. Although it is often neglected in the assessment of carbon stock of a forest (Harmon *et al.*, 1986; Delaney *et al.*, 1998; Harmon and Hua, 1991), it yielded 10.04±6.35 t C/ha which is equivalent to 11% of the AGC in this study forest. This value of lying dead wood carbon stock density in Sele-Nono forest may indicate that Sele-Nono forest in cumulative sense is not too young or early successional forest (Harmon and Hua, 1991). This result goes with the finding of Delaney and Powell (1998) who reported the carbon stock in lying dead woods at 33.3-42.3tC/ha in tropical moist and wet forest of Venezuela, which were 9.6-12.4% of the total AGC. Keller *et al.* (2001) also found the contribution of LDWs for about 16% of the AGC in the eastern Amazonia forest. Other study in the managed forests of temperate Australia also showed that LDWs contributed for about 19% of the total AGC (Roxburgh *et al.*, 2006).

In this study, the mean soil organic carbon (SOC) stored in Sele-Nono forest was estimated at 162.69 t C/ha (ranging from 36.38 tC/ha to 356.49 tC/ha). Almost similar results were reported in other southwest forests of Ethiopia. For example, the estimated soil carbon stock density of Jimma forest (De Beehouwer *et al.*, 2016), Bita forest (Abebayehu Aticho *et al.*, 2013) and Gera forest (Mohammed Abaoli and Bekele Lemma, 2014) were reported 150 tC/ha, 120 tC/ha and 95 tC/ha respectively. Our finding is also slightly higher than the default value of 130 t C/ha given by IPCC for volcanic soils (Lasco *et al.*, 2004). These differences in SOC may be attributed to differences in soil bulk densities, which could be the consequences of differences in soil types, vegetation types, climatic and forest management practices. The mean soil bulk density of Sele-Nono forest was low (1 gcm^{-3}, Appendix 27) which indicates that the study forest has high organic matter (OM) content in the soil (Brady, 1974). In line with this view researchers claim that a soil with low bulk density are often with high organic matter contents (Grigal and Vance, 2000; Sharma and Bhattacharya, 2017). Thus, the higher mean SOC stock may be due to the presence of high SOM and fast decomposition of litter which results in maximum storage of soil carbon stock (Sheikh *et al.*, 2009). The soil carbon content of Sele-Nono Forest ranges from 1.22 % to 11.37% with the mean carbon content of 6.03%. This may indicate that the soil of the study forest belongs to organic soil category than mineral soil. Pedologist often suggest that soils with > 5% of carbon content are regarded as organic soil, which otherwise referred as mineral soil (Sposito, 2008; Brady and Weil, 2016).

Overall, this study revealed that the soil of the study forest has the largest carbon stocking capacity and was found to store almost twice of the carbon stored in AGB. This goes with the result of Peruvian moist tropical forest which had twice as much carbon in soil as in aboveground biomass (Gibbon *et al.*, 2010). In the same way, the total SOC obtained in Hanang forest of Tanzania had accounted for 72.9% of the total forest carbon (Swai *et al.*, 2014). Other studies in Tanzanian Afromontane forests also reported higher amounts of carbon in the soil than for above ground biomass (Munishi *et al.*, 2000; Munishi and Shear, 2004). In line to these findings wider survey on the carbon contents of tropical forests reported the occurrence of 2/3 of the terrestrial carbon in soils (Bolin and Sukumar, 2000; Lasco *et al.*, 2004; IPCC, 2005). These seem reasonable as forest soils are not as utilizable as forest woods; and may account for higher carbon storage. However, other studies found contradictory results. For example, Djomo *et al.* (2011) suggested that an African moist tropical forest had more than three times as much carbon in aboveground biomass as in soil whereas Dixon *et al.* (1994) suggested virtually equal proportion (1:1) of carbon storage in the entire tropical forests worldwide. The differences among such reports with respect to our current study in Sele-Nono forest might be due to the variation in a number of factors including vegetation composition, disturbance history, successional stage, climate, and soil fertility.

5.1.5.2. The role of Sele-Nono forest to mitigate climate change

The finding of this study reveals that soils, above ground & below ground biomasses and lying dead woods are the most important carbon pools to store majority of the carbon in Sele-Nono forest. Similar findings were reported in other studies conducted elsewhere (Sierra *et al.*, 2007; Ngo *et al.*, 2013). Even among these four pools, the first two pools (soil and AGB) influences the current overall carbon storage of the forest, which is in concordance with other studies conducted elsewhere in Ethiopia (Adugna Feyissa *et al.*, 2013; Abel Girma *et al.*, 2014; Alefu Chinasho *et al.*, 2015; Hamere Yohannes *et al.*, 2015; Muluken Nega *et al.*, 2015; Tibebu Yelemfrhat and Teshome Soromessa, 2015). However, this result contrasts with the patterns observed by those studies who regarded the contribution of AGB higher than the soil contribution in climate change mitigation target. In this current study, the overall carbon stock of Sele-Nono forest is substantially dependent on the SOC followed by AGC. The contribution of soil for higher total carbon stock density than AGB was also indicated in other forests of Ethiopia (Alefu Chinasho *et al.*, 2015; Marshet Tefera and Teshome Soromessa, 2015) and elsewhere outside Ethiopia (Batjes, 1996; Eswaran *et al.*, 1993; Schulze and Freibauer, 2005).

In a nutshell, this study indicates that Sele-Nono forest has a considerable effect in mitigating the global climate change in general and support the country's (Ethiopia) effort in particular to meet international obligations towards climate change mitigation. It was estimated that Sele-Nono forest currently sequestered an average of 1045.25 tCO_2 per hectare (Table 34). The total average carbon stock of this forest was estimated at 284.81±107.81 tC/ha. This value seems comparable with Lewis *et al.* (2009) who estimated total average forest carbon stocks of Africa at 202 tC/ha. While comparing with other studies (Table 34), the mean total carbon stock density of Sele-Nono forest is more comparable to the Gera moist Afromontane forest which was estimated at 230.09 tC/ha (Mohammed Abaoli and Bekele Lemma, 2014) to 336.96 tC/ha (Vanderhaegen *et al.*, 2015). This might be due to the fact that Gera is structurally and compositionally more alike to Sele-Nono and is geographically more proximal to it when compared with others (Kumelachew Yeshitela and Simon Shibru, 2004). The Jimma high forest showed higher carbon stock potential than Sele-Nono; and this might be due to their more intact nature due to their protection from human interference (De Beenhouwer *et al.*, 2016). In addition, the observed anthropogenic threats including previous logging and encroachment could be the reason for the low carbon amounts in Sele-Nono forest when compared to the intact Jimma forest (De Beenhouwer *et al.*, 2016).

Table 34. Comparison of Sele-Nono forest carbon stock density with some other moist montane forests of the country

S/N	**Moist Afromontane Forest**	**Author/s**	**Mean total carbon stock (tC/ha)**	**Mean total stored Carbon-dioxide (tCO$_2$eq/ha)**	**Remark (included pools)**
1	Sele-Nono	This study (2018)	284.81	1045.25	All pools
			106.7	391.58	AGB, BGB
2	Gera	Mohammed Abaoli and Bekele Lemma (2014)	230.09	844.4303	AGB, BGB, SOC
		Vanderhaegen *et al.* (2015)	336.96	1236.6432	All pools
3	Jimma	De Beenhouwer *et al.* (2016)	413	1515.71	All pools
4	Masha/Anderacha/Gesha	EWNRA (2013)	76.83	281.9661	AGB, BGB
5	Bale (moist nondegraded forest part	Watson *et al.* (2013)	289	1060.63	AGB, BGB
6	Bale (moist degraded forest part	Watson *et al.* (2013)	199	730.33	AGB, BGB

However, when the comparison is only with AGB and BGB, the carbon stock of Sele-Nono forest would be more related to Masha, Anderacha and Gesha forest. Although the Watson's report on Bale Moist Afromontane forest did include only AGB and BGB, its carbon stock looked much higher than the current report on Sele-Nono forest. When compared only these two pools, the carbon stock of Sele-Nono forest is three times lower than the carbon stock of relatively un-degraded Bale moist forest and two times lower than the degraded Bale moist forest. This may show that Bale moist forests harbour more abundant bigger and matured tree than Sele-Nono (Watson, 2013; Watson *et al.*, 2013). In line with this assumption, Grace (2004) claim that forest types with larger trees accumulated more biomass and carbon stock than forests with smaller sized trees. The differences in their AGC and BGC may also be attributed with the differences in allometric equations used to change tree measurable parameters to carbon stocks. Geographical distance between Sele-Nono and Bale could also be another factor for the variation in their AGC and BGC. The use of visual estimation of tree height, which is often claimed to overestimate carbon stock values, could be another reason for higher values of AGC in Bale forest when compared to this study at Sele-Nono forest.

5.1.5.3. Estimated amount of total carbon dioxide equivalent absorbed by Sele-Nono forest and its role for sustainable forest management

The finding of this study reveals that more than 157 million t CO_2eq have so far been absorbed from the atmosphere by the current stand of Sele-Nono forest. We think that this value is a more precise estimate as it passed through a lists of quality controls (Appendix 30). This time there is a new business area called carbon market/carbon trade where units of CO_2 emission reductions (also known as carbon credits or tons of carbon dioxide equivalents, tCO_2eq) have become a tradable commodity (Stern, 2006; Capoor and Ambrosi, 2008; Eliasch, 2008; Hamilton *et al.*, 2008; Diaz *et al.*, 2011). So if this large absorption of atmospheric CO_2 is known by the REDD + project and/or by other partners looking to offset their emissions, then upon negotiation they could purchase it from Sele-Nono forest following the legitimate chain so as to make it their alternative viable land option for balancing their emissions (UNFCCC, 1997; IPCC, 2007). This business area arises either as a result of restrictions to emissions imposed on nations and businesses to meet international obligations, or from green businesses and consumers that want to offset their own private emissions (Beane, 2012).

Upon the sale of the absorbed atmospheric CO_2, the quantity of financial prize for enhancing conservation of Sele-Nono forest would approximate 1billion USD. Hence, the government of Ethiopia, particularly the REDD + Ethiopia, has to strive to negotiate this much money of emissions reduction payments from the sale of carbon and shall deploy for the local people of the district for justifiable forest management and climate change mitigation practices. This suggestion also goes with the climate resilient growth economy (CRGE) strategy of our country's developmental agenda as shown by the report of the ministry of Environment and Forestry of Ethiopia (MoEF) (MoEF, 2011). Similar kinds of business have been exercised elsewhere based on their carbon impacts. For instance, Norwegian government, one of the REDD+ partnership, has provided 1 billion USD to the government of Indonesia and about 250 million USD to Guyana in return of conserving their forest for carbon stock purpose (Caravani *et al.*, 2012). The same government also offered 80 million USD grant to Ethiopia to the effort that the country has made to prevent climate change (Yisehak Dinku, 2017).

5.1.6. Formulation of species specific allometric equation

5.1.6.1. Model development of trees in Sele-Nono forest

Developing & applying both site specific and species specific allometric equations is the first option for estimating above ground biomass (AGB) of trees (Brown *et al.*, 1989; Chave *et al.*, 2001; 2003; Navar, 2009a). With regard to this fact, this study formulated a model with a power function for *Albizia gummifera* ($AGB = 0.0117\ (\rho{*}DBH{*}H)^{1.32066}$), *Mimusops kummel* ($AGB = 12.5519\ (\rho{*}DBH{*}H)^{0.70164}$) and *Syzygium guineense* ($AGB = 0.98297 * (DBH)^{2.07016} * (\rho)^{1.00601} * (H)^{0.06249}$) where AGB is the dry biomass in kg, DBH is in cm, H is total height in m and ρ is the wood density in g/cm^3. Although Power functions are claimed to be scarcely reported in the scientific literature (Zianis *et al.*, 2005; Navar, 2010), it is a kind of model many authors have used (Chave *et al.*, 2005; Ebuy *et al.*, 2011; Mesele Negash, 2013; Chave *et al.*, 2014). Many works on mathematical models for biomass advocates the superiority of the power function, notably for estimation of the AGB of trees (Parde, 1980; Fownes and Harrington 1991, Ketterings *et al.* 2001). This might be because power models show the relative increment of tree biomass as a function of some scaling exponent of two or more independent variables (Parde 1980; West *et al.*, 1999). In line with our finding Mesele Negash (2013) and Chave *et al.* (2005) Dietz and Kuyah (2011) and Chave *et al.* (2014) suggested that the power equation using DBH, height & wood density is claimed as the best model for modelling AGB of trees.

5.1.6.2. Selection of model predictors for biomass allometry

This current study included wood density value in addition to tree height (H) and DBH as the most important predictor of tree biomass which leads to a substantial improvement for the biomass estimation of *Albizia gummifera, Mimusops kummel* and *Syzygium guineense* in Sele-Nono forest. This might be due to the fact that density (ρ) is directly proportional to mass (AGB) that makes it more relevant tree parameter to accurately estimate the biomass of trees. In support of this study, some recent studies elsewhere also revealed the relevance of including wood density in combination with DBH and H to estimate the biomass of trees (Deans *et al.*, 1996, Ash and Helman, 1990; Baker *et al.*, 2004; Chave *et al.*, 2005; Hung *et al.*, 2012; Nogueira *et al.*, 2007; Navar, 2009a, Navar, 2010; Chave *et al.*, 2014). In contrary to this study, other studies demonstrated the use of DBH alone to provide more accurate estimate than using two or more parameters for predicting total AGB (Brown, 1997; Ter-Mikaelian and Korzukhin 1997, Ketterings *et al.*, 2001, Gibbs *et al.*, 2007, Sawadego *et al.*, 2010). For instance, allometric model based solely on DBH was found to accurately predict biomass in *Eucalyptus pilularis* (Montagu *et al.*, 2005). Litton and Kauffman (2008) compared the efficiency of their allometric model developed for *Dodonaea viscosa* with basal diameter as the sole predictor variable with other allometric equation developed for the same species from Aplet *et al.* (1998), who used both basal diameter and total height. Their findings revealed that the equation with single parameter estimated the biomass of *Dodonaea viscosa* more accurately than using more parameters. But this fact was not the usual case in the scientific literature. Authors such as Vieira (2008), Hunter *et al.* (2013) and Rutishauser *et al.* (2013) suggested the addition of tree height in addition to DBH for better accuracy of tree biomass estimation. Other studies also concluded that the use of more parameters would improves the accurate biomass estimation (Chave *et al.*, 2005; 2014). In regard to this our current model could also be the witness.

5.1.6.3. Model validation of species specific allometric equations

Studies focusing on the comparison of tree AGB estimates by different allometric models are scarce in the published scientific literature (Ares and Fownes, 2000; Jenekins, 2004; Navar, 2010; Sileshi Guta, 2010; Mandal, 2013) and probably only few papers are available in Ethiopia (Woldeyohanes Fantu *et al.*, 2007; Mesele Negash, 2013; Mehari Alebachew, 2015; Nigatu Wondrade *et al.*, 2015) and this study could be among the few in this regard.

This current study generally showed the tendency for the overestimation of the AGB when the Brown pantropical equation is used as compared to the newly formulated site specific equations. This finding coincides with the finding of Nigatu Wondrade *et al.* (2015) who compared AGB of *Croton macrostachyus* and *Cupressus lucitanica* using local species specific equations developed by Asferachew Abate *et al.* (2004) and pantropic general allometric equations of Brown (1997) in the Lake Hawassa Watershed, Ethiopia. Among the general equations, Brown and WBISPP models are more inappropriate models to estimate the biomass of our trees (*Albizia gummifera*, *Mimusops kummel* and *Syzygium guineense*) in Sele-Nono forest. In contrary to our finding, Chave *et al.* (2005) and Gibbs *et al.* (2007) pointed out the relevancy of general allometric equation than local species-specific allometric equations. They claim these because they thought the local equations would not improve accuracy significantly. A possible explanation for higher prediction when applying the model of Brown and WBISPP to the current data is probably the difference in wood density and tree architecture. This current study also revealed that the Brown model (Brown, 1997) gives more exaggerated biased estimates than even Chaves' model (Chave *et al.*, 2005; 2014). Similar findings were noted elsewhere by Vieilledent *et al.* (2012) and Hung *et al.* (2012) who compared Brown's and Chave's equations to the moist trees of Madagascar and Viet Nam respectively. Eyosias Worku and Teshome Soromessa (2015) also supported the overestimation of biomass when Brown equation was applied to their observed data of *Juniperus procera* and *Podocarpus falcatus.* Litton and Kauffman (2008) also found related results when they compared Brown, Chave 1 and Chave 2 with the harvested biomass of *Metrosideros polymorpha* (the most common native tree in the Hawaiian land). Earlier study in the Hawaiian forest also suggested the irrelevancy of general allometric equations to predict tree biomass (Litton *et al.*, 2006).

This study on validation of species specific allometric equations generally confirmed the importance of our local allometry for the better estimation of AGB of *Albizia gummifera*, *Mimusops kummel* and *Syzygium guineense* in Sele-Nono forest than the other general models do. This might be due to the fact that our model takes into account the site effects. Results obtained in this study and elsewhere (Brown *et al.* 1989, Brown & Iverson 1992) also supports the necessity of developing specific biomass models for each region and forest type in the tropics.

5.2. CONCLUSIONS

- Sele-Nono forest covering 150, 325.27 ha area of land is characterized by mosaics of landscape. Some of these landscapes have an intact and more protected vegetation as in for example in community types 1 and 4, which may be due to their occurrence on suitable habitat and the role of the traditional knowledge of the local people to the forest (also called the KOBO system). On the contrary, some parts of the forest especially those that are represented by community types 2 and 6 are more degraded

- The forest is a reservoir of diverse vascular plants (414 species with beta diversity ( ) >12) of which 25 of them (6%) were endemic and about 88 of them (~ 50%) were rare species. Moreover, among the total woody species (176 species) in this study area, close to 33% (58 species) were identified to have poor reproduction & recruitment; and about 7% (12 species) showed to have no regeneration.

- Structurally, Sele-Nono forest is a late successional forest as it is largely characterized by small sized woody species and abundant trees of DBH > 20 cm (density = 691 ha^{-1}) along with 2-3 tree stories. The forest is also characterized by poor regeneration status as evidenced from poor density of seedling and saplings (< 50 ha^{-1}) for the majority of the woody species (75. 5%).

- Validated allometric equation was found to be helpful in estimating the aboveground biomass of Sele-Nono forest with better accuracy. The models developed by Chave *et al.* (2014), Brown *et al.* (2002), Schnitzer *et al.* (2006), Yigardu Mulat & Maseresha Fetene (2013) and Stanlay *et al.* (2003) were robust in predicting the above ground biomass of trees, palms, lianas, highland bamboos and fern trees (Cyathea manniana) respectively with an acceptable level of prediction error (Bias ≤ 10%). Moreover, the DBH-H allometric model developed by Feldpausch *et al.*

(2011) for East African moist forests was more precise to estimate height of trees in the forest rather than the usual visual estimation method.

- Tree climbing method was found to be an important feasible method for validating proposed allometric models and for formulating new allometries for aboveground biomass estimation of trees in the study area.

- Sele-Nono forest plays a considerable role in mitigating climate change as it has sequestered large amount of CO2 from the atmosphere (157.12 Mt of CO2e) and stocked with large amount of carbon (284.81 t C/ha) from emission to the atmosphere. The soil and above ground biomass are major carbon sinks in the forest and hence any sort of forest conversion would exacerbate greenhouse gas emission.

- Although Sele-Nono forest is a biodiversity rich area and contributes to climate change mitigation, it is being threatened through deforestation and selective logging. If these threats are not managed well, the forest might lose its contribution to climate change mitigation.

5.3. RECOMMENDATIONS

1) Sele-Nono forest with a large area coverage and rich plant biodiversity shall be developed as a Biosphere Reserve as such system provide the possibility to compartmentalize the forest into core zone, transition zone and buffer zone. This approach further would provide adequate protection to the forest and sustainable use of the resources for the communities around the forest.
2) Measurement of lying dead woods shall be considered in any carbon stock research of a forest ecosystem in Ethiopia.

3) Provision of environmental education to strengthen the existing participatory forest management (PFM) and KOBO systems to the local people to minimize uncontrolled logging in the forest.
4) The endemic (25 in number) and rare plant species (88) identified in this study shall be given highest priority for conservation by Oromia Forest and Wildlife Enterprise (OFWE) and the nearby higher educational institutions and other relevant stakeholders.
5) Among the plant community types in the forest, community types 2 and 6 are among the prioritized areas for possible protection as these areas have been under high level of threat.
6) Woody species identified to have poor reproduction and recruitment in the analysis of population structure (58 species) and regeneration status (12 species) are recommended to be prioritized for possible intervention for conservation efforts in the forest.
7) The allometric models validated to be appropriate for this study could be used in forests close to Sele-Nono.
8) Tree climbing method with improved facilities to be used for future allometric studies for developing biomass equations as many tree species in the SW do not have local allometry.
9) Provision of the study report on carbon stock to Oromia Forest and Wildlife Enterprise (OFWE) and the national carbon stock database of Ethiopia to encourage possible REDD+ activities and financial rewards to communities around the forest.
10) The result of this study could serve as a baseline to reassess and monitor the status of the forest in terms of composition, structure and carbon stock at regular intervals to take appropriate actions for conservation.

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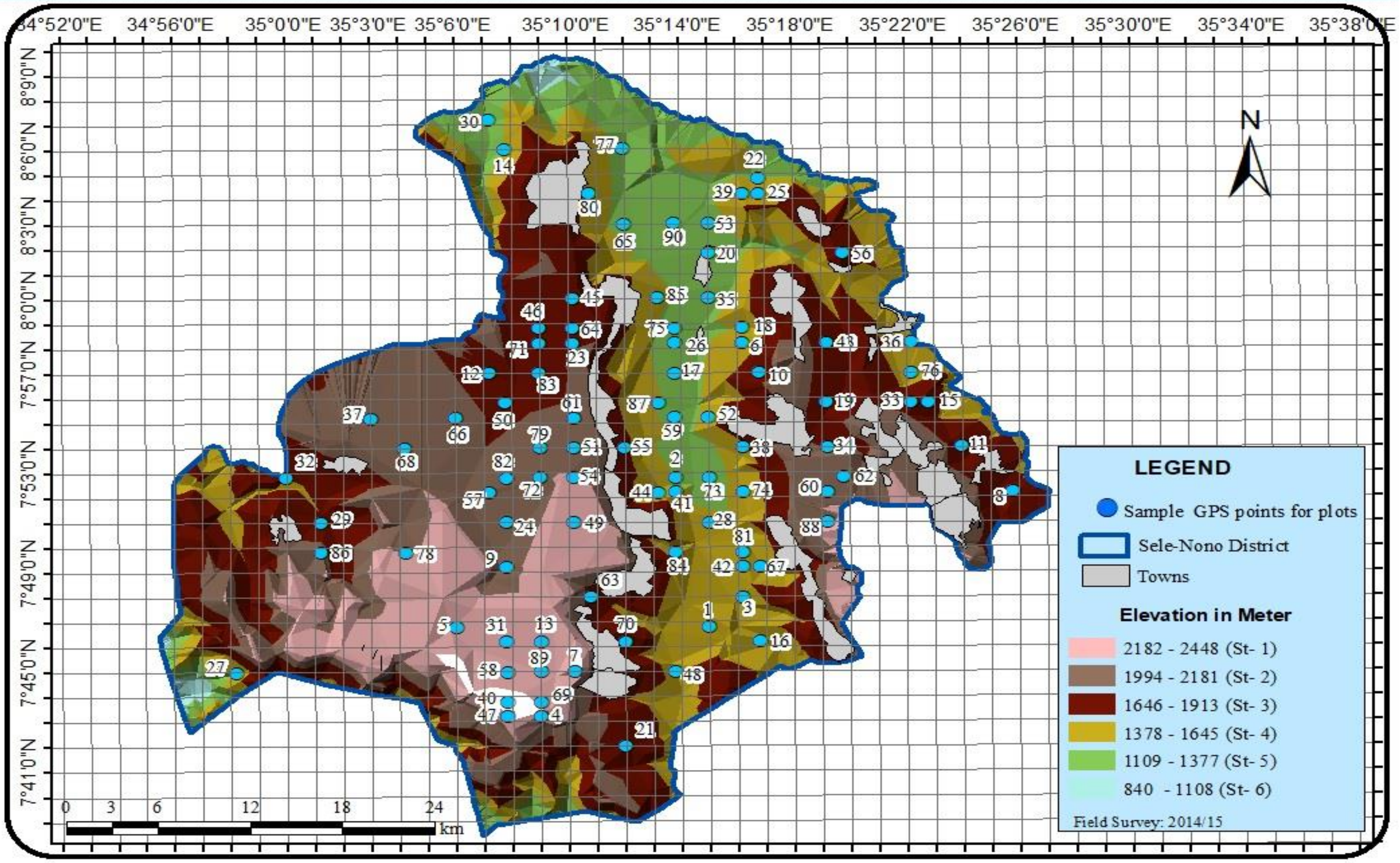
Appendix

Appendix 1. Geographical grids and GPS points used to establish the location of sample plots in the study area

Appendix 1A. Geographical grids drawn on Sale-Nono forest to establish the location of sample plots



Appendix 1B. GPS points for sample plots used for the study

Plot No.	Northing	Easting	Altitude	Strata Number
1	7°47’00’’	35°15’00’’	1640	4
2	7°53’00’’	35°14’00’’	1165	5
3	7°48’00’’	35°16’00’’	1640	4
4	7°43’00’’	35°09’00’’	2400	1
5	7°47’00’’	35°06’00’’	2240	1
6	7°58’00’’	35°16’00’’	1640	4
7	7°45’00’’	35°10’00’’	2430	1
8	7°52’00’’	35°26’00’’	1872	3
9	7°49’00’’	35°08’00’’	2180	2
10	7°57’00’’	35°17’00’’	1740	3
11	7°54’00’’	35°24’00’’	1620	3
12	7°57’00’’	35°07’00’’	1830	3
13	7°46’00’’	35°09’00’’	2380	1
14	8°06’00’’	35°08’00’’	1430	4
15	7°56’00’’	35°23’00’’	1850	3
16	7°46’00’’	35°17’00’’	1640	4
17	7°57’00’’	35°14’00’’	1230	5
18	7°59’00’’	35°16’00’’	1280	4
19	7°56’00’’	35°19’00’’	1880	3
20	8°02’00’’	35°15’00’’	1100	5
21	7°42’00’’	35°12’00’’	1860	3
22	8°05’00’’	35°17’00’’	1200	5
23	7°58’00’’	35°10’00’’	1820	3
24	7°51’00’’	35°08’00’’	2010	2
25	8°04’00’’	35°17’00’’	1600	4
26	7°58’00’’	35°14’00’’	1190	5

27	7º45’00’’	34º58’00’’	940	6
28	7º51’00’’	35º15’00’’	1636	4
29	7º51’00’’	35º01’00’’	1900	3
30	8º07’00’’	35º07’00’’	1250	5
31	7º46’00’’	35º08’00’’	2300	1
32	7º53’00’’	34º60’00’’	1905	3
33	7º56’00’’	35º22’00’’	1800	3
34	7º54’00’’	35º19’00’’	1885	3
35	8º00’00’’	35º15’00’’	1350	5
36	7º58’00’’	35º22’00’’	1394	4
37	7º55’00’’	35º03’00’’	2070	2
38	7º54’00’’	35º16’00’’	1625	4
39	8º04’00’’	35º16’00’’	1500	4
40	7º44’00’’	35º08’00’’	2350	1
41	7º52’00’’	35º14’00’’	1900	2
42	7º49’00’’	35º16’00’’	1600	4
43	7º58’00’’	35º19’00’’	1840	3
44	7º52’00’’	35º13’00’’	1630	4
45	8º00’00’’	35º10’00’’	1865	3
46	7º59’00’’	35º09’00’’	1910	3
47	7º43’00’’	35º08’00’’	2353	1
48	7º45’00’’	35º14’00’’	1645	4
49	7º51’00’’	35º10’00’’	2272	1
50	7º56’00’’	35º08’00’’	1655	3
51	7º54’00’’	35º10’00’’	2120	2
52	7º55’00’’	35º15’00’’	1420	4
53	8º03’00’’	35º15’00’’	1160	5
54	7º53’00’’	35º10’00’’	2163	2

55	7º54’00’’	35º12’00’’	1800	2
56	8º02’00’’	35º20’00’’	1895	3
57	7º52’00’’	35º07’00’’	2083	2
58	7º45’00’’	35º08’00’’	2415	1
59	7º55’00’’	35º14’00’’	1126	5
60	7º52’00’’	35º19’00’’	2058	2
61	7º55’00’’	35º10’00’’	2100	2
62	7º53’00’’	35º20’00’’	2160	2
63	7º48’00’’	35º11’00’’	1865	3
64	7º59’00’’	35º10’00’’	1870	3
65	8º03’00’’	35º12’00’’	1220	5
66	7º55’00’’	35º06’00’’	2040	2
67	7º49’00’’	35º17’00’’	1634	4
68	7º54’00’’	35º04’00’’	2095	2
69	7º44’00’’	35º09’00’’	2344	1
70	7º46’00’’	35º12’00’’	1870	3
71	7º58’00’’	35º09’00’’	1880	3
72	7º53’00’’	35º09’00’’	2150	2
73	7º53’00’’	35º15’00’’	1276	5
74	7º52’00’’	35º16’00’’	1600	4
75	7º59’00’’	35º14’00’’	1160	5
76	7º57’00’’	35º22’00’’	1390	4
77	8º06’00’’	35º12’00’’	1134	5
78	7º50’00’’	35º04’00’’	2041	2
79	7º54’00’’	35º09’00’’	2020	2
80	8º04’00’’	35º11’00’’	1900	2
81	7º50’00’’	35º16’00’’	1640	4
82	7º53’00’’	35º08’00’’	2018	2

83	7º57’00’’	35º09’00’’	1850	3
84	7º50’00’’	35º14’00’’	1887	2
85	8º00’00’’	35º13’00’’	1760	2
86	7º50’00’’	35º01’00’’	2090	2
87	7º56’00’’	35º13’00’’	1420	4
88	7º51’00’’	35º19’00’’	2100	2
89	7º45’00’’	35º09’00’’	2440	1
90	8º03’00’’	35º14’00’’	1190	5

Appendix 2. Modified Braun-Blanquet scale for cover-abundance values (Van der maarel, 2005)

Scale	Cover/abundance
1	Rare, generally represented by 1-3 individuals (Cover < 0.5%)
2	Cover 0.5-1.5%
3	Cover 1.5-3%
4	Cover 3-5%
5	Cover 5-12.5%
6	Cover 12.5-25%
7	Cover 25-50%
8	Cover 50-75%
9	Cover > 75%

Appendix 3. Checklist used to determine level of disturbance of a sample plot in Sele-Nono forest

Date: _________ Northing: __________ Slope: _________ Altitude: __________

Plot no: _______ Easting: ____________ Aspect: _________ Plot features: ____________

Disturbance: _________ (as judged from the following criteria). Note that overall disturbance in a sample plot is calculated from the sum of the scales for each points of disturbance and dividing it by the total number of points of disturbances indicated below in the table.

Note: Ranking shall be given between 0 (not at all), 1 (very low), low (2), moderate (3), high (4), and 5 (very high) to the following lists of disturbance if occurred in the sample plot

S/N	Points of disturbance indicator/s	0	1	2	3	4	5	Remarks
1	Evidence of Crops							
2	Stumps							
3	Fallen woody stems							
4	Evidence of trails							
5	Browsed or grazed plants							
6	Cattle droppings							
7	Cattle footprint							
8	Evidence of fire (e.g. Burned tree stems)							
9	Soil extraction for pottery							
10	Diggings for Dioscorea roots or other crops							
11	Other (if any)							

Note that each points or indicators of disturbance listed in the table above were scaled following Anderson and Currier (1973) with some modification. Each points of disturbance were scaled 0–5, with “0” if the plot was not disturbed with that point of disturbance, “1” when 1-20% of the quadrat disturbed with that specific point of disturbance, “2” when 21-40% of the quadrat disturbed with that particular point of disturbance, “3” if 41-60% of the quadrat disturbed with that specific point of disturbance, “4” if 61- 80% of the quadrat disturbed with that specific point of disturbance, “5” when 81-100% of the quadrat disturbed by that specific point of disturbance.

Appendix 4. Semi-structured interview checklist

Participant code: _______________

Village code: ___________________

Interview date: _________________

1. Personal history: Gender: ______ Age: ______ Language: ________
2. Where are you from originally?
    a) Born here (village):_________ (mention the specific village)
    b) Not born here: ____________(mention the place or village)
3. If your answer to question number 2 is a, for how long have you lived here?
    ____
4. If your answer to question number 2 is b, why did you move here?
    ____
5. How would you describe the importance of the forest to the local people?
    ____
    ____
    ____
    ____
6. Has forest coverage in the area changed (e.g. area covered by forest diminished than before)?
7. If yes, Please explain what factors were responsible for this?
    ____
    ____
    ____
    ____
8. Do you know exactly which areas (or villages) of the forest are cleared more?
    ____
9. If yes, why? (explain)
    ____
    ____
    ____
    ____
10. Has forest quality in the area changed (e.g. more/less trees than before)? __________
11. If yes, what were the main reasons responsible for this? (Please explain your answer)
    ____
    ____
    ____
    ____
12. When did these factors started to affect the forest? as far back as you can remember
    ____
    ____
13. Have your views to disturb the forest changed since you were a child?
    a) Yes
    b) No
14. Please explain your answer for question number 13?
    ____
    ____

____

____

15. Are there people inside/outside your community trying to convince villagers to conserve forests, other than the government?
    a) Yes
    b) No
16. If yes, who are they and what do they do?

____

____

____

____

17. Are there any forest laws /regulations or customs exist in the area (Village/District) that might have played in maintaining the forest coverage?

____

____

____

18. Have your views on these laws/regulations or customary practices changed over time?
    a) Yes
    b) No
19. If yes; how and why?

____

____

____If no; why?

____

____

____

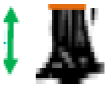
Appendix 5. Non-destructive data collection sheet for biomass estimation of trees using tree climbing method

Study site: _____________ Location: ____Stratum: ______________Plot:__________________

- ✓ Name of the tree: ________________Code:__________
- ✓ Tree Height (m): _____DBH (cm):____DSH (cm):_____wood density (g/cm^3):______
- ✓ Tree size category (small/medium/large)

Appendix 5A. Tree measurement (Biomass measurment of stump, bole, large and small branchs and foliages)

A. Stump volume measurement *(stump is defined as the main trunk from the ground up to 30 cm high)*

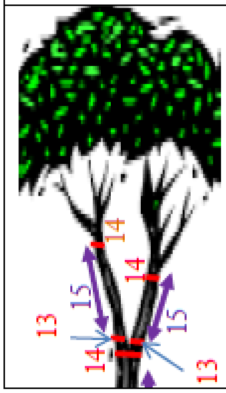
Stump volume	Lower diameter (cm)	Upper diameter (cm)	Interval length (cm)	Remark
				

B. Bole (B) volume measurement

The bole is the main trunk of the tree from the stump to the first major branch. Measurement Starts at the bottom of the bole, divide the bole into appropriate sections and measure the dimension of each section below

Bole (B) volume	S/N	Bole Section (BS) number	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)	Remark
	1	BS1				
	2	BS2				
	3	BS3				
	4	BS4				
	5	BS5				
	⋮	⋮	⋮	⋮	⋮	⋮
	nthB	BSn				

C. Large branch (LB) volume measurement (Branches ≥10 cm in basal diameter)

Large branch (LB) volume measurement	S/N	Large branch Section (LBS) number	Bottom diameter (cm)	Top diameter (cm)	Length of section (cm)	Number of visually similar branches	Remark
	1	LBS1					
	2	LBS2					
	3	LBS3					
	4	LBS4					
	5	LBS5					
	6	LBS6					
	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	nth LB	LBSn					

D. Small branches volume measurement (branches $2.5 < d <$10 cm, where d is basal diameter)

*Count total number of SBs: ____________________

*Trim randomly three (A, B, C) small branches (SBs) and measure the dimensions as usual, where A, B, C are branch category with d=7.5-10 cm, b=5-7.5 cm & c=2.5-5 cm. respectively

	Section number	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)	Total volume of each trimmed branches	Average volume of small branches (per tree)
Trimmed Small branch (SB)A	SBA1					
	SBA2					
	SBA3					
	SBA4					
	SBA5					
Trimmed (SB)B	SBB1					
	SBB2					
	SBB3					
	SBB4					
	SBB5					
Trimmed (SB)C	SBC1					
	SBC2					
	SBC3					
	SBC4					
	SBC5					
Average tree volume of small branches (per tree)						

E. Field measurement for biomass estimation of foliage (leaves & twigs with d<2.5)

S/N	Total fresh mass	Total fresh foliage weight per SB(Av.TF)= $(F_{SBA} + F_{SBB} + F_{SBC})$	Average total fresh foliage weight per SB (Av.TF)=$(Av.TF/3)$	Subsample fresh foliage mass (300-500 gm) from well mixed fresh composite sample
1	Total fresh weight of foliage that are completely removed from SBA (F_{SBA})			
2	Total fresh foliage mass that are completely removed from SBB (F_{SBB})			
3	Total fresh foliage mass that are completely removed from SBC (F_{SBC})			

F. For wood density determination

Note: cut three representative samples from each of the SBs

S/N	Tree number	Disc 1 (from SB1)	Disc 2 (from SB2)	Disc 3 (from SB3)
1	Tree 1			
2	Tree 2			
3	Tree 3			
⋮	⋮	⋮	⋮	⋮
n	Tree n			

Appendix 6. **Lab works**

A. Foliage biomass estimation through wet-dry ratio of subsamples

S/N	Total number of SB (a)	Average total fresh foliage mass per SB (b)	Subsample fresh foliage mass per SB (c)	Subsample dry foliage mass per SB (d)	Average total dry foliage mass per SB (e)= $\left(\frac{b*d}{c}\right)$	Total foliage biomass of sample tree=e*a

(B) Lab work for wood density (ρ) determination *(note that volume of discs were measured using the principle of Archimedes via water displacement method after they were saturated for 48 hours; discs dry weight were achieved by ovening them at 105°C for 48 hours)*

S/N	Tree number	Discs	Disc fresh volume (V)	Disc oven dry weight (M) (gm)	Disc density ρ=M/V	mean density per tree
1	Tree1	Disc 1				
		Disc 2				
		Disc 3				
2	Tree 2	Disc 1				
		Disc 2				
		Disc 3				
3	Tree 3	Disc 1				
		Disc 2				
		Disc 3				
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	Tree n	Disc 1				
		Disc 2				
		Disc 3				

Appendix 7. Format for biomass determination of trees with minor destruction following Picard (2012)

Tree name: _________ Tree code_________
Tree parameters: Height ___________DBH___ Wood density_______________
Reason of validation: to affirm the applicability of an equation before it can be applied to the forest (i.e., to get more appropriate and trusted equation)

A. Stump biomass

S/N	Stump ID	Volume estimation (V)				Wood density (ρ)	Stump biomass =V * ρ
		Diameter & interval length			V= πr^2h Where $r^2 = \left(\frac{d_{bot}^2 + d_{top}^2}{8}\right)$		
		d_{bot} (cm)	d_{top} (cm)	Interval length (h)(cm)			

B. Bole biomass estimation

S/N	Section ID of the bole	Volume estimation (V)				Wood density (ρ)	Bole biomass =V * ρ
		Diameter & interval length			V= πr^2h Where $r^2 = \left(\frac{d_{bot}^2 + d_{top}^2}{8}\right)$		
		d_{bot} (cm)	d_{top} (cm)	Interval length (h)(cm)			

C. Large branch (d > 10 cm) biomass estimation

S/N	Section ID of the large branches	Volume estimation (V)				Wood density (ρ)	Large branch biomass =V * ρ
		Diameter & interval length			V= πr^2h Where $r^2 = \left(\frac{d_{bot}^2 + d_{top}^2}{8}\right)$		
		d_{bot} (cm)	d_{top} (cm)	Interval length (h)(cm)			

D. Small branch (2.5 cm < d < 10 cm) biomass estimation, where d is basal diameters

S/N	Total number of SB (N)	Average volume (V) of small branches per tree	Wood density (ρ)	Average biomass of small branches per tree (B)=V* ρ	Total biomass of small branches of a sample tree=B*N

E. Foliage biomass estimation

S/N	Total number of SB (N)	Average total fresh foliage mass per SB (a)	Subsample fresh foliage mass (300-500 gm) from well mixed fresh composite sample (b)	Subsample dry foliage mass per SB (c)	Average total dry biomass of foliage per SB (d)=$(a * c/b)$	Total foliage biomass of a sample tree (B)=d*N

F. Total biomass (Kg) of sample trees

Tree No	Stump Biomass	Bole Biomass	Large branch Biomass	Small branch Biomass	Foliage Biomass	Total Biomass	Remark
Tree 1							
Tree 2							
Tree 3							
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Tree 10							

G. Summary of local data for validating existing allometric models for biomass estimation of trees in Sele-Nono forest

Sample trees		**Dendrometric parameters**				**Observed biomass (Kg)**
Code	Botanical Name	DSH	DBH	H	Wood Density	
Tree 1	*Elaeodendron buchannani*	58	55	27	0.55	205.39
Tree 2	*Sapium ellipticum*	79	76	23	0.52	324.82
Tree 3	*Syzygium guineense* subsp. *afromontanum*	75	70	32	0.7	481.86
Tree 4	*Ficus ovata*	84	79	18	0.5	246.78
Tree 5	*Olea welwitschii*	97	94	34	0.78	995.92
Tree 6	*Manilkara butugi*	90	88	31	0.92	1031.3
Tree 7	*Trelepsium madagascarense*	65	60	34	0.5	292.66
Tree 8	*Ilex mitis*	50	48	29	0.65	186.25
Tree 9	*Schefflera abyssinica*	100	98	17	0.43	294.96
Tree 10	*Morus mesozygia*	45	43	22	0.58	106.07

Appendix 8. Validation format of palms using climbing method following Picard (2012)

*Note that palms are monopodial and they don't have both small and large branches. The nature of their woods also varies from forest trees.
Palm code: ________________
Palm parameters: Height __________ DBH__________ frond number_________ wood density__________

A. **Bole (Caudex) biomass determination** (Note that wood density estimated from wood discs sampled from the base of the thicker pinnae of the fronds)

S/N	Section ID of the caudex	Volume estimation (V)				Wood density (ρ) estimation					Caudex biomass=V * ρ
		Diameter & interval length			V= πr^2h Where $r^2 = \left(\frac{d_{bot}^2 + d_{top}^2}{8}\right)$						
		d_{bot} (cm)	d_{top} (cm)	Interval length (h)(cm)		Disc Id	Disc fresh volume (V)	Disc oven dry wt. (M) (gm)	Disc wood density (ρ) =M/V	Average density (per palm)	

B. **Frond biomass estimation**

S/N	Total number of pinnae in the fronds (a)	Total fresh weight of a randomly chosen single pinnae (gm) (b)	Taking subsample fresh weight from that single pinnae (gm) (c)	Oven dry weight of the subsample (d)	Total dry frond weight (gm)=$(b * d) * a/c$	Remark

C. Total biomass of sample palm trees

Sample No	Caudex biomass	fronds biomass	Total biomass	Remark
Sample 1				
Sample 2				
Sample 3				
Sample 4				
Sample 5				

D. Summary of local data for validating existing allometric models for biomass estimation of Palms (*Phoenix recliniata*) in Sele-Nono forest

Sample fern tree		**Dendrometric parameters**		**Observed biomass (Kg)**
Sample No.	Code	DBH	H	
Sample 1	Palm 1	23	24	180.443
Sample 2	Palm 2	26	27	264.542
Sample 3	Palm 3	16	18	122.387
Sample 4	Palm 4	19	20	143.926
Sample 5	Palm 5	21	23	194.438

Appendix 9. Validation format of fern trees using wet-dry mass ratio method

*Note that fern trees are monopodial and they don't have both small and large branches. The nature of their woods also varies from forest trees. Fern tree code: _________________
Fern tree parameters: Height ____ DBH______ frond number_____ wood density___

A. Bole (caudex) biomass estimation

S/N	Total fresh weight of the caudex (a)	Subsample fresh weight of the caudex (b)	Subsample dry weight of the caudex (c)	Total caudex biomass of sample fern tree (d) d=$(a * c/b)$

B. Fronds (Leaves) biomass estimation

S/N	Total number of pinnae in the fronds (a)	Total fresh weight of a randomly chosen single pinnae (gm) (b)	Taking subsample fresh weight from that single pinnae (gm) (c)	Oven dry weight of the subsample (d)	Total dry frond weight (gm)(e) e=$(b * d) * a/c$

C. Total biomass of fern trees

Sample No	Caudex biomass	fronds biomass	Total biomass	Remark
Sample 1				
Sample 2				
Sample 3				
Sample 4				
Sample 5				

D. Summary of local data for validating existing allometric models for biomass estimation of Fern trees (*Cyathea manniana*) in Sele-Nono forest

Sample fern tree		**Dendrometric parameters**		**Observed biomass (Kg)**
Sample No.	Code	DSH	H	
Sample 1	Fern tree 1	12	2.4	3.26
Sample 2	Fern tree 2	10	2.5	3.49
Sample 3	Fern tree 3	13	3.1	3.08
Sample 4	Fern tree 4	14	2.2	3.14
Sample 5	Fern tree 5	11	2.6	3.26

Appendix 10. Validation format of liana biomass using felling method

Liana code: ________________

Liana parameters: DBH __________ H__________ Stem wood density (ρ) __________

A. **Stem biomass determination** (Smalian measurements were taken after the sample liana were completely harvested)

S/N	Section ID of the stem	Volume estimation (V)				Wood density (ρ) estimation					Stem biomass=V * ρ
		Diameter & interval length			V= πr^2h Where $r^2 = \left(\frac{d_{bot}^2 + d_{top}^2}{8}\right)$						
		d_{bot} (cm)	d_{top} (cm)	Interval length (h)(cm)		Disc Id	Disc fresh volume (V)	Disc oven dry wt. (M) (gm)	Disc wood density (ρ) =M/V	Average density (per liana)	

B. **Leave biomass estimation**

S/N	Total weight of fresh leaves (a)	Subsample fresh leaves weight (b)	Oven dry weight of the subsample (c)	Total biomass of leaves per liana (gm)=$a * c/b$	Remark

C. Total biomass of liana ramets

Sample No	Caudex biomass	fronds biomass	Total biomass	Remark
Sample 1				
Sample 2				
Sample 3				
Sample 4				
Sample 5				

D. Summary of local data for validating existing allometric models for biomass estimation of lianas in Sele-Nono forest

Sample liana ramet		**Dendrometric parameter**	**Observed biomass (Kg)**
Sample No.	Botanical Name	DBH	
Sample 1	*Landolphia buchananii*	12	182
Sample 2	*Saba comorensis*	10	98
Sample 3	*Hippocratea africana*	11	105
Sample 4	*Combretum paniculatum*	8	64
Sample 5	*Gouania longispicta*	11	102

Appendix 11. Validation format of bamboo biomass using destructive method

Bamboo code: ____Bamboo parameters: Culm height __________ DBH__________ culm density__________

A. Culm biomass estimation (using wet-dry mass ratio method)

S/N	ID of the culm section	Total fresh weight of the culm section	Subsample fresh weight of the culm section	Subsample dry weight of the culm section	Total dry weight of the culm section	Remark

B. Leaves biomass estimation

S/N	ID of leaves section measured	Total fresh weight of the leaves (gm)	Subsample fresh weight of the leaves section (gm)	Subsample dry weight of the leaves section	Total dry weight of the leaves	Remark

C. Total biomass of sample bamboos

Sample No	Total Culm Biomass	Total Leave Biomass	Grand Total Biomass	Remark
Sample 1				
Sample 2				
Sample 3				
Sample 4				
Sample 5				

D. Summary of local data for validating existing allometric models for biomass estimation of highland bamboos (*Arundinaria alpina*) **in Sele-Nono forest**

Sample bamboo			**Dendrometric parameter**		**Observed biomass (Kg)**
Sample No.	Code	Age category	DBH	H	
Sample 1	Bamboo 1	less than 1yr.old	5	7	3.11
Sample 2	Bamboo 2	2-3 yrs.old	7	10	6
Sample 3	Bamboo 3	older than 3yrs.	9.5	18	15.63
Sample 4	Bamboo 4	older than 3yrs.	9	16	12.81
Sample 5	Bamboo 5	older than 3yrs.	8.5	14	10.54

Appendix 12. Tree height data for verifying tree height estimation methods for Sele-Nono forest

strata	Sample trees	DBH	Measured Height	Visually estimated height	Height estimated by DBH-H models			
					Feldpausch_1	Feldpausch_2	Brown	Niklas
1	*Apodytes dimidiata*	30.6	23	35	43.54424554	25.33942673	6.75013	10.48839
	Polyscias fulva	31	25	30	44.48534475	25.88648045	6.804921	10.67401
	Dombeya torrida	32	25	35	45.41593931	26.42741568	6.858396	10.85686
	Syzygium guineense	51	32	35	61.54694657	35.80232352	7.693591	13.93153
	Prunus africana	55	35	50	64.65327216	37.60730878	7.838158	14.50584
	Allophylus abyssinicus	29	20	30	42.59216678	24.78597777	6.693945	10.29987
	Pouteria adolfi-friederici	62	37	45	69.90667092	40.65967908	8.073126	15.46602
	Ekebergia capensis	20	15	25	33.4273278	19.45767473	6.107972	8.443062
	Fagaropsis angolensis	62	40	50	69.90667092	40.65967908	8.073126	15.46602
	Ilex mitis	45	35	40	56.72308989	32.99914074	7.459801	13.0292
2	*Olea welwitschii*	50.8	38	40	60.75728235	35.34345981	7.65612	13.78472
	Sapium ellipticum	34	24	30	47.24734422	27.49193868	6.961678	11.21476
	Bersama abyssinica	35	30	35	48.14894456	28.0159868	7.011611	11.39004
	Brucea antidysenterica	36	27	35	49.04162597	28.53484048	7.060479	11.56301
	Croton macrostachyus	36	25	35	49.04162597	28.53484048	7.060479	11.56301
	Deinbollia kilimandscharica	36	23	30	49.04162597	28.53484048	7.060479	11.56301
	Apodytes dimidiata	43	30	40	55.06615842	32.03622624	7.376653	12.71612
	Syzygium guineense	43	30	40	55.06615842	32.03622624	7.376653	12.71612
	Sapium ellipticum	44	28	35	55.89789973	32.5195909	7.418583	12.87348
	Elaeodendron buchananii	44	30	35	55.89789973	32.5195909	7.418583	12.87348
3	*Vepris dainellii*	25	22	30	38.66310062	22.50184463	6.453422	9.513642
	Trichilia dregeana	51	37	40	61.54694657	35.80232352	7.693591	13.93153
	Diospyros abyssinica	39	30	35	51.66937761	30.06211176	7.201198	12.06892
	Sapium ellipticum	39	29	40	51.66937761	30.06211176	7.201198	12.06892
	Millettia ferruginea	39	26	40	51.66937761	30.06211176	7.201198	12.06892
	Diospyros abyssinica	39	28	40	51.66937761	30.06211176	7.201198	12.06892

	Cordia africana	40	32	40	52.52950645	30.56200753	7.246289	12.23351
	Celtis africana	40	32	30	52.52950645	30.56200753	7.246289	12.23351
	Elaeodendron buchananii	60	35	50	68.42777684	39.80042636	8.008124	15.19707
	Trilepisium madagascariense	60	40	45	68.42777684	39.80042636	8.008124	15.19707
4	*Trichilia dregeana*	37	30	30	49.92572087	29.04869342	7.108336	11.73375
	Manilkara butugi	56	34	50	65.41742007	38.05131595	7.873056	14.64635
	Albizia gummifera	64	43	50	71.36905742	41.50932155	8.136567	15.73096
	Morus mesozygia	30	26	35	43.54424554	25.33942673	6.75013	10.48839
	Morus mesozygia	55	33	40	64.65327216	37.60730878	7.838158	14.50584
	Trema orientalis	28	26	25	41.6285949	24.22583426	6.63628	10.10831
	Trilepisium madagascariense	45	27	40	56.72308989	32.99914074	7.459801	13.0292
	Baphia abyssinica	45	30	40	56.72308989	32.99914074	7.459801	13.0292
	Alstonia boonei	64	40	50	71.36905742	41.50932155	8.136567	15.73096
	Manilkara butugi	70	45	50	75.66384934	44.00447696	8.318335	16.50351
5	*Strychnos mitis*	33	22	35	46.33646945	26.96248897	6.910627	11.03707
	Baphia abyssinica	34	28	35	47.24734422	27.49193868	6.961678	11.21476
	Trichilia dregeana	34	25	35	47.24734422	27.49193868	6.961678	11.21476
	Anthocleista schweinfurthii	47	31	40	58.35458881	33.94724578	7.540209	13.33587
	Morus mesozygia	49	35	35	59.96210406	34.88138547	7.61808	13.63653
	Trilepisium madagascariense	49	36	40	59.96210406	34.88138547	7.61808	13.63653
	Albizia schimperiana	49	30	40	59.96210406	34.88138547	7.61808	13.63653
	Morus mesozygia	50	32	40	60.75728235	35.34345981	7.65612	13.78472
	Manilkara butugi	64	40	45	71.36905742	41.50932155	8.136567	15.73096
	Alstonia boonei	65	40	45	72.0942785	41.930666	8.167729	15.86199

Appendix 13. Corrected length of plots and subplot nests on field for various slope gradients. (Note that this table was printed and covered to protect it from weather and used in the field as part of the field equipment. Also note that *is projected horizontal length of plot and/or subplot (or transect line for lying dead wood, LDW) assumed on flat terrain; L_{field} is corrected length of the plot and/or subplot (or transect line for LDW) parallel to the slope on the ground.

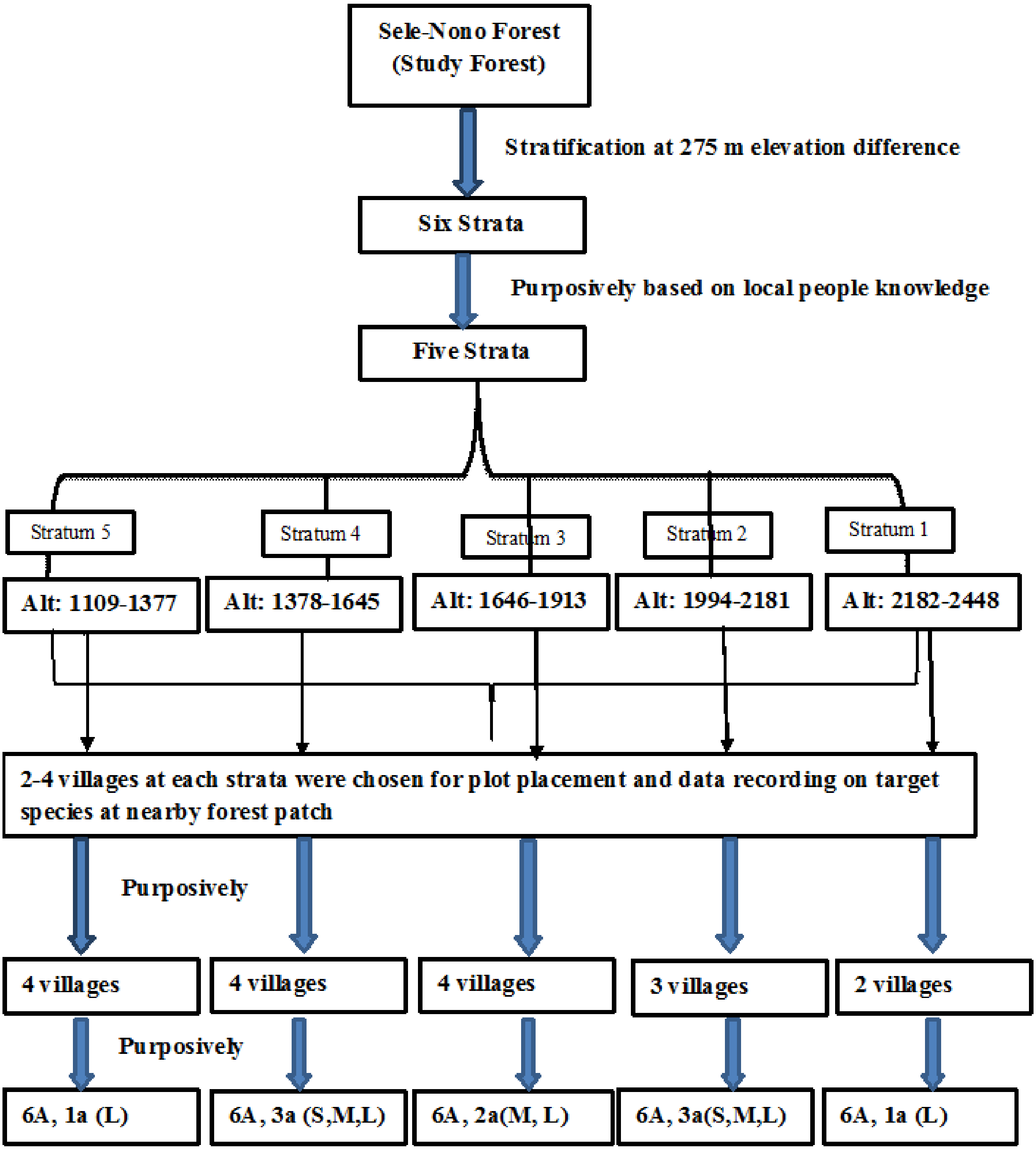
$$L_{field} = \frac{L_s}{\cos\theta} \text{ where } L_s \text{ is default length assumed on flat terrain}$$

Slope Gradient (°)		Corrected length of plots or subplots on field along the slope (L_{field}, m)					
Slope (θ)	Cosθ	Sapling* (3 m)	Shrub* (5 m)	Liana* (7 m)	Small tree* (25 m)	Large tree* (35 m)	LDW* (50 m)
6	0.99	3.0	5.0	7.0	25.2	35.3	50.5
10	0.98	3.1	5.1	7.2	25.7	36.0	51.5
15	0.97	3.2	5.3	7.4	26.5	37.1	53.1
20	0.94	3.3	5.6	7.9	28.2	39.5	56.5
25	0.91	3.7	6.2	8.6	31.0	43.4	62.1
30	0.87	4.2	7.1	9.9	35.6	49.9	71.3
35	0.81	5.2	8.8	12.3	44.0	61.6	88.1
40	0.76	6.9	11.6	16.2	57.9	81.1	115.9
45	0.7	9.9	16.6	23.2	82.8	115.9	165.6
50	0.64	15.5	25.8	36.2	129.4	181.2	258.8
55	0.57	27.2	45.4	63.6	227.0	317.9	454.1
60	0.5	54.5	90.8	127.1	454.1	635.8	908.2

Note: Measured slope gradient were approximated to the nearest slope gradient presented in table above. Then these slope corrected area would be extrapolated to hectare basis during data analysis using the following scaling factor

$$\text{Scaling factor} = \frac{10,000\ m^2}{\text{Horizontal area of nest plot } (m^2)}$$

Appendix 14. Flow chart showing the sampling procedure for *Albizia* tree selection



Note: the choice of villages were entirely based on the knowledge of the local people about where to find the plant under study. The letter 'A' indicates Albizia tree for modelling purpose; whereas the letter 'a' indicates Albizia tree for validation purpose. Trees for validation purpose were all size types, i. e., small (S), medium (M) and large (L). Thus, total 'A's are 30 and total 'a' s are 10 in number.

Appendix 15. Lists of plant species recorded from Sele-Nono forest (VN-Voucher Number; AKX –Alemayehu Kefalew and X is the number of vouchr specimen)

Family		**Botanical name**		**Local names (Oromo/sheka Name)**	**Growth form**	**Remarks**	**VN**
S/N	Family Name	S/N	Botanical Name				AKX
1	Acanthaceae	1	*Acanthopale aethiogermanica* Ensermu	Dergu/Koparo	H	Erect herb	634
	Acanthaceae	2	*Acanthus eminens* C.B.Clarke	Kosoru /Pe'cho	S		675
	Acanthaceae	3	*Asystasia gangetica* (L.) T. Anders. subsp *micrantha* (Nees) Ensermu	Dergu	H	Erect herb	629
	Acanthaceae	4	*Barleria ventricosa* Hochst. ex Nees	Dergu/ Kero	H	Erect herb	696
	Acanthaceae	5	*Brillantaisia madagascariensis* T. Anders.	Korro	H	Erect herb	294
	Acanthaceae	6	*Dicliptera maculata* Nees.	Dergu	H	Erect herb	378
	Acanthaceae	7	*Dyschoriste multicaulis* (A.Rich.) O. Kuntze		H	Erect herb	302
	Acanthaceae	8	*Hygrophila schulli* (Hamilt.)MR. & S.M Almeida	Bala weranti	H	Erect herb	581
	Acanthaceae	9	*Hypoestes forskaolii* Roem. & Schult.		H	Erect herb	346
	Acanthaceae	10	*Hypoestes triflora* (Forssk.) Soland.ex Roem. & Schult.		H	Erect herb	454
	Acanthaceae	11	*Isoglossa somalensis* Lindau	Dergu/Kero	H	Erect herb	390
	Acanthaceae	12	*Justicia bizuneshiae* Ensermu		H	Erect herb	370
	Acanthaceae	13	*Justicia diclipteroides* Lindau subsp.*aethiopica* Hedren		H	Erect herb	488
	Acanthaceae	14	*Justicia ladanoides* Lam.		H	Erect herb	333
	Acanthaceae	15	*Justicia schimperiana* T. Anders	Dhumuga/sheshero	S		589
	Acanthaceae	16	*Mellera lobulata* S. Moore	Dergu/Kero	H	Erect herb	657
	Acanthaceae	17	*Monothecium glandulosum* Hochst.		S		388
	Acanthaceae	18	*Phaulopsis imbricata* (Forssk.) Sweet	Dergu/Kero	H	Erect herb	306
	Acanthaceae	19	*Ruellia prostrata* Poir.		H	Erect herb	419
	Acanthaceae	20	*Thunbergia alata* Boj.ex Sims		H	Scarmbling herb	536
	Acanthaceae	21	*Whitfieldia elongata* (P.Beauv) De Wild. & T.Dur	Erikoy	S		300
2	Alangiaceae	22	*Alangium chinense* (Lour)Harms	Shotto	T		389
3	Amaranthaceae	23	*Achyranthes aspera* L.	Metene	H	Erect herb	464
	Amaranthaceae	24	*Amaranthus hybridus* L.		H	Erect herb	313
	Amaranthaceae	25	*Celosia argentea* L.	Ababo	H	Erect herb	331
	Amaranthaceae	26	*Cyathula cylinderica* Moq.	Metene	H	Erect herb	524

	Amaranthaceae	27	*Cyathula polycephala* Bak.	Metene	H	Erect herb	374
	Amaranthaceae	28	*Cyathula prostrata* (L.) Blume	Kero	H	Erect herb	475
	Amaranthaceae	29	*Cyathula uncinulata* (Schard.) Schinz	Bokkoosso	H	Erect herb	655
4	Amaryllidaceae	30	*Crinum ornatum* (Ait.) Bury	Kulubi werabesa	H	Erect herb	659
	Amaryllidaceae	31	*Scadoxus nutans* Friis & Nordal	Qicuu	H	Erect herb	490
5	Anacardiaceae	32	*Lannea schimperi* (A. Rich.) Engl.		T		600
	Anacardiaceae	33	*Lannea schweinfurthii* (Engl.) Engl.		T		562
	Anacardiaceae	34	*Rhus glutinosa* A. Rich.	Xaxesa	S		636
6	Anthericaeae	35	*Chlorophytum macrophyllum* (A. Rich.) Aschers.		H	Erect herb	556
7	Apiaceae	36	*Centella asiatica* (L.) Urban.	Gura hantuta	H	Erect herb	611
	Apiaceae	37	*Hydrocotyle mannii* Hook.f.	Mijidikkoo	H	Erect herb	585
	Apiaceae	38	*Sanicula elata* Buch.Ham. ex D. Don	Metene	H	Erect herb	358
8	Apocynaceae	39	*Alstonia boonei* De Wild.	Joga	T		349
	Apocynaceae	40	*Landolphia buchananii* (Hallf) Stapf	Gebo/yebo	L		645
	Apocynaceae	41	*Oncinotis tenuiloba* Stapf.	Hidda gebo qemele	L		410
	Apocynaceae	42	*Saba comorensis* (Boj.) Pichon	Gelenchi/Shogaye	L		315
9	Aquifoliaceae	43	*Ilex mitis* (L.) Radlk.	Qeto	T		500
10	Araceae	44	*Amorphophallus gallaensis* (Engl.) N.E.Br.	Qicuu	H	Erect herb	697
	Araceae	45	*Arisaema schimperianaum* Schott.	Qicuu	H	Erect herb	628
	Araceae	46	*Colocasia esculatum* (L.) Schott		H	Erect herb	455
	Araceae	47	*Culcasia falcifolia* Engl.		H	Epiphytic herb	326
11	Araliaceae	48	*Polyscias fulva* (Hiern) Harms	Kereso/Keresho	T		663
	Araliaceae	49	*Schefflera abyssinica* Harms	Getema/menjo	T		505
	Araliaceae	50	*Schefflera myriantha* (Bak.) Drake	Kermato	L		365
	Araliaceae	51	*Schefflera volkensii* (Engl.) Harms	Qerro	T		426
12	Arecaceae	52	*Phoenix reclinata* Jacq.	Mexi	T		322
13	Asclepidaceae	53	*Tylophora sylvatica* Decne.		L		622
	Asclepidaceae	54	*Ceropegia cufodontis* Chiov.		H	Scarmbling herb	644
	Asclepidaceae	55	*Leptadeni hastata* (Pers.) Decne.		H	Scarmbling herb	359
14	Asparagaceae	56	*Asparagus africanus* Lam.	Seriti	H	Scarmbling herb	700

	Asparagaceae	57	*Asparagus racemosus* Willd.	Seriti	H/L		394
15	Aspleniaceae	58	*Aspidium gemmiferum* (Fee) Ching.	Shesso	H	Epiphytic herb	517
	Aspleniaceae	59	*Asplenium aethiopicum* (Burm. F.) Becherer	Shesso	H	Epiphytic herb	506
	Aspleniaceae	60	*Asplenium bugoiense* Hieron.	Shesso	H	Epiphytic herb	511
	Aspleniaceae	61	*Asplenium ceii* Pich.Serm.	Shesso	H	Epiphytic herb	483
	Aspleniaceae	62	*Asplenium elliottii* C.H.Wright	Shesso	H	Epiphytic herb	439
	Aspleniaceae	63	*Asplenium erectum* Bory ex Willd.	Shesso	H	Epiphytic herb	353
	Aspleniaceae	64	*Asplenium friesiorum* C.Chr.	Shesso	H	Epiphytic herb	411
	Aspleniaceae	65	*Asplenium hypomelas* Kuhn	Shesso	H	Epiphytic herb	416
	Aspleniaceae	66	*Asplenium linckii* Kuhn	Shesso	H	Epiphytic herb	667
	Aspleniaceae	67	*Asplenium mannii* Hook.	Shesso	H	Epiphytic herb	448
	Aspleniaceae	68	*Asplenium sandersonii* Hook.	Shesso	H	Epiphytic herb	683
	Aspleniaceae	69	*Asplenium theciferum* (HBK) Mett	Shesso	H	Epiphytic herb	304
16	Asteraceae	70	*Acmella caulirhiza* Del.	Guticha gura	H	Erect herb	423
	Asteraceae	71	*Adenostemma mauritianum* DC.		H	Erect herb	309
	Asteraceae	72	*Ageratum conyzoides* L.		H	Erect herb	321
	Asteraceae	73	*Bidens pilosa* L.		H	Erect herb	558
	Asteraceae	74	*Bidens prestinaria* (Sch.Bip.) Cufod.	Adeye Abeba	H	Erect herb	689
	Asteraceae	75	*Bothriocline schimperi* Oliv. & Hiern ex Benth.	Illebu	S		354
	Asteraceae	76	*Carduus leptacanthus* Fresen.		H	Erect herb	303
	Asteraceae	77	*Conyza agrostophylla* F.G. Davies		H	Erect herb	310
	Asteraceae	78	Crassocephalum crepidioides S. Moore		H	Erect herb	317
	Asteraceae	79	*Crassocephalum macropappum* S. Moore		H	Erect herb	296
	Asteraceae	80	*Crassocephalum montuosum* (S.Moore) Milne-Redh.		H	Erect herb	456
	Asteraceae	81	*Dichrocephala integrifolia* O. Kuntze	Areema	H	Erect herb	601
	Asteraceae	82	*Guizotia scabra* (Vis) Chiov.	Haddaa	H	Erect herb	554
	Asteraceae	83	*Guizotia schimperi* Sch.Bip.ex Walp.	Tuffo	H	Erect herb	573
	Asteraceae	84	*Helichrysum schimperi* Moesner		H	Erect herb	620
	Asteraceae	85	*Lactuca paradoxa* Sch.Bip.ex A. Rich.		H	Scarmbling herb	308
	Asteraceae	86	*Laggera crispate* (Vahl) Hepper & Wood	Nop'ee/Nop'oo	H	Erect herb	295

	Asteraceae	87	*Mikaniopsis clematoides* (Sch. Bip. ex A. Rich.) Milne-Redh.		L/S		646
	Asteraceae	88	*Solanecio gigas* (Vatke) C.Jeffrey	Debeka	S/T		338
	Asteraceae	89	*Solanecio mannii* (Hook.f.) C.Jeffrey	Eqibelo	S/T		545
	Asteraceae	90	*Sonchus bipontini* Asch.	Ananna	H	Erect herb	406
	Asteraceae	91	*Tagetes minuta* L.		H	Erect herb	595
	Asteraceae	92	*Tridax procumbens* L.		H	Scarmbling herb	428
	Asteraceae	93	*Vernonia amygdalina* Del.	Ebicha	S/T		519
	Asteraceae	94	*Vernonia auriculifera* Hiern	Reji	S/T		491
	Asteraceae	95	*Vernonia hochstetteri* Sch. Bip. ex Walp .	Ilebu kefekatu	S		641
	Asteraceae	96	*Vernonia karaguensis* Oliv. & Hiern	Soyema dima	S		540
	Asteraceae	97	*Vernonia leopoldi* Vatke	Soyema adi	S		361
	Asteraceae	98	*Xanthium strumarium* L.		H	Erect herb	702
17	Balanitaceae	99	*Balanites aegyptiaca* (L.) Dei.		T		520
18	Balsaminaceae	100	*Impatiens ethiopica* Grey-Wilson	Ensosela kenfekatu/tebecho	H	Erect herb	521
	Balsaminaceae	101	*Impatiens hochstetteri* Warb.	Tebecho	H	Erect herb	435
	Balsaminaceae	102	*Impatiens rothii* Hook.f .		H	Erect herb	445
	Balsaminaceae	103	*Impatiens tinctoria* A.Rich.	Ensosiillaa/Tebecho	H	Erect herb	298
19	Basellaceae	104	*Basella alba* L.		H	Scarmbling herb	476
20	Begoniaceae	105	*Begonia wallastonii* Bak.		H	Erect herb	413
21	Bignoniaceae	106	*Kigelia africana* (Lam.) Benth.		T		577
	Bignoniaceae	107	*Spathoda campanulata* P.Beauv		T		450
	Bignoniaceae	108	*Stereospermum kunthianum* Cham.	Botorro	T		474
22	Blechnaceae	109	*Blechnum tabulare* (Thunb.) Kuhn		H	Erect herb	660
23	Boraginaceae	110	*Cordia africana* Lam.	Wedessa/Deo	T		312
	Boraginaceae	111	*Cynoglossum amplifolium* DC.	Metene adi	H	Erect herb	603
	Boraginaceae	112	*Ehertia cymosa* Thonn.	Ulagga	L/S/T		343
24	Campanulaceae	113	*Canarina eminii* Schwein.		H	Scarmbling herb	560
	Campanulaceae	114	*Lobelia giberroa* Hemsl.	Dumberko/Gederano	T		307
25	Cannaceae	115	*Canna indica* L.		H	Erect herb	612
26	Capparidaceae	116	*Gynandropsis gynandra* (L.) Briq.	Rafu mejenger	H	Erect herb	692

	Capparidaceae	117	*Maerua oblongifolia* (Forssk.) A. Rich.		T		693
	Capparidaceae	118	*Ritchiea albersii* Gilg.	Deqoo	T		676
27	Caryophyllaceae	119	*Drymaria cordata* (L.) Schultes		H	Scarmbling herb	653
	Caryophyllaceae	120	*Stellaria sennii* Chiov.		H	Erect herb	647
28	Celasteraceae	121	*Catha edulis* (Vahl) Forssk. ex Endl.		T		698
	Celasteraceae	122	*Elaeodendron buchananii* (Loes.) Loes.	Loko adi/wasso	T		497
	Celasteraceae	123	*Hippocratea africana* (Willd) Loes	Hidda galle	L		457
	Celasteraceae	124	*Hippocratea goetzei* Loes.	Hidda tiyo	L		459
	Celasteraceae	125	*Hippocratea pallens* Planch. ex Oliv.	Hidda qawo	L		467
	Celasteraceae	126	*Maytenus arbutifolia* (A. Rich.) Wilczek	Qorati/kombolecha	T		468
	Celasteraceae	127	*Maytenus gracilipes* (Welw.ex Oliv.) Exell	Qorati/kombolecha	S/T		385
	Celasteraceae	128	*Maytenus obscura* (A.Rich.) Cuf.		S/T		363
	Celasteraceae	129	*Maytenus undata* (Thunb.) Blakelok	Qorati/kombolecha	S/T		701
29	Combretaceae	130	*Combretum adenogonium* Steud. ex A. Rich.		T		399
	Combretaceae	131	*Combretum molle* R. Br. ex G. Don		T		546
	Combretaceae	132	*Combretum paniculatum* Vent.	Begge	L		477
	Combretaceae	133	*Terminalia schimperiana* Hochst.	Debeqa	S/T		588
30	Commelinaceae	134	*Commelina africana* L.	O'ka jebi (yellow)	H	Erect herb	393
	Commelinaceae	135	*Commelina benghalensis* L.	O'ka jebi	H	Erect herb	678
	Commelinaceae	136	*Commelina diffusa* Burm.f.	Qorexobo (Blue)	H	Erect herb	340
	Commelinaceae	137	*Floscopa glomerata* (Willd. ex J.A. Schult. & J.H Schult.) Hassk.		H	Erect herb	407
	Commelinaceae	138	*Pollia condensata* C. B. Clarke		H	Erect herb	436
31	Convolvulaceae	139	*Ipomoea purpurea* (L.) Roth.	Kelala	H	Scarmbling herb	325
	Convolvulaceae	140	*Stiotocardia beraviensis* (Vatke) Hall. F.		L		570
32	Costaceae	141	*Costus afer* Ken-Gawl	Ogiyo Sambiro	H	Erect herb	501
	Costaceae	142	*Costus lucanusianus* J. Braun & K. Schum.	Ogiyo Sambiro	H	Erect herb	649
33	Crassulaceae	143	*Kalanchoe densiflora* Rolfe.		H	Erect herb	513
34	Cucurbitaceae	144	*Momordica foetida* Schumach.	Humbaho	H	Scarmbling herb	429
	Cucurbitaceae	145	*Peponium vogelii* (Hook.f.) Engl.	Toojjo (edible)	H	Scarmbling herb	569
	Cucurbitaceae	146	*Zehneria scabra* (Lf) Sond.		H	Erect herb	541

35	Cyatheaceae	147	*Cyathea manniana* Hook.	Sessino/Gixo	T		703
36	Cyperaceae	148	*Carex chlorosaccus* C.B. Clarke		H	Erect herb	421
	Cyperaceae	149	*Carex thomasii* Nelmes		H	Erect herb	662
	Cyperaceae	150	*Coleochloa abyssinica* (Hochst. ex A. Rich.) Gilly		H	Erect herb	624
	Cyperaceae	151	*Cyperus dereilema* Steud.	Quni	H	Erect herb	330
	Cyperaceae	152	*Cyperus digitatus* Roxb.	Quni	H	Erect herb	316
	Cyperaceae	153	*Cyperus longibracteatus* (Cherm.) Kük.	Quni	H	Erect herb	668
	Cyperaceae	154	*Cyperus rotundus* L.	Quni	H	Erect herb	582
	Cyperaceae	155	*Cyperus schimperianus* Steud.	Quni	H	Erect herb	650
37	Dioscoreaceae	156	*Dioscorea praehensilis* Benth.	Buri mejenger	L		548
	Dioscoreaceae	157	*Dioscorea quartiniana* A.Rich.	Muke funo	S/T		327
38	Dracaenaceae	158	*Dracaena afromontana* Mildbr.	Serxe bala qeqello	S/T		397
	Dracaenaceae	159	*Dracaena fragrans* (L.) Ker-Gawl.	Serxe mesgo/Algae/Fishino	T		658
	Dracaenaceae	160	*Dracaena steudneri* Scw.ex Engl.	Serxe/Yuddii/yubedi	T		386
39	Dryopteridaceae	161	*Didymochlaena truncatula* (Swartz) J. Sm.		H	Epiphytic herb	509
	Dryopteridaceae	162	*Polystichum transvaalense* N.C. Anthony		H	Erect herb	613
40	Ebenaceae	163	*Diospyros abyssinica* F. White	Loko guracha/Kuri	T		329
41	Euphorbiaceae	164	*Acalypha acrogyna* Pax	Derie	S		691
	Euphorbiaceae	165	*Acalypha ornata* A. Rich.	Derie	S		341
	Euphorbiaceae	166	*Argomuellera macrophylla* Pax	qintebus	S		549
	Euphorbiaceae	167	*Bridelia micranta* (Hochst.) Baill.	Rigaraba	S/T		401
	Euphorbiaceae	168	*Bridelia scleroneura* Muell. Arg.		S		478
	Euphorbiaceae	169	*Croton macrostachyus* Del.	Bekenisa/mekenisa/Shomo	T		625
	Euphorbiaceae	170	*Erythrococca trichogyne* Prain	Chakko/Bichirkucho	S		446
	Euphorbiaceae	171	*Euphorbia ampliphylla* Pax	Adami	T		578
	Euphorbiaceae	172	*Macaranga capensis* (Baill.) Sim	O'ngo/werango	T		380
	Euphorbiaceae	173	*Phyllanthus limmuensis* Cuf.		S		348
	Euphorbiaceae	174	*Phyllanthus ovalifolius* Forssk.		S		515
	Euphorbiaceae	175	*Ricinus communis* L.	Qobbo	S/T		648
	Euphorbiaceae	176	*Sapium ellipticum* (Krauss) Pax	Bossoqqa/Sheddo	S/T		706

42	Fabaceae	177	*Caesalpinia decapetala* (Roth) Alston	Yeferenj Kontir	H	Scarmbling herb	654
	Fabaceae	178	*Crotalaria brevidens* Benth.	Kishekishe	H	Erect herb	563
	Fabaceae	179	*Crotalaria gillettii* Polhill	Gura wango	H	Erect herb	626
	Fabaceae	180	*Dalbergia lactea* Vatke	Gimero	L		403
	Fabaceae	181	*Desmodium repandum* Vahl	Metene	H	Erect herb	463
	Fabaceae	182	*Entada abyssinica* Steud. ex A. Rich.	Ambelta	S		492
	Fabaceae	183	*Erythrina abyssinica* (Lam. ex. DC.)		T		690
	Fabaceae	184	*Glycine wightii* (Wight & Am) Verde.	Kelala hoolla/Kelalo	H	Scarmbling herb	637
	Fabaceae	185	*Indigofera atriceps* Hook.f.		S		371
	Fabaceae	186	*Piliostigma thonningii* (Schumach.) Milne-Redh.		T		502
	Fabaceae	187	*Pterolobium stellatum* Brenan	Aregema chaka	H	Scarmbling herb	404
	Fabaceae	188	*Senna petersiana* (Bolle) Lock	Semenek	S/T		484
	Fabaceae	189	*Senna septemtrionali* (Viv.) Irwin & Barneby	Semenek	S		522
	Fabaceae	190	*Trifolium baccarinii* Chiov.	Sidisa	H	Erect herb	375
	Fabaceae	191	*Trifolium mattirolianum* Chiov.	Sidisa	H	Erect herb	661
	Fabaceae	192	*Vigna membranacea* A. Rich.		H	Scarmbling herb	638
	Fabaceae	193	*Vigna vexillata* (L.) A. Rich.	Kelala hoolla	H	Scarmbling herb	627
	Fabaceae	194	*Albizia grandibracteata* Taub.	Ambelta	T		347
	Fabaceae	195	*Albizia gummifera* (J. F. Gmel.) C. A. Sm.	Ambebesa	T		591
	Fabaceae	196	*Albizia schimperiana* Oliv.	Ambebesa gemoji	T		431
	Fabaceae	197	*Baphia abyssinica* Brummitt	Dewie	T		458
	Fabaceae	198	*Calpurina aurea* (Ait.) Benth	Ceeka	S		510
	Fabaceae	199	*Erythrina brucei* Schweinf.	Wellensu	T		486
	Fabaceae	200	*Millettia ferruginea* (Hochst.) Baker	Sotolo/Yaggo	T		531
43	Flacourtiaceae	201	*Flacourtia indica* (Burm.f.) Merrill	Akuku/shuretto	S/T		533
	Flacourtiaceae	202	*Oncoba spinosa* Forssk.	Shurato	S/T		350
44	Geraniaceae	203	*Geranium arabicum* Forrsk.		H	Erect herb	543
45	Guttiferae	204	*Garcinia ovalifolia* Oliver	Karawayu	S/T		504
	Guttiferae	205	*Garcinia buchananii* Bak.	Gerjeja	S/T		498
46	Hypolepidaceae	206	*Blotiella glabra* (Bory) R.M. Tryon		H	Epiphytic herb	355

	Hypolepidaceae	207	*Pteridium aquilinum* (L.) Kuhn		H	Epiphytic herb	452
47	Icacinaceae	208	*Apodytes dimidiata* E. Mey. ex. Arn.	Wendebiyo	T		479
48	Lamiaceae	209	*Achyrospermum parviflorum* S.Moore	Kerro	S		485
	Lamiaceae	210	*Achyrospermum schimperi* (Hochst. ex Briq) Perkins (EH)	Korro	S		527
	Lamiaceae	211	*Ajuga integrifolia* Buch. Ham. ex D.Don		H	Erect herb	487
	Lamiaceae	212	*Ajuga leucantha* Lukhoba		H	Erect herb	430
	Lamiaceae	213	*Isodon schimperi* (Vatke)JK. Morton		H	Erect herb	550
	Lamiaceae	214	*Leucas calostachys* Oliv.		H	Erect herb	605
	Lamiaceae	215	*Ocimum grattissimum* L.	Anchebi	H	Erect herb	619
	Lamiaceae	216	*Ocimum lamiifolium* Hochst ex. Bent.	Demakessie	H/S		574
	Lamiaceae	217	*Plectranthus garckeanus* (Vatke) J. K. Morton	Yeriyo/yeriho	H	Erect herb	433
	Lamiaceae	218	*Plectranthus punctatus* (L.f.)L'Her.		H	Erect herb	469
	Lamiaceae	219	*Pycnostachys abyssinica* Fresen.		H	Erect herb	337
	Lamiaceae	220	*Salvia nilotica* Juss. ex Jacq.		H	Erect herb	670
	Lamiaceae	221	*Satureja paradoxa* (Vatke) Engl.	Naddo	H	Erect herb	530
49	Lauraceae	222	*Ocotea kenyensis* (Chiov.) Robyns & Wilcz		T		694
50	Loganiaceae	223	*Anthocleista schweinfurthii* Gilg.	Belety	T		460
	Loganiaceae	224	*Nuxia congesta* R.Br.ex Fresen.	Qeyisa	T		470
	Loganiaceae	225	*Strychnos mitis* S.Moore	Satto/shifu	T		369
51	Lomariopsidaceae	226	*Elaphoglossum deckenii* (Kuhn) C.Chr.		H	Epiphytic herb	508
	Lomariopsidaceae	227	*Elaphoglossum lastii* (Bak.)		H	Epiphytic herb	301
52	Loranthaceae	228	*Tapinanthus globiferus* (A. Rich.) Tieghem	Dheretu/eretu/harme ada	H	Epiphytic herb	336
53	Lycopodiaceae	229	*Huperzia dacrydioides* (Baker) Pic.Serm.		H	Epiphytic herb	320
	Lycopodiaceae	230	*Lycopodiella cernua* (L.) Pic.Serm.		H	Erect herb	351
	Lycopodiaceae	231	*Lycopodium clavatum* L.		H	Epiphytic herb	494
54	Malvaceae	232	*Abutilon longicuspe* Hochst. ex A.Rich.	Qunch	S		417
	Malvaceae	233	*Hibiscus berberidifolius* A. Rich	Inchini	S		664
	Malvaceae	234	*Hibiscus calyphyllus* Cavan.	Inchini	S		451
	Malvaceae	235	*Kosteletzkya begoniifolia* (Ulbr.) Ulbr.	Debessie	S		602
	Malvaceae	236	*Pavonia schimperiana* Hochst .ex A.Rich.	Debessie adi	H	Erect herb	656

	Malvaceae	237	*Pavonia urens* Cav.	Debessie dimma	S		572
	Malvaceae	238	*Sida rhombifolia* L.	Kereba	H	Erect herb	614
55	Marantaceae	239	*Marantochloa leucantha* (K.Schun).Milne-Redh.	Berebere sambiro	H	Erect herb	575
56	Marattiaceae	240	*Marattia fraxinea* Sm.	Shesso	H	Epiphytic herb	580
57	Melastomataceae	241	*Dissotis senegambiensis* Triana		H	Erect herb	705
	Melastomataceae	242	*Tristemma mauritianum* J. F. Gmel		H	Erect herb	471
58	Meliaceae	243	*Ekebergia capensis* Sparrm.	Sombo/ororo	T		507
	Meliaceae	244	*Lepidotrichilia volkensii* (Gurke) Leory	Alele/shawa	T		335
	Meliaceae	245	*Pseudocedrela kotschyi* (Schweinf.) Harms		T		441
	Meliaceae	246	*Trichilia dregeana* Sond.	Luya/yuya	T		610
	Meliaceae	247	*Turraea holstii* Guerke		S/T		539
59	Melianthaceae	248	*Bersama abyssinica* Fresen.	Lolchisa/bokko	T		677
60	Menispermaceae	249	*Cissampelos mucronata* A.Rich.	Kelala/maki mesengo	H	Scarmbling herb	598
	Menispermaceae	250	*Stephania abyssinica* (Dill & A. Rich.) Walp		H	Scarmbling herb	699
	Menispermaceae	251	*Tiliacora troupinii* Cufod.	Liqixi/acho	L		364
61	Moraceae	252	*Antiaris toxicaria* Lesch subsp. *toxicaria*		T		395
	Moraceae	253	*Ficus exasperata* Vahl	Balantaie	T		552
	Moraceae	254	*Ficus ovata* Vahl	Dembi guracha/qilinexu	T		482
	Moraceae	255	*Ficus sur* Forssk.	Harbu/hexo	T		440
	Moraceae	256	*Ficus sycomorus* L.	Dembi gemoji/hexo	T		420
	Moraceae	257	*Ficus thonningii* Blume	Dembi shifi	S/T		449
	Moraceae	258	*Ficus vasta* Vahl.	Dembi dimma/qilexu	T		547
	Moraceae	259	*Milicia excelsa* (Welw.) C. C. Berg		T		392
	Moraceae	260	*Morus mesozygia* Stapf	Sacho	T		621
	Moraceae	261	*Trilepisium madagascariense* DC.	Semeko/Che'ii anneno	T		362
62	Musaceae	262	*Ensete ventricosum* (Welw.) Cheesman	Qocho sexana/ae'co	H	Erect herb	396
63	Myrsinaceae	263	*Embelia schimperi* Vatke		L/S		514
	Myrsinaceae	264	*Maesa lanceolata* Forssk.	Abeyii/Cheggo	S/T		366
	Myrsinaceae	265	*Myrsine africana* L.		S		383
64	Myrtaceae	266	*Psidium guajava* L.		S		414

	Myrtaceae	267	*Syzygium guineense* (Wild.) DC. subsp. *afromontanum* F. White	Beddesa/Yino/Gejo	T		669
65	Nephrolepidaceae	268	*Nephrolepis biserrata* (Sw.) Schott		H	Epiphytic herb	526
	Nephrolepidaceae	269	*Nephrolepis undulata* (Afzel. ex Sw.)J.Sm.		H	Epiphytic herb	535
66	Oleaceae	270	*Jasminum abyssinicum* DC.	Ilchime	L		525
	Oleaceae	271	*Chionanthus mildbraedii* Stearn	Shigewo	T		564
	Oleaceae	272	*Olea capensis* L.Subsp.macrocarpa (C.A. Wright.) Verdc.	Gegema/shega'o	T		559
	Oleaceae	273	*Olea welwitschii* (Knobl.) Gilg & Schellenb.	Baha/yaho	T		368
67	Oleandraceae	274	*Arthropteris monocarpa* (Cordem.) C.Chr.		H	Epiphytic herb	680
68	Onagraceae	275	*Epilobium stereophyllum* Fresen.		H	Erect herb	596
69	Orchidaceae	276	*Aerangis brachycarpa* (Rich) Reichb.f.		H	Epiphytic herb	461
	Orchidaceae	277	*Aerangis thomsonii* (Rolfe) Schltr		H	Epiphytic herb	642
	Orchidaceae	278	*Bulbophyllum intertextum* Lindl.		H	Epiphytic herb	345
	Orchidaceae	279	*Bulbophyllum josephii* (Kuntze) Summerh.		H	Epiphytic herb	299
	Orchidaceae	280	*Corymborkis corymbis* Thouars		H	Erect herb	523
	Orchidaceae	281	*Diaphananthe adoxa* Rasm.		H	Epiphytic herb	447
	Orchidaceae	282	*Eulophia guineensis* Lindl.		H	Erect herb	630
	Orchidaceae	283	*Habenaria holubii* Rolfe		H	Erect herb	444
	Orchidaceae	284	*Polystachya cultriformis* (Thon.) Sprengel		H	Epiphytic herb	566
	Orchidaceae	285	*Polystachya steudneri* Rchlo.f		H	Epiphytic herb	608
70	Oxalidaceae	286	*Oxalis radicosa* A.Rich.		H	Erect herb	538
71	Passifloraceae	287	*Passiflora edulis* Sims	Aburuta	H	Scarmbling herb	496
72	Phytolaccaceae	288	*Phytolacca dodecandra* L.Herit.		L		679
73	Piperaceae	289	*Peperomia abyssinica* Miq.		H	Epiphytic herb	593
	Piperaceae	290	*Peperomia molleri* C. DC.		H	Erect herb	599
	Piperaceae	291	*Peperomia retusa* (L.f.) A. Dietr.		H	Erect herb	643
	Piperaceae	292	*Peperomia tetraphylla* (Forst.) Hook. & Arn		H	Epiphytic herb	551
	Piperaceae	293	*Piper capense* L.f.	Turfo	H	Erect herb	418
	Piperaceae	294	*Piper umbellatum* L.	Tunjo deljessa	H	Erect herb	687
74	Pittosporaceae	295	*Pittosporum viridiflorum* Sims	Soole/Shoole	T		503
75	Plantaginaceae	296	*Plantago lanceolata* L.		H	Erect herb	586

	Plantaginaceae	297	*Plantago palmata* Hook.f.		H	Erect herb	432
76	Poaceae	298	*Arundinaria alpina* K.Schum.	Hoto	H	Erect herb	688
	Poaceae	299	*Digitaria abyssinica* (Hochst.ex A. Rich.) Stapf	Merga	H	Erect herb	684
	Poaceae	300	*Eleusine floccifolia* (Forssk.) Spreng.		H	Erect herb	635
	Poaceae	301	*Heteropogon contortus* Roem. & Schult.		H	Erect herb	434
	Poaceae	302	*Hyparrhenia pilgeriana* C.E. Hubb.		H	Erect herb	442
	Poaceae	303	*Oplismenus hirtellus* (L.) P. Beauv.	Mergagogori/Qemexe/Shuto	H	Erect herb	673
	Poaceae	304	*Oryra latifolia* L.	Go'a	S		553
	Poaceae	305	*Panicum atrosanguineum* A. Rich.		H	Erect herb	493
	Poaceae	306	*Panicum calvum* Stapf.		H	Erect herb	372
	Poaceae	307	*Panicum maximum* Jacq.		H	Erect herb	623
	Poaceae	308	*Paspalum scrobiculatum* L.	Merga	H	Erect herb	342
	Poaceae	309	*Pennisetum macrourum* Trin.	Duko	H	Erect herb	640
	Poaceae	310	*Pennisetum trachyphyllum* Pilg.	Duko	H	Erect herb	391
	Poaceae	311	*Setaria megaphylla* (Steud.) Th. Dur.	Jejeba	H	Erect herb	512
	Poaceae	312	*Snowdenia polystachya* (Fresen.) Pilg.	Merga/Muja	H	Erect herb	686
	Poaceae	313	*Sporobolus pyramidalis* P.Beauv.		H	Erect herb	382
77	Podocarpaceae	314	*Podocarpus falcatus*Thunb.	Birbirsa	T		565
78	Polygonaceae	315	*Persicaria setosula* (A. Rich.) K.L. Wilson	Wetland herb	H	Erect herb	465
	Polygonaceae	316	*Rumex abyssinicus* Jacq.		H	Erect herb	480
	Polygonaceae	317	*Rumex nepalensis* Spreng.	Soroto	H	Erect herb	373
79	Polypodiaceae	318	*Drynaria volkensii* Hieron	Baala belesa	H	Epiphytic herb	379
	Polypodiaceae	319	*Lepisorus excavatus* (Willd.) Ching.		H	Epiphytic herb	633
	Polypodiaceae	320	*Loxogramme abyssinica* (Baker) M.G. Price		H	Epiphytic herb	557
	Polypodiaceae	321	*Pleopeltis macrocarpa* (Willd.) Kaul		H	Epiphytic herb	606
80	Pteridaceae	322	*Pteris dentata* Forssk.		H	Epiphytic herb	615
	Pteridaceae	323	*Pteris pteridioides* (Hook.) Ballard		H	Erect herb	352
81	Ranunculaceae	324	*Clematis hirsuta* Perr. & Guill.	Shego	L		666
	Ranunculaceae	325	*Clematis longicauda* Steud.ex A.Rich.	Emano	H	Scarmbling herb	594
	Ranunculaceae	326	*Clematis simensis* Fresen.		L		499

	Ranunculaceae	327	*Ranunculus multifidus* Forssk.	Gubedu/Qoricha ilekana	H	Erect herb	356
	Ranunculaceae	328	*Thalictrum rhynchocarpum* Dill. & A. Rich	Shererit/Serebizu	H	Erect herb	323
82	Resedaceae	329	*Caylusea abyssinica* (Fresen.) Fisch. & Mey		H	Erect herb	443
83	Rhamnaceae	330	*Gouania longispicta* Engl.	Homecho	L		377
	Rhamnaceae	331	*Rhamnus prinoides* L.Herit.	Gesho	S/T		567
84	Rhizophoraceae	332	*Cassipourea malosana* (Baker) Alston	Loko ququme/Werallo	T		609
85	Rosaceae	333	*Alchemilla fischeri* Engl.		H	Erect herb	674
	Rosaceae	334	*Prunus africana* (Hook.f.) Kalkam	Omi/Omo	T		528
	Rosaceae	335	*Rubus apetalus* Poir.	Gora/Injori	S		412
	Rosaceae	336	*Rubus steudneri* Schweinf.		H	Scarmbling herb	328
86	Rubiaceae	337	*Canthium oligocarpum* Hiern	Doqonu/Mesho	S/T		319
	Rubiaceae	338	*Coffea arabica* L.	Bunna/Bunno	S/T		618
	Rubiaceae	339	*Galiniera saxifraga* (Hochst.) Bridson	Simereru/Diddo	T		597
	Rubiaceae	340	*Gardenia ternifolia* Schumach. & Thonn.		S/T		704
	Rubiaceae	341	*Hallea rubrostipulata* (K.Schum.) J.F.Leroy	Bootto/Ooboo	T		398
	Rubiaceae	342	*Oxyanthus speciosus* DC.	Abrango deljesa/O'pero	S/T		360
	Rubiaceae	343	*Pavetta abyssinica* Fresen.	Buna qemele/Cheka	S		314
	Rubiaceae	344	*Pavetta oliveriana* Hiern	Buna qemele/Cheka	S		537
	Rubiaceae	345	*Pentas lanceolata* (Forssk.) Defl. subsp. lanceolata		S		367
	Rubiaceae	346	*Psychotria orophila* Petit	Rocha/a'emato/aberango	S/T		685
	Rubiaceae	347	*Rothmannia urcelliformis* (Hiern) Robyns	Dibbo	S/T		561
	Rubiaceae	348	*Rytigynia neglecta* (Hiern) Robyns	Mixo sere/Nechato	S		576
	Rubiaceae	349	*Vangueria madagascariensis* Gmel.	Bururi adi	S		616
87	Rutaceae	350	*Clausena anisata* (Wild.) Benth.	Ulmayii/eremicho	S		695
	Rutaceae	351	*Fagaropsis angolensis* (Engl.) Dale	Muukke/Guraye/yahoo	T		409
	Rutaceae	352	*Teclea noblis* Del.	Molaye/Eleke/Kono	T		672
	Rutaceae	353	*Vepris dainellii* (Pichi-Serm.) Kokwaro	Haddesa/Mergetto	T		424
	Rutaceae	354	*Zanthoxylum usambarense* (Engl.) Kokwaro	Muke-armie	T		387
88	Sapindaceae	355	*Allophylus abyssinicus* (Hochst.) Radlkofer	Sheo	T		495
	Sapindaceae	356	*Allophylus macrobotrys* Gilg	Guresede	T		516

	Sapindaceae	357	*Blighia unijugata* Bak.	Ade jebbo	T		590
	Sapindaceae	358	*Deinbollia kilimandscharica* Taub.	Kesso	T		357
	Sapindaceae	359	*Lecaniodiscus fraxinifolius* Bak.	Keyeni	T		415
	Sapindaceae	360	*Paullinia pinnata* L.	Hidda gefersa	L		665
89	Sapotaceae	361	*Manilkara butugi* Chiov.		T		571
	Sapotaceae	362	*Mimusops kummel* A.DC.	Qolati/Qoladi	T		532
	Sapotaceae	363	*Pouteria adolfi-friederici* (Engl.) Baehni	Qerero/shao	T		408
	Sapotaceae	364	*Pouteria alnifolia* (Bak.) Roberty	Gommo	T		402
	Sapotaceae	365	*Pouteria altissima* (A.Chev.) Baehni	Semeko/Che'ii anneno	T		632
90	Scrophulariaceae	366	*Veronica abyssinica* Fres.		H	Erect herb	617
91	Selaginellaceae	367	*Selaginella kalbreyeri* Bak.		H	Epiphytic herb	681
	Selaginellaceae	368	*Selaginella kraussiana* (Kunze) A.Braun		H	Epiphytic herb	400
92	Simaroubaceae	369	*Brucea antidysenterica* J. F. Mill	Qomegno/Nukasho	T		518
93	Sinopteridaceae	370	*Doryopteris concolor* (Langsd. & Fisch.) Kuhn		H	Epiphytic herb	324
	Sinopteridaceae	371	*Pellaea viridis* (Forssk.) Prantl		H	Epiphytic herb	405
94	Smilacaceae	372	*Smilax anceps* Willd.		L		652
	Smilacaceae	373	*Smilax aspera* L.		H	Scarmbling herb	332
95	Solanaceae	374	*Datura stramonium* L.		H	Erect herb	311
	Solanaceae	375	*Nicotiana glauca* Graham		S		534
	Solanaceae	376	*Physalis peruviana* L.	Xossi	H	Erect herb	297
	Solanaceae	377	*Solanium incanum* L	Hiddi	H	Erect herb	473
	Solanaceae	378	*Solanum anguivi* Lam.		S		584
	Solanaceae	379	*Solanum nigrum* L.	Awiti ken bokkee	H	Erect herb	529
	Solanaceae	380	*Solanum pseudocapsicum* L.		H	Erect herb	466
96	Sterculiaceae	381	*Dombeya torrida* (J.F.Gmel.)P.Bamps	Adanisa	S/T		437
	Sterculiaceae	382	*Sterculia africana* (Lour.) Fiori		T		607
97	Tectariaceae	383	*Tectaria gemmifera* (Fee) Alston		H	Epiphytic herb	453
98	Thelypteridaceae	384	*Amauropelta bergiana* (Schltdl.) Holttum		H	Epiphytic herb	427
99	Tilaceae	385	*Triumfetta rhomboidea* Jacq.		S		462
	Tiliaceae	386	*Grewia ferruginea* Hochst. ex A.Rich.		T		542

	Tiliaceae	387	*Grewia mollis* A. Juss.		S		639
	Tiliaceae	388	*Triumfetta brachyceras* K. Schum.	Inchini	S		422
100	Typhaceae	389	*Typha latifolia* L.		H	Erect herb	583
101	Ulmaceae	390	*Celtis africana* Burm. f.		T		579
	Ulmaceae	391	*Celtis gomphophylla* Bak.		T		592
	Ulmaceae	392	*Celtis philippensis* Blanco	Chai/Kokaey	T		381
	Ulmaceae	393	*Celtis toka* (Forssk.) Hepper & Wood	Chai	T		293
	Ulmaceae	394	*Celtis zenkeri* Engl	Kobay	T		472
	Ulmaceae	395	*Trema orientalis* (L.) Blume	Sooxoo/huduferda	S/T		481
102	Urticaceae	396	*Elatostema monticolum* Hook.f	Merga bosonu	H	Erect herb	489
	Urticaceae	397	*Pilea rivularis* Wedd.	Kachi/Kafi	H	Erect herb	376
	Urticaceae	398	*Urera hypselodendron* (A.Rich.)Wedd.	Hidda chepo/Lanqisa	L		339
	Urticaceae	399	*Urtica simensis* Steudel	Dobi	H	Erect herb	631
103	Verbenaceae	400	*Clerodendrum myricoides* Vatke	Merassisa/Misirch	L		568
	Verbenaceae	401	*Lantana trifolia* L.		S		318
	Verbenaceae	402	*Lippia adoensis* Hochst. ex Walp.	Kusaye	S		604
	Verbenaceae	403	*Premna schimperi* Engl.	Uregessa	S		555
	Verbenaceae	404	*Verbena officinalis* L.	Arenchy/Arencho	H	Erect herb	587
104	Violaceae	405	*Rinorea friisii* M.Gilbert		S		425
105	Vitaceae	406	*Ampelocissus schimperiana* (Hochst. ex A.Rich.) Planch.	Cheep'oo	H	Scarmbling herb	344
	Vitaceae	407	*Cyphostemma adenocaule* (Steud ex A. Rich.) Desc. ex Wild & Drummond	Hidda renefa	H	Scarmbling herb	334
	Vitaceae	408	*Cyphostemma dembianense* (Chiov.) Vollesen		H	Scarmbling herb	384
106	Vittariaceae	409	*Antrophyum mannianum* Hook.f.		H	Epiphytic herb	544
	Vittariaceae	410	*Vittaria guineensis* Desv.		H	Epiphytic herb	682
107	Woodsiaceae	411	*Athyrium scandicinum* (Willd.) C. Persl.		H	Epiphytic herb	438
	Woodsiaceae	412	*Athyrium schimperi* Mouq. ex Fee		H	Epiphytic herb	671
108	Zingiberaceae	413	*Aframomum corrorima* (Braun) Jansen	Ogiyo	H	Erect herb	651
	Zingiberaceae	414	*Aframomum zambesiacum* (Baker) K. Schum.	Ogiyo deljessa	H	Erect herb	305

Appendix 16. New species records to Illubabur (IL) floristic region in the flora of Ethiopia and Eritrea

S/N	Botanical name	Family	Local name	GF	Remark
1	*Aerangis brachycarpa* (Rich) Reichb.f.	Orchidaceae		H	Epiphytic herb
2	*Aerangis thomsonii* (Rolfe) Schltr	Orchidaceae		H	Epiphytic herb
3	*Ageratum conyzoides* L.	Asteraceae		H	Erect herb
4	*Ajuga integrifolia* Buch. Ham. ex D.Don	Lamiaceae		H	Erect herb
5	*Allophylus abyssinicus* (Hochst.) Radlkofer	Sapindaceae	Sheo	T	
6	*Amaranthus hybridus* L.	Amaranthaceae		H	Erect herb
7	*Arundinaria alpina* K.Schum.	Poaceae	Hoto	H	Erect herb
8	*Asparagus africanus* Lam.	Asparagaceae	Seriti	H	Scarmbling herb
9	*Asparagus racemosus* Willd.	Asparagaceae	Seriti	H/L	
10	*Bulbophyllum josephii* (Kuntze) Summerh.	Orchidaceae		H	Epiphytic herb
11	*Caesalpinia decapetala* (Roth) Alston	Fabaceae	Yeferenj Kontir	H	Scarmbling herb
12	*Calpurina aurea* (Ait.) Benth	Fabaceae	Ceeka	S	
13	*Canarina eminii* Schwein.	Campanulaceae		H	Scarmbling herb
14	*Catha edulis* (Vahl) Forssk. ex Endl.	Celasteraceae		T	
15	*Ceropegia cufodontis* Chiov.	Asclepidaceae		H	Scarmbling herb
16	*Clematis simensis* Fresen.	Ranunculaceae		L	
17	*Commelina africana* L.	Commelinaceae	O'ka jebi (yellow)	H	Erect herb
18	*Desmodium repandum* Vahl	Fabaceae	Metene	H	Erect herb
19	*Dracaena steudneri* Scw.ex Engl.	Dracaenaceae	Serxe/Yuddii/yubedi	T	
20	*Elaeodendron buchananii* (Loes.) Loes.	Celasteraceae	Loko adi/wasso	T	
21	*Eleusine floccifolia* (Forssk.) Spreng.	Poaceae		H	Erect herb
22	*Epilobium stereophyllum* Fresen.	Onagraceae		H	Erect herb
23	*Ficus ovata* Vahl	Moraceae	Dembi guracha/qilinexu	T	
24	*Garcinia ovalifolia* Oliver	Guttiferae	Karawayu	S/T	
25	*Helichrysum schimperi* Moesner	Asteraceae		H	Erect herb
26	*Impatiens rothii* Hook.f .	Balsaminaceae		H	Erect herb
27	*Impatiens tinctoria* A.Rich.	Balsaminaceae	Ensosiillaa/Tebecho	H	Erect herb

28	*Indigofera atriceps* Hook.f.	Fabaceae		S	
29	*Ipomoea purpurea* (L.)Roth.	Convolvulaceae	Kelala	H	Scarmbling herb
30	*Isodon schimperi* (Vatke)JK. Morton	Lamiaceae		H	Erect herb
31	*Lannea schimperi* (A. Rich.) Engl.	Anacardiaceae		T	
32	*Lantana trifolia* L.	Verbenaceae		S	
33	*Leucas calostachys* Oliv.	Lamiaceae		H	Erect herb
34	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Kusaye	S	
35	*Maytenus undata* (Thunb.) Blakelok	Celasteraceae	Qorati/kombolecha	S/T	
36	*Nicotiana glauca* Graham	Solanaceae		S	
37	*Panicum atrosanguineum* A. Rich.	Poaceae		H	Erect herb
38	*Plantago palmata* Hook.f.	Plantaginaceae		H	Erect herb
39	*Plectranthus garckeanus* (Vatke) J. K. Morton	Lamiaceae	Yeriyo/yeriho	H	Erect herb
40	*Premna schimperi* Engl.	Verbenaceae	Uregessa	S	
41	*Rhus glutinosa* A. Rich.	Anacardiaceae	Xaxesa	S	
42	*Rubus steudneri* Schweinf.	Rosaceae		H	Scarmbling herb
43	*Sanicula elata* Buch.Ham. ex D. Don	Apiaceae	Metene	H	Erect herb
44	*Smilax anceps* Willd.	Smilacaceae		L	
45	*Smilax aspera* L.	Smilaceae		H	Scarmbling herb
46	*Solanium incanum* L	Solanaceae	Hiddi	H	Erect herb
47	*Solanum nigrum* L.	Solanaceae	Awiti ken bokkee	H	Erect herb
48	*Solanum pseudocapsicum* L.	Solanaceae		H	Erect herb
49	*Sporobolus pyramidalis* P.Beauv.	Poaceae		H	Erect herb
50	*Stephania abyssinica* (Dill & A. Rich.) Walp	Menispermaceae		H	Scarmbling herb
51	*Syzygium guineense* (Wild.) DC. Subsp. *afromontanum*	Myrtaceae	Beddesa/Yino/Gejo	T	
52	*Tagetes minuta* L.	Asteraceae		H	Erect herb
53	*Trilepisium madagascariense* DC.	Moraceae	Semeko/Che'ii anneno	T	
54	*Typha latifolia* L.	Typhaceae		H	Erect herb
55	*Vangueria madagascariensis* Gmel.	Rubiaceae	Bururi adi	S	
56	*Verbena officinalis* L.	Verbenaceae	Arenchy/Arencho	H	Erect herb

57	*Vernonia leopoldi* Vatke	Asteraceae	Soyema adi	S	
58	*Veronica abyssinica* Fres.	Scrophulariaceae		H	Erect herb
59	*Zanthoxylum usambarense* (Engl.) Kokwaro	Rutaceae	Muke-armie	T	

Appendix 17. Endemic plant recorded from Sele-Nono forest

Family	S/N	Botanical name	Local name	Status	GF	Remark
Acanthaceae	1	*Justicia bizuneshiae* Ensermu			H	Erect herb
Acanthaceae	2	*Justicia diclipteroides* Lindau subsp.*aethiopica* Hedren			H	Erect herb
Amaryllidaceae	3	*Scadoxus nutans* Friis & Nordal	Qicuu		H	Erect herb
Anacardiaceae	4	*Rhus glutinosa* A. Rich.	Xaxesa		S	
Araceae	5	*Amorphophallus gallaensis* (Engl.) N.E.Br.	Qicuu		H	Erect herb
Asteraceae	6	*Bothriocline schimperi* Oliv. & Hiern ex Benth.	Illebu		S	
Asteraceae	7	*Mikaniopsis clematoides* (Sch. Bip. ex A. Rich.) Milne-Redh.		LC	L/S	
Asteraceae	8	*Solanecio gigas* (Vatke) C.Jeffrey	Debeka	LC	S/T	
Asteraceae	9	*Vernonia leopoldi* Vatke	Soyema adi		S	
Balsaminaceae	10	*Impatiens rothii* Hook.f .			H	Erect herb
Euphorbiaceae	11	*Phyllanthus limmuensis* Cuf.		VU	S	
Fabaceae	12	*Crotalaria gillettii* Polhill	Gura wango		H	Erect herb
Fabaceae	13	*Trifolium mattirolianum* Chiov.	Sidisa		H	Erect herb
Fabaceae	14	*Erythrina brucei* Schweinf.	Wellensu		T	
Fabaceae	15	*Millettia ferruginea* (Hochst.) Baker	Sotolo/Yaggo	LC	T	
Lamiaceae	16	*Plectranthus garckeanus* (Vatke) J. K. Morton	Yeriyo/yeriho		H	Erect herb
Lamiaceae	17	*Pycnostachys abyssinica* Fresen.			H	Erect herb
Lamiaceae	18	*Satureja paradoxa* (Vatke) Engl.	Naddo		H	Erect herb
Menispermaceae	19	*Tiliacora troupinii* Cufod.	Liqixi/acho	VU	L	
Ranunculaceae	20	*Clematis longicauda* Steud.ex A.Rich.	Emano		H	Scarmbling herb
Rutaceae	21	*Vepris dainellii* (Pichi-Serm.) Kokwaro	Haddesa/Mergetto	LC	T	
Urticaceae	22	*Urtica simensis* Steudel	Dobi		H	Erect herb
Verbenaceae	23	*Lippia adoensis* Hochst. ex Walp.	Kusaye	LC	S	
Violaceae	24	*Rinorea friisii* M.Gilbert			S	
Zingiberaceae	25	*Aframomum corrorima* (Braun) Jansen	Ogiyo	VU	H	Erect herb

Appendix 18. Outlier species excluded from the analysis

S/N	Botanical name	Family
1	*Kigelia africana* (Lam.) Benth.	Bignoniaceae
2	*Maerua oblongifolia* (Forssk.) A. Rich.	Capparidaceae
3	*Erythrina abyssinica* (Lam. ex. DC.)	Fabaceae
4	*Erythrina brucei* Schweinf.	Fabaceae
5	*Ocimum lamiifolium* Hochst ex. Bent.	Lamiaceae
6	*Pseudocedrela kotschyi* (Schweinf.) Harms	Meliaceae
7	*Podocarpus falcatus*Thunb.	Podocarpaceae
8	*Sterculia africana* (Lour.) Fiori.	Sterculiaceae

Appendix 19. Synoptic value of plants species for each clusters

	Cluster number	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
S/N	Cluster size	19	13	9	29	8	5	7
1	*Abutilon longicuspe*	0.000	0.000	0.000	0.172	0.000	0.000	0.000
2	*Acalypha acrogyna*	0.235	0.923	0.000	0.000	0.000	0.000	0.222
3	*Acalypha ornata*	0.411	2.307	0.000	0.000	0.000	0.000	2.555
4	*Acanthopale aethiogermanica*	0.000	0.000	0.000	0.241	0.000	0.000	0.000
5	*Acanthus eminens*	0.000	0.000	0.000	0.862	0.000	0.000	0.000
6	*Achyranthes aspera*	0.000	0.000	0.444	0.275	0.000	0.000	0.555
7	*Achyrospermum parviflorum*	0.000	0.153	0.000	0.034	0.000	0.000	0.000
8	*Achyrospermum schimperi*	0.000	0.000	0.000	0.068	0.000	0.400	0.000
9	*Acmella caulirhiza*	0.000	0.000	3.111	0.103	0.000	0.000	0.000
10	*Adenostemma mauritianum*	0.000	0.000	0.000	0.000	0.875	0.000	0.000
11	*Aframomum corrorima*	2.705	0.000	0.000	0.137	0.000	0.000	1.22
12	*Aframomum zambesiacum*	0.941	0.076	0.000	0.000	0.000	0.000	0.000
13	*Ageratum conyzoides*	0.000	0.000	0.000	0.000	0.750	0.000	0.000
14	*Ajuga integrifolia*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
15	*Ajuga leucantha*	0.000	0.000	0.000	0.034	0.500	0.000	0.000
16	*Alangium chinense*	0.294	0.000	0.000	0.172	0.000	0.000	0.000
17	*Albizia grandibracteata*	1.941	1.461	0.000	0.137	0.000	0.000	2.888
18	*Albizia gummifera*	0.882	0.384	0.000	1.275	0.000	0.000	0.888
19	*Albizia schimperiana*	0.000	2.307	0.000	0.000	0.000	0.000	0.555
20	*Alchemilla ellenbeckii*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
21	*Alchemilla fischeri*	0.000	0.000	0.000	0.103	1.750	0.000	0.000
22	*Allophylus abyssinicus*	0.941	0.000	0.000	0.827	0.000	0.000	0.000
23	*Allophylus macrobotrys*	0.000	1.846	0.000	0.000	0.000	0.000	0.000
24	*Alstonia boonei*	0.000	5.000	0.000	0.000	0.000	0.000	1.444
25	*Amauropelta bergiana*	0.000	0.000	1.888	0.000	0.000	0.000	0.000
26	*Amorphophallus gallaensis*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
27	*Ampelocissus schimperiana*	0.000	0.461	0.000	0.068	0.000	0.000	0.000
28	*Anthocleista schweinfurthii*	0.000	1.384	0.000	0.000	0.000	0.000	3.777
29	*Antiaris toxicaria*	0.000	0.615	0.000	0.000	0.000	0.000	0.000
30	*Apodytes dimidiata*	0.000	0.769	0.000	2.655	0.000	0.000	0.000
31	*Argomuellera macrophylla*	0.000	3.230	0.000	0.000	0.000	3.600	0.000
32	*Arisaema schimperianaum*	0.000	0.000	0.000	0.137	0.000	0.000	0.666
33	*Arthropteris monocarpa*	0.000	0.000	2.666	0.000	0.750	0.000	0.000
34	*Arundinaria alpina*	0.000	0.000	7.666	0.000	0.000	0.000	0.000
35	*Asparagus africanus*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
36	*Asparagus racemosus*	0.000	0.000	1.333	0.034	0.000	0.000	0.000
37	*Asplenium sandersonii*	0.470	0.000	0.000	0.137	0.000	0.000	0.000
38	*Asystasia gangetica* subsp *micrantha*	0.117	0.461	0.000	0.103	0.000	0.000	0.000
39	*Athyrium scandicinum*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
40	*Athyrium schimperi*	0.000	0.000	2.222	0.000	0.000	0.000	0.000
41	*Baphia abyssinica*	0.000	3.461	0.000	0.000	0.000	0.000	0.000
42	*Barleria ventricosa*	0.058	0.384	0.000	0.206	0.000	0.000	0.000

43	*Basella alba*	0.000	0.000	0.000	0.000	0.500	0.000	0.000
44	*Begonia wollastonii*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
45	*Bersama abyssinica*	2.294	0.000	0.000	1.620	0.000	4.000	0.000
46	*Bidens prestinaria*	0.000	0.000	3.333	0.000	0.000	0.000	0.000
47	*Blechnum tabulare*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
48	*Blighia unijugata*	0.000	1.230	0.000	0.000	0.000	0.000	1.666
49	*Blotiella glabra*	0.000	0.000	1.777	0.000	0.000	0.000	0.000
50	*Bridelia micranta*	0.000	0.000	0.000	0.000	0.000	0.000	0.555
51	*Brillantaisia madagascariensis*	0.000	0.000	0.000	0.482	0.000	0.000	0.000
52	*Brucea antidysenterica*	0.588	0.000	0.000	0.482	0.000	0.000	0.000
53	*Calpurina aurea*	0.058	0.000	0.000	0.000	0.000	0.000	0.000
54	*Canthium oligocarpum*	0.235	0.000	0.000	0.862	0.000	0.000	0.000
55	*Carex chlorosaccus*	0.058	0.000	0.000	0.000	0.000	0.000	0.000
56	*Carex thomasii*	0.000	0.000	0.000	0.000	1.250	0.000	0.000
57	*Cassipourea malosana*	0.000	0.000	0.000	0.000	0.000	0.000	0.777
58	*Caylusea abyssinica*	0.000	0.000	0.000	0.000	0.750	0.000	0.000
59	*Celosia argentea*	0.000	0.000	0.000	0.034	0.000	1.800	0.000
60	*Celtis africana*	0.000	0.230	0.000	0.620	0.000	0.000	0.000
61	*Celtis gomphophylla*	0.000	0.692	0.000	0.000	0.000	0.000	0.000
62	*Celtis philippensis*	0.000	2.153	0.000	0.000	0.000	0.000	1.000
63	*Celtis zenkeri*	0.000	1.461	0.000	0.000	0.000	0.000	0.000
64	*Centella asiatica*	0.000	0.000	2.666	0.241	0.000	0.000	0.000
65	*Ceropegia cufodontis*	0.000	0.000	0.000	0.000	0.000	0.400	0.111
66	*Chionanthus mildbraedii*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
67	*Chlorophytum macrophyllum*	0.000	0.000	0.000	0.000	0.000	0.600	0.333
68	*Cissampelos mucronata*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
69	*Clausena anisata*	0.352	0.076	0.000	0.862	0.000	0.000	0.000
70	*Clematis hirsuta*	0.000	0.153	0.000	0.000	0.000	0.000	0.000
71	*Clematis longicauda*	0.000	0.153	0.000	0.034	0.000	0.000	0.000
72	*Clematis simensis*	0.058	0.000	0.000	0.000	0.000	0.000	0.000
73	*Clerodendrum myricoides*	0.352	0.000	0.000	0.103	0.000	0.000	0.000
74	*Coffea arabica*	2.647	1.923	0.000	0.000	0.000	2.600	1.888
75	*Combretum paniculatum*	0.411	0.000	0.000	0.448	0.000	1.200	0.555
76	*Commelina africana*	0.000	0.000	0.444	0.103	0.000	0.000	0.000
77	*Commelina benghalensis*	0.000	0.000	0.111	0.103	0.000	0.000	0.000
78	*Commelina diffusa*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
79	*Conyza agrostophylla*	0.000	0.000	0.000	0.034	0.375	0.000	0.000
80	*Cordia africana*	3.294	0.769	0.000	0.620	0.000	4.600	1.666
81	*Costus afer*	0.000	0.461	0.000	0.000	0.000	0.000	0.444
82	*Costus lucanusianus*	0.000	0.000	0.000	0.000	0.000	0.000	0.555
83	*Crassocephalum crepidioides*	0.117	0.000	0.000	0.000	0.000	0.000	0.000
84	*Crassocephalum macropappum*	0.235	0.000	0.000	0.000	0.000	0.000	0.000
85	*Crassocephalum montuosum*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
86	*Crinum ornatum*	0.294	0.000	0.000	0.000	0.000	0.000	0.000
87	*Crotalaria brevidens*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
88	*Crotalaria gillettii*	0.000	0.000	0.000	0.034	0.000	0.000	0.000

89	*Croton macrostachyus*	1.352	0.000	0.000	1.517	0.000	0.000	0.000
90	*Culcasia falcifolia*	0.000	0.000	0.000	0.172	0.000	1.000	0.000
91	*Cyathula cylinderica*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
92	*Cyathea manniana*	0.000	0.000	0.000	0.413	0.000	0.000	0.000
93	*Cyathula polycephala*	0.000	0.000	0.333	0.000	0.375	0.000	0.000
94	*Cyathula prostrata*	0.000	0.000	0.111	0.000	0.000	0.000	0.000
95	*Cyathula uncinulata*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
96	*Cynoglossum amplifolium*	0.058	0.000	0.222	0.172	0.000	0.000	0.000
97	*Cyperus aterrimus*	0.000	0.000	0.000	0.000	5.375	0.000	0.000
98	*Cyperus dereilema*	0.000	0.000	0.000	0.068	0.500	0.000	0.000
99	*Cyperus digitatus*	0.058	0.000	0.000	0.000	0.000	0.000	0.222
100	*Cyperus elegantulus*	0.000	0.000	0.777	0.000	5.500	0.000	0.000
101	*Cyperus rotundus*	0.000	0.000	0.000	0.137	0.000	0.000	1.111
102	*Cyperus schimperianus*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
103	*Cyphostemma adenocaule*	0.235	0.000	0.000	0.137	0.000	0.000	0.000
104	*Cyphostemma dembianense*	0.058	0.000	0.000	0.000	0.000	0.000	0.000
105	*Dalbergia lactea*	0.000	0.076	0.000	0.000	0.000	0.000	0.000
106	*Deinbollia kilimandscharica*	1.235	0.000	0.000	3.103	0.000	1.000	0.000
107	*Desmodium repandum*	0.352	0.000	1.777	1.551	0.000	0.000	1.000
108	*Dichrocephala integrifolia*	0.000	0.000	0.666	0.137	0.500	0.000	0.000
109	*Dicliptera maculata*	0.058	0.000	0.000	0.034	0.000	0.000	0.000
110	*Digitaria abyssinica*	0.000	0.307	0.000	0.000	0.625	0.000	0.000
111	*Diospyros abyssinica*	2.235	1.923	0.000	0.620	0.000	4.000	3.111
112	*Dioscorea praehensilis*	0.000	0.000	0.000	0.000	0.000	0.000	0.222
113	*Dissotis senegambiensis*	0.000	0.000	0.000	0.000	0.125	0.000	0.000
114	*Dombeya torrida*	0.000	0.000	0.000	0.172	0.000	0.000	0.000
115	*Doryopteris concolor*	0.823	0.000	0.000	0.482	0.000	2.200	0.777
116	*Dracaena afromontana*	0.294	0.000	0.000	4.413	0.000	0.000	0.000
117	*Dracaena fragrans*	1.294	1.692	0.000	0.103	0.000	4.600	3.666
118	*Dracaena steudneri*	2.000	0.000	0.000	0.172	0.000	0.000	4.666
119	*Drymaria cordata*	0.000	0.000	0.555	0.000	0.000	0.000	0.000
120	*Dyschoriste multicaulis*	0.117	0.000	0.000	0.034	0.000	0.000	0.000
121	*Ehertia cymosa*	1.117	0.000	0.000	0.068	0.000	0.000	0.000
122	*Ekebergia capensis*	0.647	0.000	0.000	1.103	0.000	0.000	0.000
123	*Elaeodendron buchananii*	3.941	0.307	0.000	2.517	0.000	0.000	0.666
124	*Elatostema monticolum*	0.411	0.000	0.000	1.310	1.125	0.000	1.333
125	*Eleusine floccifolia*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
126	*Embelia schimperi*	0.000	0.076	0.000	0.000	0.000	0.000	0.000
127	*Ensete ventricosum*	0.117	0.076	0.000	0.034	0.000	0.000	0.333
128	*Entada abyssinica*	1.823	0.846	0.000	0.103	0.000	0.000	1.444
129	*Epilobium stereophyllum*	0.000	0.000	0.666	0.000	0.625	0.000	0.000
130	*Erythrococca trichogyne*	1.647	0.000	0.000	0.000	0.000	0.000	1.111
131	*Eulophia guineensis*	0.000	0.000	0.000	0.000	0.000	0.000	0.333
132	*Euphorbia ampliphylla*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
133	*Fagaropsis angolensis*	0.764	0.307	0.000	0.344	0.000	0.000	0.000
134	*Ficus exasperata*	0.000	0.769	0.000	0.000	0.000	0.000	1.444

135	*Ficus ovata*	1.176	0.384	0.000	0.000	0.000	0.000	2.333
136	*Ficus sur*	1.058	0.384	0.000	2.068	0.000	0.000	2.222
137	*Ficus sycomoru*	0.176	1.076	0.000	0.000	0.000	2.000	0.444
138	*Ficus thonningii*	0.470	0.000	0.000	0.000	0.000	0.000	1.777
139	*Ficus vasta*	0.941	0.000	0.000	0.000	0.000	0.000	0.000
140	*Flacourtia indica*	0.000	0.000	0.000	0.689	0.000	0.000	0.000
141	*Floscopa glomerata*	0.000	0.000	0.555	0.034	0.750	0.000	0.000
142	*Galiniera saxifraga*	0.588	0.000	0.000	1.517	0.000	0.000	0.000
143	*Garcinia buchananii*	0.000	1.461	0.000	0.000	0.000	0.000	0.000
144	*Garcinia ovalifolia*	0.000	2.230	0.000	0.000	0.000	0.000	0.000
145	*Geranium arabicum*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
146	*Glycine wightii*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
147	*Gouania longispicta*	0.000	0.000	0.000	0.137	0.000	1.800	0.333
148	*Guizotia scabra*	0.000	0.000	3.111	0.034	0.000	0.000	0.000
149	*Guizotia schimperi*	0.000	0.000	1.333	0.000	0.000	0.000	0.000
150	*Gynandropsis gynandra*	0.000	0.153	0.000	0.000	0.000	0.000	0.000
151	*Habenaria holubii*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
152	*Hallea rubrostipulata*	0.000	0.000	0.000	0.344	0.000	1.000	0.000
153	*Helichrysum formosissimum*	0.000	0.000	0.000	0.000	0.500	0.000	0.000
154	*Heteropogon contortus*	0.000	0.000	0.000	0.000	0.500	0.000	0.000
155	*Hippocratea africana*	0.941	0.000	0.000	0.000	0.000	1.000	0.777
156	*Hippocratea goetzei*	1.588	0.461	0.000	0.000	0.000	0.000	1.000
157	*Hippocratea pallens*	1.176	0.307	0.000	0.793	0.000	0.000	1.222
158	*Hydrocotyle mannii*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
159	*Hygrophila schulli*	0.000	0.000	0.000	0.034	0.750	0.000	0.000
160	*Hyparrhenia pilgeriana*	0.000	0.000	0.000	0.000	0.750	0.000	0.000
161	*Hypoestes forskaolii*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
162	*Hypoestes triflora*	0.000	0.000	0.666	0.103	0.000	0.000	0.000
163	*Ilex mitis*	0.470	0.000	0.000	1.241	0.000	0.000	0.000
164	*Impatiens ethiopica*	0.000	0.000	0.444	0.103	0.000	0.000	0.000
165	*Impatiens hochstetteri*	0.000	0.000	1.333	0.172	0.000	0.000	0.000
166	*Impatiens tinctoria*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
167	*Indigofera atriceps*	0.058	0.000	0.111	0.000	0.000	0.000	0.000
168	*Ipomoea purpurea*	0.235	0.000	0.000	0.000	0.000	0.000	0.000
169	*Isodon schimperi*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
170	*Isoglossa somalensis*	0.000	0.000	0.000	0.206	0.000	0.000	0.000
171	*Jasminum abyssinicum*	0.117	0.076	0.000	0.275	0.000	0.000	0.000
172	*Justicia bizuneshiae*	0.117	0.000	0.000	0.103	0.000	0.000	0.000
173	*Justicia diclipteroides* subsp.*aethiopica*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
174	*Justicia ladanoides*	0.117	0.384	0.000	0.034	0.000	0.000	0.000
175	*Justicia schimperiana*	0.000	0.000	0.000	0.827	0.000	0.000	0.000
176	*Lactuca paradoxa*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
177	*Laggera crispate*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
178	*Landolphia buchananii*	1.647	0.000	0.000	1.103	0.000	0.000	0.000
179	*Lantana trifolia*	0.117	0.000	0.000	0.000	0.000	0.000	0.000

180	*Lecaniodiscus fraxinifolius*	0.000	1.384	0.000	0.000	0.000	0.000	0.000
181	*Lepidotrichilia volkensii*	0.235	0.000	0.000	1.689	0.000	1.600	0.000
182	*Leptadeni hastata*	0.000	0.000	0.000	0.000	0.000	0.000	0.222
183	*Leucas calostachys*	0.000	0.000	0.000	0.000	0.000	0.000	0.111
184	*Lippia adoensis*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
185	*Lobelia giberroa*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
186	*Lycopodiella cernua*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
187	*Lycopodium clavatum*	0.000	0.000	0.000	0.000	0.250	0.000	0.000
188	*Macaranga capensis*	0.000	0.000	0.000	1.241	0.000	0.000	0.000
189	*Maesa lanceolata*	0.000	0.000	0.000	0.068	0.000	0.000	0.777
190	*Manilkara butugi*	0.000	4.769	0.000	0.000	0.000	0.000	0.444
191	*Marattia fraxinea*	0.294	0.000	0.000	0.344	0.000	0.000	0.000
192	*Marantochloa leucantha*	0.000	0.000	0.000	0.000	0.000	0.000	0.666
193	*Maytenus arbutifolia*	0.000	0.000	0.000	0.172	0.000	0.000	0.000
194	*Maytenus gracilipes*	0.117	0.000	0.000	0.793	0.000	0.000	0.000
195	*Maytenus obscura*	0.000	0.000	0.555	0.000	0.000	0.000	0.000
196	*Maytenus undata*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
197	*Mellera lobulata*	0.000	0.384	0.000	0.103	0.000	0.000	0.000
198	*Mikaniopsis clematoides*	0.000	0.000	0.444	0.000	0.625	0.000	0.000
199	*Milicia excelsa*	0.000	0.769	0.000	0.000	0.000	0.000	0.000
200	*Millettia ferruginea*	0.823	0.000	0.000	0.551	0.000	0.000	2.111
201	*Mimusops kummel*	1.058	2.307	0.000	0.000	0.000	0.800	2.666
202	*Momordica foetida*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
203	*Morus mesozygia*	2.000	1.923	0.000	0.000	0.000	4.200	4.888
204	*Myrsine africana*	0.117	0.000	0.000	0.000	0.000	0.000	0.000
205	*Nephrolepis biserrata*	0.058	0.076	0.000	0.034	0.500	0.000	0.000
206	*Nuxia congesta*	0.000	0.692	0.000	0.000	0.000	0.000	0.000
207	*Ocimum grattissimum*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
208	*Ocotea kenyensis*	0.000	0.000	0.000	0.344	0.000	0.000	0.000
209	*Olea capensis* subsp.*macrocarpa*	0.411	0.000	0.000	1.241	0.000	0.000	0.666
210	*Olea welwitschii*	4.000	0.000	0.000	2.827	0.000	0.000	0.444
211	*Oncinotis tenuiloba*	0.588	0.000	0.000	0.413	0.000	0.000	0.444
212	*Oncoba spinosa*	0.000	0.153	0.000	0.000	0.000	0.000	0.000
213	*Oplismenus hirtellus*	1.176	0.000	6.000	1.517	1.125	0.000	1.111
214	*Oryra latifolia*	0.647	0.000	0.000	0.137	1.375	0.000	1.444
215	*Oxalis radicosa*	0.000	0.000	0.444	0.000	0.375	0.000	0.000
216	*Oxyanthus speciosus*	0.411	0.000	0.000	0.827	0.000	0.000	0.000
217	*Panicum atrosanguineum*	0.000	0.615	0.000	0.000	0.750	0.000	0.000
218	*Panicum calvum*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
219	*Paspalum scrobiculatum*	0.000	0.153	0.000	0.000	0.875	0.000	0.000
220	*Paullinia pinnata*	0.000	0.000	0.000	0.068	0.000	0.000	0.444
221	*Pavetta abyssinica*	0.000	0.000	0.000	0.206	0.000	0.000	0.000
222	*Pavetta oliveriana*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
223	*Pellaea viridis*	0.411	0.000	0.000	0.034	0.000	0.800	0.000
224	*Pennisetum macrourum*	0.000	0.000	0.000	0.000	2.250	0.000	2.222

225	*Pennisetum trachyphyllum*	0.000	0.000	0.000	0.000	0.000	0.000	0.222
226	*Pentas lanceolata*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
227	*Peperomia molleri*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
228	*Peperomia retusa*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
229	*Peponium vogelii*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
230	*Persicaria setosula*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
231	*Phaulopsis imbricata*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
232	*Phoenix reclinata*	0.176	0.384	0.000	0.275	0.000	3.200	3.444
233	*Phyllanthus limmuensis*	0.000	0.153	0.000	0.000	0.125	0.000	0.000
234	*Phyllanthus ovalifolius*	0.000	0.000	0.000	0.068	0.000	0.000	0.111
235	*Physalis peruviana*	0.000	0.000	0.000	0.000	0.000	0.200	0.111
236	*Phytolacca dodecandra*	0.117	0.000	0.000	0.000	0.000	0.000	0.000
237	*Pilea rivularis*	0.000	0.000	0.000	0.034	0.500	0.000	0.000
238	*Piper capense*	0.647	0.000	0.000	0.586	0.000	0.000	1.777
239	*Piper umbellatum*	0.000	0.000	0.000	0.000	0.000	0.000	0.666
240	*Pittosporum viridiflorum*	0.470	0.000	0.000	0.655	0.000	2.800	0.000
241	*Plantago lanceolata*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
242	*Plantago palmata*	0.000	0.000	0.000	0.000	0.500	0.000	0.000
243	*Plectranthus garckeanus*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
244	*Plectranthus punctatus*	0.117	0.000	0.000	0.000	0.000	0.000	0.222
245	*Pollia condensata*	0.000	0.000	0.000	0.000	0.000	0.200	0.222
246	*Polyscias fulva*	0.294	0.384	0.000	0.896	0.000	0.000	1.000
247	*Pouteria adolfi-friederici*	0.000	0.000	0.000	5.517	0.000	0.000	0.000
248	*Pouteria alnifolia*	0.000	1.538	0.000	0.000	0.000	0.000	0.000
249	*Pouteria altissima*	0.000	0.769	0.000	0.000	0.000	0.000	0.000
250	*Premna schimperi*	0.117	0.000	0.000	0.068	0.000	0.000	0.000
251	*Prunus africana*	0.000	0.000	0.000	0.689	0.000	0.000	0.000
252	*Psidium guajava*	0.000	0.000	0.000	0.000	0.000	0.400	0.333
253	*Psychotria orophila*	0.058	0.153	0.000	1.448	0.000	0.200	0.555
254	*Pteris dentata*	0.000	0.000	0.000	0.896	0.000	0.000	0.000
255	*Pteris pteridioides*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
256	*Pterolobium stellatum*	0.000	0.000	0.000	0.379	0.000	0.000	0.222
257	*Pycnostachys abyssinica*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
258	*Ranunculus multifidus*	0.000	0.000	0.000	0.000	0.625	0.000	0.000
259	*Rhamnus prinoides*	0.000	0.000	1.333	0.103	0.000	0.000	0.000
260	*Rhus glutinosa*	0.000	0.000	0.000	0.000	0.000	0.000	0.555
261	*Rinorea friisii*	0.000	0.615	0.000	0.000	0.000	0.000	0.000
262	*Ritchiea albersii*	0.000	0.000	0.000	0.000	0.000	0.000	3.111
263	*Rothmannia urcelliformis*	0.764	0.307	0.000	0.655	0.000	0.000	0.000
264	*Rubus apetalus*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
265	*Ruellia prostrata*	0.000	0.000	0.000	0.241	0.000	0.200	0.000
266	*Rumex abyssinicus*	0.000	0.000	0.000	0.000	0.500	0.000	0.000
267	*Rumex nepalensis*	0.000	0.000	0.000	0.034	0.375	0.000	0.000
268	*Rytigynia neglecta*	0.000	0.307	0.000	0.931	0.000	0.000	0.000
269	*Saba comorensis*	0.000	1.000	0.000	0.000	0.000	1.200	0.000
270	*Salvia nilotica*	0.000	0.000	0.444	0.000	0.000	0.000	0.000

271	*Sanicula elata*	0.117	0.000	0.888	0.068	0.875	0.000	0.000
272	*Sapium ellipticum*	3.176	0.000	0.000	0.965	0.000	5.400	0.000
273	*Satureja paradoxa*	0.000	0.000	0.666	0.000	0.000	0.000	0.000
274	*Scadoxus nutans*	0.000	0.000	0.000	0.310	0.000	0.000	0.000
275	*Schefflera abyssinica*	1.176	0.000	0.000	4.551	0.000	0.000	2.333
276	*Schefflera myriantha*	0.000	0.000	0.000	0.172	0.000	0.000	0.000
277	*Schefflera volkensii*	0.000	0.000	0.000	1.517	0.000	0.000	0.000
278	*Selaginella kraussiana*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
279	*Senna petersiana*	0.117	0.000	0.000	0.000	0.000	0.000	0.000
280	*Senna septemtrionali*	0.000	0.000	0.000	0.068	0.000	0.600	0.000
281	*Setaria megaphylla*	0.000	0.000	0.000	0.068	1.625	0.000	2.444
282	*Smilax anceps*	0.000	0.000	0.000	0.000	0.000	0.000	0.111
283	*Smilax aspera*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
284	*Snowdenia polystachya*	0.000	0.000	0.000	0.000	0.750	0.000	0.000
285	*Solanecio gigas*	0.294	0.000	0.000	0.137	0.000	0.000	0.000
286	*Solanecio mannii*	0.058	0.000	0.000	0.103	0.000	0.000	0.000
287	*Solanum incanum*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
288	*Sonchus bipontini*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
289	*Sporobolus pyramidalis*	0.000	0.000	0.000	0.000	1.500	0.000	0.000
290	*Stellaria sennii*	0.000	0.000	0.000	0.000	0.125	0.400	0.000
291	*Stephania abyssinica*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
292	*Stereospermum kunthianum*	0.000	0.692	0.000	0.000	0.000	1.000	0.666
293	*Stiotocardia beraviensis*	0.000	0.153	0.000	0.000	0.000	0.000	0.000
294	*Strychnos mitis*	0.000	2.461	0.000	0.000	0.000	0.000	0.000
295	*Syzygium guineense* Subsp. *afromontanum*	1.764	0.000	0.000	2.931	0.000	0.000	0.000
296	*Tagetes minuta*	0.000	0.000	0.333	0.000	0.000	0.000	0.000
297	*Teclea noblis*	0.000	1.076	0.000	0.517	0.000	2.600	0.000
298	*Tectaria gemmifera*	1.000	0.000	0.000	1.137	0.000	0.000	0.000
299	*Terminalia schimperiana*	0.000	0.384	0.000	0.000	0.000	0.000	0.000
300	*Thalictrum rhynchocarpum*	0.000	0.000	0.000	0.344	0.000	0.000	0.777
301	*Thunbergia alata*	0.058	0.230	0.000	0.000	0.000	0.000	0.000
302	*Tiliacora troupinii*	0.000	0.000	0.000	0.620	0.000	0.000	0.333
303	*Trema orientalis*	1.117	0.230	0.000	0.000	0.000	0.000	0.000
304	*Trichilia dregeana*	1.470	0.923	0.000	0.000	0.000	4.800	3.777
305	*Trifolium baccarinii*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
306	*Trifolium mattirolianum*	0.000	0.000	0.111	0.275	0.000	0.000	0.000
307	*Trifolium polystachyum*	0.000	0.000	0.444	0.000	0.500	0.000	0.000
308	*Trilepisium madagascariense*	1.058	1.307	0.000	0.137	0.000	1.600	5.000
309	*Tristemma mauritianum*	0.000	0.000	0.333	0.000	1.750	0.000	0.000
310	*Turraea holstii*	0.000	0.846	0.000	0.000	0.000	0.000	0.000
311	*Tylophora sylvatica*	0.000	0.000	0.000	0.000	0.000	0.000	0.555
312	*Urera hypselodendron*	0.705	0.384	0.000	0.241	0.000	0.000	0.444
313	*Urtica simensis*	0.000	0.000	0.000	0.034	0.000	0.000	0.555
314	*Vangueria madagascariensis*	0.000	0.538	0.000	0.137	0.000	0.000	0.000
315	*Vepris dainellii*	1.941	0.000	0.000	3.034	0.000	3.600	0.000

316	*Verbena officinalis*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
317	*Vernonia amygdalina*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
318	*Vernonia auriculifera*	0.000	0.000	0.000	0.344	0.000	0.000	0.000
319	*Vernonia hochstetteri*	0.000	0.000	0.000	0.137	0.000	0.000	0.000
320	*Vernonia karaguensis*	0.000	0.000	0.000	0.034	0.000	0.000	0.000
321	*Vernonia leopoldi*	0.000	0.000	0.000	0.103	0.000	0.000	0.000
322	*Veronica abyssinica*	0.000	0.000	0.444	0.000	0.000	0.000	0.000
323	*Vigna membranacea*	0.000	0.000	0.000	0.068	0.000	0.000	0.000
324	*Vigna vexillata*	0.000	0.076	0.000	0.034	0.000	0.200	0.000
325	*Whitfieldia elongata*	0.000	1.769	0.000	0.000	0.000	0.000	0.000
326	*Zanthoxylum usambarense*	0.000	1.923	0.000	0.000	0.000	0.000	0.000
327	*Zehneria scabra*	0.000	0.000	0.444	0.034	0.000	0.000	0.000

Appendix 20. Enviromental data recorded for each sample plot in Sele-Nono forest

Plot No	Altitude (m)	Slope (º)	Aspect	Disturbance	pH (H20)	P (ppm)	EC (mm/cm)	OM (%)	K (meq/100gm)	CEC (meq/100gm)	TN (%)	Sand (%)	Silt (%)	Clay (%)
1	1640	33	1	2	4.7	6.75	0.32	11.06	0.72	54.62	0.65	25	43.14	31.86
2	1165	25	0	4	5.64	8.53	0.563	7.293	1.34	29.22	0.34	25	36	39
3	1640	42	2	1	4.88	5.12	0.23	9.431	0.63	74.23	0.75	35	35	30
4	2400	20	1.3	2	4.76	3.23	0.185	5.913	0.46	90.2	0.94	32.5	42.75	24.75
5	2240	40	2	1	4.89	4.74	0.253	6.189	0.46	72.17	0.87	32	41.25	26.75
6	1640	0	0	3	4.4	4.63	0.204	15.58	0.46	30.1	1.02	37.5	41.25	21.25
7	2430	12	0	2	4.89	3.93	0.211	7.396	0.28	84.29	0.56	32.5	40	27.5
8	1872	35	1	3	4.98	5.94	0.37	11.70	0.69	65.97	0.52	25	37	38
9	2180	36	2	1	5.21	4.03	0.132	10.39	0.32	83.21	0.96	26	41.25	32.75
10	1740	0	0	3	5.93	6.98	0.254	18.55	0.32	40	1.03	37.5	41.25	21.25
11	1620	14	2.5	5	5.61	5.6	0.389	12.36	0.89	58.32	0.53	34.11	32.23	33.66
12	1830	0	0	3	5.55	3.93	0.379	5.551	0.54	29.22	1	40	35	25
13	2380	15	1.3	5	4.24	4.74	0.282	19.62	0.22	89.04	0.87	40	38.75	21.25
14	1430	23	3	3	5.42	6.73	0.43	15.89	0.87	54.12	0.44	28.48	37.35	34.17
15	1850	0	0	3	5.18	4.74	0.452	14.51	0.43	51.56	1.04	32.5	40	27.5
16	1640	0	0	3	4.89	4.21	0.329	5.224	0.46	34.56	1.05	32.5	42.75	24.75
17	1230	29	3	4	6.27	7.12	0.698	16.29	0.98	51.56	0.29	40	35	25
18	1280	25	2	4	5.15	6.98	0.45	15.89	0.83	56.42	0.47	40	38.75	21.25
19	1880	48	1	1	5.61	4.54	0.148	9.706	0.54	79.11	0.63	27	35	38
20	1100	34	3	4	5.42	10.11	0.474	14.01	0.96	34.56	0.32	49.34	26.44	24.22
21	1860	38	2	2	5.64	4.12	0.158	11.29	0.54	83.29	0.72	32	40	28
22	1200	30	1.3	3	5.15	8.8	0.541	13.98	1.04	38.42	0.3	50.94	21	28.06
23	1820	45	0	3	4.89	5.43	0.26	11.43	0.62	77.34	0.54	23	40	37
24	2010	40	3	1	5.21	4.48	0.261	7.396	0.72	56.12	0.7	22	42.75	35.25
25	1600	35	1	2	4.73	5.37	0.236	12.43	0.74	70.52	0.75	35	40	25
26	1190	36	0	4	6.16	7.51	0.53	3.741	1.34	34.8	0.43	55.43	24.13	20.44
27	940	35	0	3	5.66	8.05	0.499	8.017	1.43	44.22	0.37	46.34	32.5	21.16
28	1636	32	1	2	4.89	5.2	0.231	5.724	0.66	79.34	0.66	54	24	22

29	1900	46	3	3	5.42	5.03	0.184	10.08	0.36	69.25	0.88	31	40	29
30	1250	27	1.3	4	6.13	9.6	0.518	7.068	0.97	45.32	0.39	37.5	33	29.5
31	2300	18	0	2	4.11	4.21	0.203	10.20	0.29	89.89	1.02	28.75	45	26.25
32	1905	30	3	2	4.89	4.87	0.232	7.862	0.42	73.11	0.58	27.23	38.75	34.02
33	1800	18	2.5	5	5.21	5.87	0.352	11.29	0.72	68.13	0.55	36.04	28.17	35.79
34	1885	40	2	2	4.37	5.73	0.167	9.948	0.43	86.34	0.96	20	45	35
35	1350	28	3.3	3	5.45	6.66	0.48	10.27	0.94	63.24	0.38	45	38.75	16.25
36	1394	40	1.3	3	4.89	5.36	0.21	16.34	0.53	68.46	0.56	37	46	17
37	2070	35	2	2	4.89	5.64	0.261	9.137	0.46	90.01	1.01	25	42.75	32.25
38	1625	36	0	2	4.76	4.67	0.13	11.53	0.64	64.88	0.5	43	35	22
39	1500	12	3	4	5.66	5.98	0.42	14.18	1.01	48.63	0.48	37.5	41.25	21.25
40	2350	22	1.3	2	4.04	4.44	0.186	7.931	0.25	84.47	0.96	47.5	38.75	13.75
41	1900	33	1.3	2	4.89	4.58	0.25	11	0.69	74.38	0.72	25	40	35
42	1600	35	4	1	5.12	3.87	0.375	12.36	0.61	82.38	0.7	32.5	42.75	24.75
43	1840	0	0	3	4.99	5.4	0.318	16.10	1.11	51.56	0.94	32.5	40	27.5
44	1630	20	3.3	4	5.61	6.22	0.32	13.51	0.73	64.26	0.5	37.83	27.25	34.92
45	1865	43	2	2	4.65	4.32	0.188	7.620	0.29	74.11	0.75	22	40	38
46	1910	26	1.3	4	4.45	4.23	0.217	6.448	0.36	88.49	0.98	31.25	42.5	26.25
47	2353	44	0	2	5.04	5.22	0.38	9.948	0.72	74.55	0.64	32.5	40	27.5
48	1645	48	3	2	4.4	4.05	0.211	7.396	0.52	74.32	0.94	24	38.75	37.25
49	2272	35	3	1	4.6	4.74	0.282	10.08	0.43	74.51	0.74	28.75	45	26.25
50	1655	0	0	3	4.89	4.67	0.1536	2.120	0.96	74.38	1.03	40	38.75	21.25
51	2120	35	3	1	5.55	4.21	0.176	10.20	0.26	80.54	0.67	37	38.75	24.25
52	1420	35	3	3	6.16	6.8	0.436	14.56	0.82	63.6	0.52	37.5	41.25	21.25
53	1160	23	0	2	5.52	6.98	0.467	14.36	1.23	52.31	0.33	55	21	24
54	2163	35	3	1	4.14	5.76	0.127	7.931	0.46	82.56	0.72	31.25	42.5	26.25
55	1800	25	1	5	4.89	5.79	0.23	9.586	0.51	80.55	0.72	22	37.5	40.5
56	1895	15	1.3	5	5.64	7.51	0.38	13.18	0.68	59.46	0.57	45	24.21	30.79
57	2083	25	1	1	4.52	4.52	0.183	9.172	0.42	76.05	0.86	28	46	26
58	2415	14	2.5	5	4.11	4.3	0.165	6.793	0.26	90.32	0.96	32.5	37.5	30

59	1126	26	0	4	5.91	8.23	0.483	5.879	1.11	42.43	0.35	41.36	32.11	26.53
60	2058	38	1	1	4.89	3.93	0.235	10.27	0.46	83	0.84	45	38.75	16.25
61	2100	25	2	1	4.93	3.53	0.143	7.793	0.43	82.38	0.73	22.5	32.5	45
62	2160	25	2	1	5.61	4.21	0.185	7.982	0.46	78.85	0.7	37.5	37.5	25
63	1865	40	0	2	5.93	4.88	0.32	11.44	0.64	72.59	0.63	32	38.75	29.25
64	1870	35	2	1	4.89	3.17	0.154	9.413	0.29	90.32	0.74	55	30	15
65	1220	30	1	4	5.08	5.41	0.218	11.29	0.53	68.41	0.6	28.75	45	26.25
66	2040	16	1.3	3	4.89	4.12	0.175	7.965	0.38	74.38	1.01	50	11	39
67	1634	35	2	2	4.41	4.34	0.264	7.482	0.37	67.91	0.69	32.5	40	27.5
68	2095	35	1	2	5.18	4.74	0.267	6.103	0.51	77.04	0.65	28	38.75	33.25
69	2344	34	2	2	4.89	3.88	0.159	8.603	0.42	74.4	0.72	32.5	42.75	24.75
70	1870	40	2	2	5.52	6.12	0.416	4.379	0.85	58.36	0.46	40	35	25
71	1880	38	1	2	4.89	5.71	0.261	6.137	0.62	74.58	0.63	31.25	42.5	26.25
72	2150	32	1	3	6.22	4.74	0.546	6.672	0.96	29.44	0.45	58.01	30.33	11.66
73	1276	41	1	2	4.99	4.46	0.25	14.51	0.7	78.52	0.72	18	37.5	44.5
74	1600	33	0	4	4.73	5.4	0.473	17.87	0.79	35.06	0.42	41.24	20	38.76
75	1160	46	2	3	4.89	4.05	0.166	6.189	0.46	96.47	0.83	32.5	40	27.5
76	1390	30	2	2	4.37	3.86	0.158	17.87	0.3	85.06	0.8	40	38.75	21.25
77	1134	25	1.3	3	4.89	4.92	0.256	11.51	0.65	68.33	0.5	26	34	40
78	2041	30	2	2	5.21	4.74	0.282	11.94	0.55	72.37	0.58	46	31	23
79	2020	25	2	1	4.89	4.75	0.286	10.03	0.47	90.25	0.78	33	45	22
80	1900	35	0	3	5.21	7.27	0.261	13.98	0.79	82.38	0.94	28.75	45	26.25
81	1640	32	1.3	2	5.61	5.23	0.315	11.06	0.68	68.38	0.68	37.5	41.25	21.25
82	2018	28	0	3	4.89	8.6	0.557	8.241	0.91	22.92	0.36	51.24	18.42	30.34
83	1850	0	0	3	4.28	5.72	0.234	11.29	0.32	74.38	0.75	31	42.75	26.25
84	1887	50	2	1	4.55	5.34	0.211	7.396	0.52	82.38	0.73	29	40	31
85	1760	25	3	5	4.89	4.21	0.284	10.08	0.44	83.61	0.83	40	38.75	21.25
86	2090	28	2.5	4	5.21	4.74	0.325	12.36	0.81	69.36	0.51	33.41	32.46	34.13
87	1420	15	3	3	6.05	5.86	0.403	16.29	0.93	35.06	0.42	32.5	40	27.5
88	2100	35	1	1	4.62	5.36	0.209	7.465	0.42	85.62	0.72	45	38.75	16.25

89	2440	12	1.3	2	4.03	4.64	0.379	7.310	0.42	82.38	0.75	45	38.75	16.25
90	1190	25	0	4	4.89	5.79	0.462	14.62	1.43	35.12	0.3	42.32	29.25	28.43

Appendix 21. Species conservation priority class based on the population structure of woody plants in Sele-Nono forest

Group 1	**Group 2**	**Group 3**
Alangium chinense	*Albizia gummifera*	*Albizia grandibracteata*
Alstonia boonei	*Allophylus macrobotrys*	*Allophylus abyssinicus*
Antiaris toxicaria	*Anthocleista schweinfurthii*	*Bersama abyssinica*
Baphia abyssinica	*Apodytes dimidiata*	*Bridelia micranta*
Celtis africana	*Brucea antidysenterica*	*Dracaena afromontana*
Celtis toka	*Cassipourea malosana*	*Dracaena fragrans*
Cordia africana	*Celtis philippensis*	*Dracaena steudneri*
Croton macrostachyus	*Cyathea manniana*	*Elaeodendron buchananii*
Deinbollia kilimandscharica	*Diospyros abyssinica*	*Erythrococca trichogyne*
Ekebergia capensis	*Dombeya torrida*	*Ficus exasperata*
Fagaropsis angolensis	*Ficus sycomorus*	*Ficus thonningii*
Ficus ovata	*Lecaniodiscus fraxinifolius*	*Galiniera saxifraga*
Ficus sur	*Manilkara butugi*	*Justicia schimperiana*
Ficus vasta	*Olea welwitschii*	*Lepidotrichilia volkensii*
Garcinia ovalifolia	*Sapium ellipticum*	*Lobelia giberroa*
Garcinia buchananii	*Solanecio gigas*	*Macaranga capensis*
Hallea rubrostipulata	*Turraea holstii*	*Maytenus arbutifolia*
Ilex mitis		*Maytenus gracilipes*
Milicia excelsa		*Maytenus obscura*
Morus mesozygia		*Millettia ferruginea*
Polyscias fulva		*Mimusops kummel*
Pouteria adolfi-friederici		*Olea capensis*
Pouteria alnifolia		*Oxyanthus speciosus*
Pouteria altissima		*Phoenix reclinata*
Prunus africana		*Pittosporum viridiflorum*
Schefflera abyssinica		*Psychotria orophila*
Trichilia dregeana		*Ritchiea albersii*
Trilepisium madagascariense		*Rothmannia urcelliformis*
		Solanecio mannii
		Stereospermum kunthianum
		Strychnos mitis
		Syzygium guineense
		Teclea noblis
		Trema orientalis
		Vepris dainellii

Appendix 22. Density (D) in indv.ha^{-1}, Frequency (F) in %, Basal area (BA) in m^{2}, Dominance (Do) in m^{2}ha^{-1} , Relative density (RD), Relative frequency (RF), Relative dominance (RDo) and IVI in % of woody plants in Sele-Nono Forest.

Species Name	Mean DBH	Mean H	D	Mean BA	Total BA	Do	F	RD	RF	RDo	IVI
Coffea arabica L.	3.40	3.50	3928.89	0.00	19.93	3.54	92.22	18.76	2.03	2.70	23.50
Schefflera abyssinica Harms	174.70	17.76	11.56	2.38	154.74	27.51	34.44	0.06	0.76	20.99	21.80
Rytigynia neglecta (Hiern) Robyns	2.70	2.60	2337.78	0.00	7.48	1.33	56.67	11.16	1.25	1.01	13.43
Pouteria adolfi-friederici (Engl.) Baehni	65.70	28.90	39.64	0.34	75.08	13.35	24.44	0.19	0.54	10.19	10.91
Olea welwitschii (Knobl.) Gilg & Schellenb	62.30	30.21	41.60	0.30	70.84	12.59	22.22	0.20	0.49	9.61	10.30
Trilepisium madagascariense DC.	66.90	29.00	28.98	0.35	56.90	10.12	40.00	0.14	0.88	7.72	8.74
Canthium oligocarpum Hiern	2.50	2.10	1564.44	0.00	4.29	0.76	15.56	7.47	0.34	0.58	8.40
Manilkara butugi Chiov.	63.80	29.46	29.69	0.32	53.02	9.43	21.11	0.14	0.46	7.19	7.80
Elaeodendron buchananii (Loes.) Loes.	53.40	27.17	29.33	0.22	36.70	6.52	57.78	0.14	1.27	4.98	6.39
Acalypha acrogyna Pax	3.10	3.30	1128.89	0.00	4.76	0.85	14.44	5.39	0.32	0.65	6.35
Acanthus eminens C.B.Clarke	2.80	3.10	706.67	0.00	2.43	0.43	90.00	3.37	1.98	0.33	5.68
Morus mesozygia Stapf	49.20	28.64	28.09	0.19	29.83	5.30	38.89	0.13	0.86	4.05	5.04
Vangueria madagascariensis Gmel.	3.20	3.50	826.67	0.00	3.71	0.66	18.89	3.95	0.42	0.50	4.87
Embelia schimperi Vatke	2.60	2.50	720.00	0.00	2.14	0.38	25.56	3.44	0.56	0.29	4.29
Albizia gummifera (J. F. Gmel.) C. A. Sm.	34.80	27.91	38.04	0.09	20.21	3.59	48.89	0.18	1.08	2.74	4.00
Clausena anisata (Wild.) Benth.	4.10	4.10	640.00	0.00	4.72	0.84	8.89	3.06	0.20	0.64	3.89
Whitfieldia elongata (P.Beauv) De Wild. & T.Dur	3.55	3.80	635.56	0.00	3.51	0.62	16.67	3.04	0.37	0.48	3.88
Flacourtia indica (Burm.f.) Merrill	2.51	2.40	702.22	0.00	1.94	0.35	6.67	3.35	0.15	0.26	3.76
Alstonia boonei De Wild.	48.40	24.45	19.02	0.18	19.55	3.48	40.00	0.09	0.88	2.65	3.62
Argomuellera macrophylla Pax	2.80	3.20	546.67	0.00	1.88	0.33	25.56	2.61	0.56	0.26	3.43
Syzygium guineense (Wild.) DC. Subsp. *afromontanum*	34.10	27.54	33.60	0.09	17.14	3.05	38.89	0.16	0.86	2.33	3.34
Deinbollia kilimandscharica Taub.	54.50	27.75	13.51	0.23	17.61	3.13	40.00	0.06	0.88	2.39	3.33
Pavetta oliveriana Hiern	3.80	3.80	506.67	0.00	3.21	0.57	15.56	2.42	0.34	0.44	3.20
Dracaena afromontana Mildbr.	10.70	14.03	130.84	0.01	6.57	1.17	58.89	0.62	1.30	0.89	2.81

Ilex mitis (L.) Radlk.	41.60	27.23	15.64	0.13	11.88	2.11	42.22	0.07	0.93	1.61	2.62
Vepris dainellii (Pichi-Serm.)Kokwaro	6.80	4.30	122.67	0.00	2.49	0.44	70.00	0.59	1.54	0.34	2.46
Acalypha ornata A. Rich.	3.30	3.50	364.44	0.00	1.74	0.31	20.00	1.74	0.44	0.24	2.42
Dracaena fragrans	3.30	4.90	137.24	0.00	0.66	0.12	72.22	0.66	1.59	0.09	2.33
Diospyros abyssinica F. White	39.70	26.27	10.31	0.12	7.13	1.27	57.78	0.05	1.27	0.97	2.29
Entada abyssinica Steud. ex A. Rich.	5.80	6.80	320.00	0.00	4.72	0.84	4.44	1.53	0.10	0.64	2.27
Bothriocline schimperi Oliv. & Hiern ex Benth.	2.40	2.00	368.89	0.00	0.93	0.17	12.22	1.76	0.27	0.13	2.16
Psychotria orophila Petit	2.88	3.30	127.29	0.00	0.46	0.08	66.67	0.61	1.47	0.06	2.14
Ficus ovata Vahl.	136.80	23.14	1.60	1.46	13.14	2.34	14.44	0.01	0.32	1.78	2.11
Ficus vasta Vahl.	125.20	22.68	1.96	1.22	13.45	2.39	12.22	0.01	0.27	1.82	2.10
Oxyanthus speciosus DC.	2.78	3.10	72.53	0.00	0.25	0.04	74.44	0.35	1.64	0.03	2.02
Trichilia dregeana Sond.	56.50	25.61	6.04	0.25	8.47	1.51	33.33	0.03	0.73	1.15	1.91
Rothmannia urcelliformis (Hiern) Robyns	5.22	4.90	95.29	0.00	1.14	0.20	57.78	0.46	1.27	0.15	1.88
Teclea noblis Del.	2.50	2.20	66.49	0.00	0.18	0.03	67.78	0.32	1.49	0.02	1.83
Landolphia buchananii (Hallf) Stapf	2.60	2.50	71.47	0.00	0.21	0.04	62.22	0.34	1.37	0.03	1.74
Premna schimperi Engl.	3.25	3.50	275.56	0.00	1.28	0.23	10.00	1.32	0.22	0.17	1.71
Lippia adoensis Hochst. ex Walp.	3.11	3.40	275.56	0.00	1.17	0.21	10.00	1.32	0.22	0.16	1.69
Calpurina aurea (Ait.) Benth	4.20	4.20	226.67	0.00	1.75	0.31	13.33	1.08	0.29	0.24	1.61
Rhamnus prinoides L.Herit.	2.80	3.20	271.11	0.00	0.93	0.17	5.56	1.29	0.12	0.13	1.54
Apodytes dimidiata E. Mey. ex. Arn.	13.60	13.87	12.98	0.01	1.05	0.19	60.00	0.06	1.32	0.14	1.53
Bersama abyssinica Fresen.	11.90	14.92	11.20	0.01	0.70	0.12	62.22	0.05	1.37	0.09	1.52
Olea capensis L.Subsp.*macrocarpa* (C.A. Wright.) Verdc.	4.20	4.80	112.89	0.00	0.87	0.16	37.78	0.54	0.83	0.12	1.49
Maytenus gracilipes (Welw.ex Oliv.) Exell	2.70	2.70	27.56	0.00	0.09	0.02	60.00	0.13	1.32	0.01	1.46
Senna septemtrionali (Viv.) Irwin&Barneby	2.60	2.50	248.89	0.00	0.74	0.13	6.67	1.19	0.15	0.10	1.44
Pittosporum viridiflorum Sims	8.60	9.70	12.98	0.01	0.42	0.07	58.89	0.06	1.30	0.06	1.41
Maesa lanceolata Forssk.	4.33	4.30	213.33	0.00	1.75	0.31	6.67	1.02	0.15	0.24	1.40
Psidium guajava L.	4.20	4.10	151.11	0.00	1.17	0.21	20.00	0.72	0.44	0.16	1.32

Solanecio mannii (Hook.f.)C.Jeffrey	2.55	2.40	26.13	0.00	0.07	0.01	52.22	0.12	1.15	0.01	1.28
Macaranga capensis (Baill.) Sim	14.10	14.84	10.13	0.02	0.88	0.16	50.00	0.05	1.10	0.12	1.27
Polyscias fulva (Hiern) Harms	13.90	16.69	13.33	0.02	1.13	0.20	47.78	0.06	1.05	0.15	1.27
Millettia ferruginea (Hochst.) Baker	7.40	9.17	17.42	0.00	0.42	0.07	51.11	0.08	1.12	0.06	1.26
Allophylus abyssinicus (Hochst.) Radlkofer	8.40	9.21	14.58	0.01	0.45	0.08	50.00	0.07	1.10	0.06	1.23
Phoenix reclinata Jacq.	6.30	8.20	14.40	0.00	0.25	0.04	51.11	0.07	1.12	0.03	1.23
Gardenia ternifolia Schumach. & Thonn.	2.30	2.00	213.33	0.00	0.50	0.09	5.56	1.02	0.12	0.07	1.21
Maytenus obscura (A.Rich.)Cui	3.15	3.40	8.36	0.00	0.04	0.01	52.22	0.04	1.15	0.00	1.19
Solanecio gigas (Vatke) C.Jeffrey	2.63	2.60	25.42	0.00	0.08	0.01	47.78	0.12	1.05	0.01	1.18
Croton macrostachyus Del.	12.40	15.35	14.40	0.01	0.97	0.17	44.44	0.07	0.98	0.13	1.18
Galiniera saxifraga (Hochst.) Bridson	5.30	5.00	91.02	0.00	1.12	0.20	26.67	0.43	0.59	0.15	1.17
Lepidotrichilia volkensii (Gurke) Leory	14.90	18.30	10.84	0.02	1.06	0.19	44.44	0.05	0.98	0.14	1.17
Sapium ellipticum (Krauss) Pax	12.30	15.14	9.07	0.01	0.60	0.11	46.67	0.04	1.03	0.08	1.15
Pavetta abyssinica Fresen.	4.70	4.60	124.44	0.00	1.21	0.21	17.78	0.59	0.39	0.16	1.15
Trema orientalis (L.) Blume	10.60	12.79	10.49	0.01	0.52	0.09	46.67	0.05	1.03	0.07	1.15
Vernonia hochstetteri Sch-Bip.	2.70	2.70	128.89	0.00	0.41	0.07	21.11	0.62	0.46	0.06	1.14
Ficus thonningii Blume	12.10	14.18	11.20	0.01	0.72	0.13	43.33	0.05	0.95	0.10	1.10
Garcinia ovalifolia Oliver	16.20	15.06	7.47	0.02	0.86	0.15	42.22	0.04	0.93	0.12	1.08
Vernonia auriculifera Hiern	3.87	4.10	24.53	0.00	0.16	0.03	42.22	0.12	0.93	0.02	1.07
Strychnos mitis S.Moore	5.70	6.30	9.78	0.00	0.14	0.02	45.56	0.05	1.00	0.02	1.07
Dalbergia lactea Vatke	5.70	6.40	13.16	0.00	0.19	0.03	44.44	0.06	0.98	0.03	1.07
Maytenus undata (Thunb.) Blakelok	2.77	3.10	14.22	0.00	0.05	0.01	44.44	0.07	0.98	0.01	1.05
Oncoba spinosa Forssk.	2.66	2.60	7.64	0.00	0.02	0.00	45.56	0.04	1.00	0.00	1.04
Vernonia leopoldi Vatke	2.80	3.20	164.44	0.00	0.57	0.10	7.78	0.79	0.17	0.08	1.03
Arundinaria alpina	2.90	3.30	135.47	0.00	0.50	0.09	12.22	0.65	0.27	0.07	0.98
Grewia mollis A. Juss.	4.56	4.40	106.67	0.00	0.97	0.17	14.44	0.51	0.32	0.13	0.96
Cyathea manniana Hook.	13.50	16.06	17.42	0.01	1.39	0.25	31.11	0.08	0.68	0.19	0.96
Jasminum abyssinicum DC.	3.60	3.80	6.58	0.00	0.04	0.01	41.11	0.03	0.90	0.01	0.94

Oncinotis tenuiloba Stapf.	2.50	2.30	6.58	0.00	0.02	0.00	41.11	0.03	0.90	0.00	0.94
Urera hypselodendron (A.Rich.)Wedd.	11.83	15.99	7.29	0.01	0.45	0.08	37.78	0.03	0.83	0.06	0.93
Blighia unijugata Bak.	7.90	9.40	7.64	0.00	0.21	0.04	37.78	0.04	0.83	0.03	0.90
Celtis africana Burm. f.	13.70	16.62	10.13	0.01	0.83	0.15	33.33	0.05	0.73	0.11	0.90
Pentas lanceolata (Forssk.) Defl. Subsp. *lanceolata*	2.74	3.10	151.11	0.00	0.50	0.09	4.44	0.72	0.10	0.07	0.89
Ritchiea albersii Gilg.	11.80	15.92	7.82	0.01	0.48	0.08	35.56	0.04	0.78	0.06	0.88
Vernonia amygdalina Del.	2.61	2.60	14.04	0.00	0.04	0.01	36.67	0.07	0.81	0.01	0.88
Bridelia micranta (Hochst.) Baill.	5.12	4.70	9.60	0.00	0.11	0.02	36.67	0.05	0.81	0.01	0.87
Vernonia karaguensis Oliv. & Hiern	2.50	2.20	106.67	0.00	0.29	0.05	14.44	0.51	0.32	0.04	0.87
Maytenus arbutifolia (A. Rich.) Wilczek	6.80	9.17	8.71	0.00	0.18	0.03	35.56	0.04	0.78	0.02	0.85
Mimusops kummel A.DC.	13.60	15.50	6.76	0.01	0.55	0.10	33.33	0.03	0.73	0.07	0.84
Ekebergia capensis Sparrm.	13.40	11.90	8.18	0.01	0.64	0.11	31.11	0.04	0.68	0.09	0.81
Combretum paniculatum Vent.	5.70	6.40	9.60	0.00	0.14	0.02	33.33	0.05	0.73	0.02	0.80
Albizia grandibracteata Taub.	11.60	13.49	12.09	0.01	0.71	0.13	28.89	0.06	0.64	0.10	0.79
Tiliacora troupinii Cufod.	3.40	3.50	5.51	0.00	0.03	0.00	34.44	0.03	0.76	0.00	0.79
Chionanthus mildbraedii Stearn	5.90	7.20	23.47	0.00	0.36	0.06	26.67	0.11	0.59	0.05	0.75
Garcinia buchananii Bak.	14.70	13.82	10.49	0.02	0.99	0.18	25.56	0.05	0.56	0.13	0.75
Clerodendrum myricoides Vatke	4.24	4.30	12.09	0.00	0.10	0.02	30.00	0.06	0.66	0.01	0.73
Prunus africana (Hook.f.) Kalkam	13.60	15.14	4.98	0.01	0.40	0.07	28.89	0.02	0.64	0.05	0.71
Dracaena steudneri Scw.ex Engl.	13.30	14.99	8.00	0.01	0.62	0.11	26.67	0.04	0.59	0.08	0.71
Justicia schimperiana T. Anders	4.20	4.20	31.64	0.00	0.24	0.04	23.33	0.15	0.51	0.03	0.70
Anthocleista schweinfurthii Gilg.	9.60	10.18	10.31	0.01	0.42	0.07	26.67	0.05	0.59	0.06	0.69
Phytolacca dodecandra L.Herit.	10.20	13.41	5.16	0.01	0.24	0.04	28.89	0.02	0.64	0.03	0.69
Erythrococca trichogyne Prain	3.80	3.90	25.96	0.00	0.16	0.03	24.44	0.12	0.54	0.02	0.68
Bridelia scleroneura Muell. Arg.	3.00	3.30	80.00	0.00	0.32	0.06	11.11	0.38	0.24	0.04	0.67
Gouania longispicta Engl.	5.50	5.00	4.98	0.00	0.07	0.01	28.89	0.02	0.64	0.01	0.67
Lobelia giberroa Hemsl.	10.10	13.02	13.87	0.01	0.62	0.11	23.33	0.07	0.51	0.08	0.66
Myrsine africana L.	2.80	3.10	84.44	0.00	0.29	0.05	10.00	0.40	0.22	0.04	0.66
Ricinus communis L.	3.36	3.50	4.62	0.00	0.02	0.00	28.89	0.02	0.64	0.00	0.66

Paullinia pinnata L.	6.10	7.30	4.44	0.00	0.07	0.01	27.78	0.02	0.61	0.01	0.64
Dioscorea praehensilis Benth.	2.80	4.80	4.98	0.00	0.02	0.00	27.78	0.02	0.61	0.00	0.64
Triumfetta brachyceras K. Schum.	2.50	2.10	53.33	0.00	0.15	0.03	15.56	0.25	0.34	0.02	0.62
Ficus exasperata Vahl.	14.70	18.30	10.67	0.02	1.01	0.18	18.89	0.05	0.42	0.14	0.60
Senna petersiana (Bolle)Lock	2.35	2.00	17.07	0.00	0.04	0.01	23.33	0.08	0.51	0.01	0.60
Hallea rubrostipulata (K.Schum.)J.F.Leroy	9.90	11.14	8.18	0.01	0.35	0.06	23.33	0.04	0.51	0.05	0.60
Ehretia cymosa Thonn.	10.28	15.64	6.58	0.01	0.30	0.05	23.33	0.03	0.51	0.04	0.59
Fagaropsis angolensis (Engl.) Dale	10.50	12.47	4.80	0.01	0.23	0.04	23.33	0.02	0.51	0.03	0.57
Saba comorensis (Boj.) Pichon	5.00	4.70	8.36	0.00	0.09	0.02	23.33	0.04	0.51	0.01	0.57
Allophylus macrobotrys Gilg	11.80	11.98	9.60	0.01	0.59	0.10	20.00	0.05	0.44	0.08	0.57
Turraea holstii Guerke	2.70	2.70	20.98	0.00	0.07	0.01	20.00	0.10	0.44	0.01	0.55
Ficus sur Forssk.	15.70	15.14	5.33	0.02	0.58	0.10	20.00	0.03	0.44	0.08	0.54
Cassipourea malosana (Baker) Alston	7.50	9.20	8.36	0.00	0.21	0.04	20.00	0.04	0.44	0.03	0.51
Euphorbia ampliphylla Pax	7.40	9.20	4.98	0.00	0.12	0.02	21.11	0.02	0.46	0.02	0.50
Rhus glutinosa A. Rich.	3.80	4.10	66.67	0.00	0.42	0.08	5.56	0.32	0.12	0.06	0.50
Baphia abyssinica Brummitt	15.80	21.00	5.33	0.02	0.58	0.10	17.78	0.03	0.39	0.08	0.50
Schefflera volkensii (Engl.) Harms	11.90	13.87	4.98	0.01	0.31	0.05	18.89	0.02	0.42	0.04	0.48
Hippocratea goetzei Loes.	4.80	4.70	4.27	0.00	0.04	0.01	20.00	0.02	0.44	0.01	0.47
Dombeya torrida (J.F.Gmel.)P.Bamps	10.80	13.80	6.04	0.01	0.31	0.05	17.78	0.03	0.39	0.04	0.46
Pouteria altissima (A.Chev.)Baehni	63.70	21.73	1.42	0.32	2.53	0.45	4.44	0.01	0.10	0.34	0.45
Rubus apetalus Poir.	3.50	3.70	40.00	0.00	0.21	0.04	10.00	0.19	0.22	0.03	0.44
Ocotea kenyensis (Chiov.) Robyns & Wilcz	11.30	13.65	2.84	0.01	0.16	0.03	17.78	0.01	0.39	0.02	0.43
Hippocratea africana (Willd) Loes	5.00	4.70	4.98	0.00	0.05	0.01	17.78	0.02	0.39	0.01	0.42
Triumfetta rhomboidea Jacq.	3.10	3.30	57.78	0.00	0.24	0.04	4.44	0.28	0.10	0.03	0.41
Celtis philippensis Blanco	12.70	14.25	4.44	0.01	0.31	0.06	15.56	0.02	0.34	0.04	0.41
Alangium chinense (Lour)Harms	14.30	16.96	3.73	0.02	0.33	0.06	15.56	0.02	0.34	0.05	0.41
Albizia schimperiana Oliv.	10.30	15.21	4.62	0.01	0.22	0.04	15.56	0.02	0.34	0.03	0.39
Monothecium glandulosum Hochst.	2.50	2.10	35.56	0.00	0.10	0.02	8.89	0.17	0.20	0.01	0.38

Brucea antidysenterica J. F. Mill	10.50	15.78	7.29	0.01	0.35	0.06	13.33	0.03	0.29	0.05	0.38
Schefflera myriantha (Bak.) Drake	2.50	2.20	2.49	0.00	0.01	0.00	15.56	0.01	0.34	0.00	0.36
Indigofera atriceps Hook.f.	4.20	4.20	31.11	0.00	0.24	0.04	7.78	0.15	0.17	0.03	0.35
Lecaniodiscus fraxinifolius Bak.	6.30	8.30	4.80	0.00	0.08	0.01	14.44	0.02	0.32	0.01	0.35
Stereospermum kunthianum Cham.	6.30	8.40	2.31	0.00	0.04	0.01	14.44	0.01	0.32	0.01	0.33
Cordia africana Lam.	14.50	17.30	4.98	0.02	0.46	0.08	11.11	0.02	0.24	0.06	0.33
Phyllanthus limmuensis Cuf.	2.50	2.10	35.56	0.00	0.10	0.02	6.67	0.17	0.15	0.01	0.33
Balanites aegyptiaca (L.) Dei.	2.54	2.40	48.89	0.00	0.14	0.02	3.33	0.23	0.07	0.02	0.33
Ficus sycomorus L.	8.90	9.54	4.09	0.01	0.14	0.03	12.22	0.02	0.27	0.02	0.31
Rhamnus prinoides L.Herit.	6.20	8.10	5.16	0.00	0.09	0.02	12.22	0.02	0.27	0.01	0.31
Milicia excelsa (Welw.) C. C. Berg	48.20	24.34	1.24	0.18	1.27	0.23	5.56	0.01	0.12	0.17	0.30
Hippocratea pallens Planch. Ex oliver	6.30	8.30	3.20	0.00	0.06	0.01	12.22	0.02	0.27	0.01	0.29
Lannea schimperi (A. Rich.) Engl.	6.70	9.17	2.84	0.00	0.06	0.01	12.22	0.01	0.27	0.01	0.29
Phyllanthus ovalifolius Forssk.	4.80	4.60	31.11	0.00	0.31	0.06	4.44	0.15	0.10	0.04	0.29
Rinorea friisii M.Gilbert	5.80	6.40	31.11	0.00	0.46	0.08	3.33	0.15	0.07	0.06	0.28
Pouteria alnifolia (Bak.)Roberty	14.80	14.47	2.13	0.02	0.21	0.04	11.11	0.01	0.24	0.03	0.28
Celtis toka (Forssk.) Hepper & Wood	9.30	11.20	3.20	0.01	0.12	0.02	10.00	0.02	0.22	0.02	0.25
Celtis gomphophylla Bak.	9.50	10.18	5.87	0.01	0.23	0.04	7.78	0.03	0.17	0.03	0.23
Clematis hirsuta Perr. & Guill.	2.90	3.30	1.42	0.00	0.01	0.00	8.89	0.01	0.20	0.00	0.20
Mikaniopsis clematoides (Sch. Bip. ex A. Rich.) Milne-Redh.	2.80	3.20	1.42	0.00	0.00	0.00	8.89	0.01	0.20	0.00	0.20
Nuxia congesta R.Br.ex Fresen.	5.90	7.10	6.76	0.00	0.10	0.02	6.67	0.03	0.15	0.01	0.19
Antiaris toxicaria Lesch subsp. *toxicaria*	13.20	14.18	1.24	0.01	0.10	0.02	7.78	0.01	0.17	0.01	0.19
Stiotocardia beraviensis (Vatke) Hall. F.	3.20	3.50	3.02	0.00	0.01	0.00	7.78	0.01	0.17	0.00	0.19
Tylophora sylvatica Decne.	2.76	3.10	3.02	0.00	0.01	0.00	7.78	0.01	0.17	0.00	0.19
Celtis zenkeri Engl	8.40	7.60	3.73	0.01	0.12	0.02	6.67	0.02	0.15	0.02	0.18
Smilax anceps Willd.	2.50	2.30	1.24	0.00	0.00	0.00	7.78	0.01	0.17	0.00	0.18
Clematis simensis Fresen.	2.60	2.50	1.07	0.00	0.00	0.00	6.67	0.01	0.15	0.00	0.15
Solanum anguivi Lam.	2.55	2.40	13.33	0.00	0.04	0.01	3.33	0.06	0.07	0.01	0.14

Maerua oblongifolia (Forssk.) A. Rich.	4.20	4.20	1.42	0.00	0.01	0.00	5.56	0.01	0.12	0.00	0.13
Erythrina brucei Schweinf.	18.20	13.20	0.71	0.03	0.10	0.02	4.44	0.00	0.10	0.01	0.12
Lannea schweinfurthii (Engl.) Engl.	6.30	8.20	2.31	0.00	0.04	0.01	4.44	0.01	0.10	0.01	0.11
Combretum molle R. Br. ex G. Don	7.80	9.40	1.42	0.00	0.04	0.01	4.44	0.01	0.10	0.01	0.11
Zanthoxylum usambarense (Engl.) Kokwaro	6.34	8.50	1.42	0.00	0.03	0.00	4.44	0.01	0.10	0.00	0.11
Terminalia schimperiana Hochst.	9.40	7.90	0.71	0.01	0.03	0.00	4.44	0.00	0.10	0.00	0.10
Catha edulis (Vahl) Forssk. ex Endl.	8.30	11.90	1.07	0.01	0.03	0.01	2.22	0.01	0.05	0.00	0.06
Kigelia africana (Lam.) Benth.	9.40	8.30	0.89	0.01	0.03	0.01	2.22	0.00	0.05	0.00	0.06
Pseudocedrela kotschyi (Schweinf.) Harms	5.60	6.20	0.71	0.00	0.01	0.00	2.22	0.00	0.05	0.00	0.05
Combretum adenogonium Steud ex A. Rich.	11.40	15.92	1.24	0.01	0.07	0.01	1.11	0.01	0.02	0.01	0.04
Erythrina abyssinica (Lam. ex. DC.)	12.30	13.80	0.36	0.01	0.02	0.00	1.11	0.00	0.02	0.00	0.03
Sterculia africana (Lour.) Fiori.	8.50	8.90	0.53	0.01	0.02	0.00	1.11	0.00	0.02	0.00	0.03
Total						131.05					

Appendix 23. Occurance of woody species in Sele-Nono forest

Appendix 23A. Degree of occurrences of woody species in Sele-Nono Forest based on Raunkiaer (1934) suggestion

Frequency class	Degree of species occurrences	Description for the frequency class or species occurrence	No. of woody species from Sele-Nono forest	%
1	Rarely occuring	present in 1-20% of the plots	88	50
2	Seldom occurring	present in 21-40% of the plots	48	27.27
3	Often occurring	present in 41-60% of the plots	31	17.61
4	Mostly occurring	present in 61-80% of the plots	7	3.98
5	Constantly occurring	present in 81-100% of the plots	2	1.14

Appendix 23B. Relative density of woody species that falls in the different level of storeys and different level of Raunkiaer frequency class in Sele-Nono forest.

Raunkiaer frequency class	**Description for the frequency class**	**Lower storey (% RD)**	**Middle storey (%RD)**	**Upper storey (%RD)**
1	1-20 of the total plots	14.45	2.52	3.12
2	21-40 of the total plots	15.94	13.8	1.05
3	41-60 of the total plots	21.14	9.4	
4	61-80 of the total plots	7.51		
5	81-100 of the total plots	11.21		

Appendix 24. Species conservation priority class based on the regeneration status of woody plants in Sele-Nono forest

Priority class 1	Priority class 2				Priority class 3
-*Cordia africana* -*Cassipourea malosana* -*Ficus thonningii* -*Ritchiea albersii* -*Schefflera abyssinica* -*Hallea rubrostipulata* -*Euphorbia ampliphylla* -*Schefflera volkensii* -*Baphia abyssinica* -*Ficus ovata* -*Antiaris toxicaria* -*Ekebergia capensis*	-*Oncoba spinosa* -*Mimusops kummel* -*Schefflera myriantha* -*Dombeya torrida* -*Ficus vasta* -*Ficus sycomorus* -*Fagaropsis angolensis* -*Ehretia cymosa* -*Celtis toka* -*Ocotea kenyensis* -*Saba comorensis* -*Triumfetta brachyceras* -*Stiotocardia beraviensis* -*Tylophora sylvatica* -*Clerodendrum myricoides* -*Bridelia micranta* -*Vernonia karaguensis* -*Stereospermum kunthianum* -*Hippocratea goetzei*	-*Celtis africana* -*Jasminum abyssinicum* -*Ricinus communis* -*Gouania longispicta* -*Oncinotis tenuiloba* -*Trema orientalis* -*Urera hypselodendron* -*Tiliacora troupinii* -*Gardenia ternifolia* -*Solanecio mannii* *Calpurina aurea* -*Vernonia hochstetteri* -*Indigofera atriceps* -*Smilax anceps* -*Rubus apetalus* -*Arundinaria alpina* -*Hippocratea pallens* -*Dioscorea praehensilis* -*Pavetta oliveriana*	-*Erythrococca trichogyne* -*Solanecio gigas* -*Celtis gomphophylla* -*Ilex mitis* -*Turraea holstii* -*Blighia unijugata* -*Syzygium guineense* -*Rhamnus prinoides* -*Albizia grandibracteata* -*Rinorea friisii* -*Maytenus obscura* -*Macaranga capensis* -*Sapium ellipticum* -*Pentas lanceolata* -*Lannea schweinfurthii* -*Garcinia buchananii* -*Combretum paniculatum* -*Trilepisium madagascariense* -*Lippia adoensis*	-*Alstonia boonei* -*Croton macrostachyus* -*Lannea schimperi* -*Pouteria alnifolia* -*Garcinia ovalifolia* -*Myrsine africana* -*Pavetta abyssinica* -*Chionanthus mildbraedii* -*Vernonia amygdalina* -*Anthocleista schweinfurthii* -*Deinbollia kilimandscharica* -*Vernonia leopoldi* -*Pittosporum viridiflorum* -*Manilkara butugi* -*Morus mesozygia* -*Flacourtia indica* -*Pseudocedrela kotschyi* -*Nuxia congesta*	-*Acalypha acrogyna* -*Dalbergia lactea* -*Rytigynia neglecta* -*Balanites aegyptiaca* -*Argomuellera macrophylla* -*Maytenus arbutifolia* -*Entada abyssinica* -*Embelia schimperi* -*Olea capensis* -*Vangueria madagascariensis* -*Acanthus eminens* -*Millettia ferruginea* -*Apodytes dimidiata* -*Lepidotrichilia volkensii* -*Bersama abyssinica* -*Teclea noblis* -*Cyathea manniana* -*Maytenus gracilipes* -*Phoenix*

	-Hippocratea africana *-Milicia excelsa* *-Maerua oblongifolia* *-Bridelia scleroneura* *-Maytenus undata* *-Alangium chinense* *-Grewia mollis* *-Lecaniodiscus fraxinifolius* *-Phytolacca dodecandra* *-Terminalia schimperiana* *-Zanthoxylum usambarense*	*-Celtis philippensis* *-Phyllanthus limmuensis* *-Phyllanthus ovalifolius* *-Triumfetta rhomboidea* *-Pouteria altissima* *-Trichilia dregeana* *-Prunus africana* *-Ficus sur* *-Diospyros abyssinica* *-Senna petersiana* *-Combretum molle* *-Dracaena afromontana* *-Acalypha ornata* *-Albizia schimperiana* *-Maesa lanceolata* *-Oxyanthus speciosus*	*-Premna schimperi* *-Polyscias fulva* *-Erythrina brucei* *-Kigelia africana* *-Catha edulis* *-Combretum adenogonium* *-Sterculia africana* *-Celtis zenkeri* *-Solanum anguivi* *-Rhus glutinosa* *-Rhamnus prinoides* *-Brucea antidysenterica* *-Dracaena steudneri*	*-Ficus exasperata* *-Strychnos mitis* *-Whitfieldia elongata* *-Psidium guajava* *-Elaeodendron buchananii* *-Senna septemtrionali* *-Lobelia giberroa* *-Rothmannia urcelliformis* *-Olea welwitschii* *-Erythrina abyssinica* *-Allophylus macrobotrys*	*reclinata* *-Galiniera saxifraga* *-Justicia schimperiana* *-Pouteria adolfi-friederici* *-Psychotria orophila* *-Coffea arabica* *-Canthium oligocarpum* *-Allophylus abyssinicus* *-Albizia gummifera* *-Dracaena fragrans* *-Vepris dainellii* *-Clausena anisata*

Appendix 25. Wood density determination for all the three classes of lying dead woods (LDWs) in Sele-Nono forest. Note that S refers to "Sound" LDW sample, I refers to "Intermediate" LDW sample and R refers to "Rotten" LDW sample. M is oven dry mass (gm), and V is saturated/fresh volume (cm3).

Plot No.	**Wood density determination of "Sound" LDWs**				**Wood density determination of "Intermediate" LDWs**				**Wood density determination of "Rotten" LDWs**			
	Code	M	V	Density	Code	M	V	Density	Code	M	V	Density
1	S1	171.5	140	1.225	I1	122.7	220	0.557727	R1	22	350	0.062857
2	S2	38	65	0.584615	I2	56	125	0.448	R2	18.4	130	0.141538
3	S3	37	60	0.616667	I3	47	90	0.522222	R3	10.2	50	0.204
4	S4	0		0	I4	0		0	R4	18.8	90	0.208889
5	S5	101.5	180	0.563889	I5	75.5	150	0.503333	R5	22.3	85	0.262353
6	S6	0		0	I6	0		0	R6	11.6	45	0.257778
7	S7	0		0	I7	0		0	R7	25.9	75	0.345333
8	S8	70	65	1.076923	I8	58	100	0.58	R8	19.4	65	0.298462
9	S9	32.5	45	0.722222	I9	60	100	0.6	R9	28	115	0.243478
10	S10	29.8	45	0.662222	I10	68.5	150	0.456667	R10	12.5	50	0.25
11	S11	59.7	75	0.796	I11	43.6	75	0.581333	R11	19	65	0.292308
12	S12	29	25	1.16	I12	47	150	0.313333	R12	12.5	60	0.208333
13	S13	16.8	25	0.672	I13	40	95	0.421053	R13	8.2	30	0.273333
14	S14	40	75	0.533333	I14	39.3	175	0.224571	R14	4.9	20	0.245
15	S15	0		0	I15	0		0	R15	22	65	0.338462
16	S16	229	260	0.880769	I16	52	150	0.346667	R16	16.8	60	0.28
17	S17	46	50	0.92	I17	40.7	100	0.407	R17	23	45	0.511111
18	S18	17.8	15	1.186667	I18	67	120	0.558333	R18	17.3	45	0.384444
19	S19	29.5	15	1.966667	I19	38	100	0.38	R19	16.5	40	0.4125
20	S20	24	50	0.48	I20	15	45	0.333333	R20	27	70	0.385714
21	S21	20	50	0.4	I21	40	125	0.32	R21	15	45	0.333333
22	S22	23	25	0.92	I22	33.5	125	0.268	R22	5	65	0.076923
23	S23	39	50	0.78	I23	26.5	140	0.189286	R23	7.5	40	0.1875
24	S24	92.5	150	0.616667	I24	37.5	125	0.3	R24	3.5	30	0.116667

25	S25	81.5	150	0.543333	I25	19	100	0.19	R25	20.6	80	0.2575
26	S26	6	10	0.6	I26	20	50	0.4	R26	15.9	60	0.265
27	S27	113	200	0.565	I27	28.5	125	0.228	R27	15.1	60	0.251667
28	S28	32	150	0.213333	I28	15.5	50	0.31	R28	2.4	35	0.068571
29	S29	90.5	190	0.476316	I29	36.3	120	0.3025	R29	20.8	150	0.138667
30	S30	67	100	0.67	I30	103.5	150	0.69	R30	25.4	160	0.15875
31	S31	60.5	90	0.672222	I31	35.5	85	0.417647	R31	25	75	0.333333
32	S32	58.7	150	0.391333	I32	29.5	110	0.268182	R32	15.4	80	0.1925
33	S33	109.2	210	0.52	I33	42	90	0.466667	R33	16.2	50	0.324
34	S34	37	80	0.4625	I34	22	50	0.44	R34	23	65	0.353846
35	S35	39	85	0.458824	I35	15	50	0.3	R35	10.6	30	0.353333
36	S36	49	90	0.544444	I36	53	125	0.424	R36	24	60	0.4
37	S37	91	140	0.65	I37	31	75	0.413333	R37	23	80	0.2875
38	S38	171.5	225	0.762222	I38	20	40	0.5	R38	15.1	80	0.18875
39	S39	42.8	60	0.713333	I39	11.5	30	0.383333	R39	10.5	35	0.3
40	S40	0		0	I40	0		0	R40	21	100	0.21
41	S41	35.7	80	0.44625	I41	20.5	50	0.41	R41	17	60	0.283333
42	S42	99.7	250	0.3988	I42	9	10	0.9	R42	25.7	95	0.270526
43	S43	0		0	I43	0		0	R43	10.4	40	0.26
44	S44	160.9	210	0.76619	I44	64.7	140	0.462143	R44	12.3	55	0.223636
45	S45	68.7	125	0.5496	I45	52	135	0.385185	R45	12	50	0.24
46	S46	29.5	70	0.421429	I46	70.6	155	0.455484	R46	18	65	0.276923
47	S47	39.3	60	0.655	I47	71	110	0.645455	R47	15.2	80	0.19
48	S48	69.5	110	0.631818	I48	76.9	95	0.809474	R48	20.3	110	0.184545
49	S49	32.1	65	0.493846	I49	52	80	0.65	R49	5.6	25	0.224
50	S50	0		0	I50	0	0	0	R50	18.4	60	0.306667
51	S51	45.8	85	0.538824	I51	80.6	130	0.62	R51	32	230	0.13913
52	S52	65.7	120	0.5475	I52	72	120	0.6	R52	5	25	0.2
53	S53	218	410	0.531707	I53	53	85	0.623529	R53	25.7	100	0.257

54	S54	50	125	0.4	I54	86	140	0.614286	R54	19.5	65	0.3
55	S55	15.6	35	0.445714	I55	37	105	0.352381	R55	11.5	50	0.23
56	S56	27.4	55	0.498182	I56	44	155	0.283871	R56	24	90	0.266667
57	S57	23.4	35	0.668571	I57	78	125	0.624	R57	30	250	0.12
58	S58	18	45	0.4	I58	64	165	0.387879	R58	21.5	65	0.330769
59	S59	21.3	25	0.852	I59	53	110	0.481818	R59	20.5	70	0.292857
60	S60	39	90	0.433333	I60	48	80	0.6	R60	14.5	60	0.241667
61	S61	92.5	250	0.37	I61	20.5	75	0.273333	R61	36.5	260	0.140385
62	S62	85.5	140	0.610714	I62	8	25	0.32	R62	24	60	0.4
63	S63	24	55	0.436364	I63	57	115	0.495652	R63	26	70	0.371429
64	S64	109	365	0.29863	I64	28.3	95	0.297895	R64	33	150	0.22
65	S65	53.6	145	0.369655	I65	15.7	105	0.149524	R65	38	205	0.185366
66	S66	93.4	225	0.415111	I66	33	85	0.388235	R66	19	45	0.422222
67	S67	64	120	0.533333	I67	16.7	80	0.20875	R67	26	50	0.52
68	S68	58.7	95	0.617895	I68	24	75	0.32	R68	25	85	0.294118
69	S69	0		0	I69	0		0	R69	14	60	0.233333
70	S70	106.5	350	0.304286	I70	20.5	80	0.25625	R70	20.5	70	0.292857
71	S71	34.8	80	0.435	I71	43	160	0.26875	R71	14.5	40	0.3625
72	S72	34.9	85	0.410588	I72	130	270	0.481481	R72	36.5	210	0.17381
73	S73	45	90	0.5	I73	30	80	0.375	R73	21	45	0.466667
74	S74	88	110	0.8	I74	32	75	0.426667	R74	17	40	0.425
75	S75	172	340	0.505882	I75	39	85	0.458824	R75	13	40	0.325
76	S76	74.7	70.5	1.059574	I76	20	65	0.307692	R76	22	90	0.244444
77	S77	32.5	74.5	0.436242	I77	18	60	0.3	R77	15	55	0.272727
78	S78	28.8	55.5	0.518919	I78	47	115	0.408696	R78	9	40	0.225
79	S79	55.4	80.5	0.688199	I79	34	70	0.485714	R79	12	65	0.184615
80	S80	34	55	0.618182	I80	15	55	0.272727	R80	25	150	0.166667
81	S81	17	60	0.283333	I81	11	35	0.314286	R81	22	40	0.55
82	S82	40	60	0.666667	I82	28.4	65	0.436923	R82	20.6	75	0.274667

83	S83	66	110	0.6	I83	23.2	60	0.386667	R83	11.5	75	0.153333
84	S84	225	300	0.75	I84	5	20	0.25	R84	2	10	0.2
85	S85	44.7	70	0.638571	I85	130.4	280	0.465714	R85	12.5	85	0.147059
86	S86	16.5	40	0.4125	I86	52.5	235	0.223404	R86	21.5	65	0.330769
87	S87	30.4	30	1.013333	I87	50	120	0.416667	R87	20.5	60	0.341667
88	S88	23.4	50	0.468	I88	65	155	0.419355	R88	14.5	60	0.241667
89	S89	23	48	0.479167	I89	78	140	0.557143	R89	11	70	0.157143
90	S90	87	110	0.790909	I90	64	110	0.581818	R90	21	130	0.161538
Average				**0.563515**				**0.383302**				**0.263616**

Appendix 26. Total biomass (TB), total carbon stock (TC) and soil organic carbon (SOC) of Sele-Nono forest at plot level (t/ha)

Plot No.	Strata No.	AGB	AGC	BGB	BGC	LB	LC	HB	HC	LDWB	LDWC	SOC	TB	TC
1	4	309.4	145.42	61.882	29.084	8.82	4.1454	2.78	1.3066	30.14	14.1658	227.6	413.032	421.72
2	5	87.27	41.016	17.454	8.2033	2.56	1.2032	1.05	0.4935	9.67	4.5449	66.58	118.004	122.04
3	4	201.4	94.686	40.292	18.937	6.19	2.9093	2.58	1.2126	18.84	8.8548	247.89	269.362	374.49
4	1	118.4	55.685	23.696	11.137	2.97	1.3959	4.05	1.9035	0	0	64.4	149.196	134.52
5	1	360.8	169.58	72.164	33.917	12.86	6.0442	1.96	0.9212	38.63	18.1561	174.02	486.434	402.64
6	4	40.07	18.832	8.014	3.7665	8.51	3.9997	4.51	2.1197	0	0	246.82	61.104	275.53
7	1	98	46.06	19.6	9.212	2.01	0.9447	5.88	2.7636	0	0	52.11	125.49	111.09
8	3	268.6	126.27	53.736	25.255	7.04	3.3088	1.67	0.7849	31.96	15.0212	262.04	363.086	432.69
9	2	360.6	169.49	72.124	33.898	14.93	7.0171	2.42	1.1374	45.03	21.1641	184.6	495.124	417.30
10	3	43.24	20.322	8.648	4.0645	9.58	4.5026	4.16	1.9552	0.5	0.235	208.17	66.128	239.25
11	3	120.5	56.644	24.104	11.328	5.16	2.4252	3.67	1.7249	14.83	6.9701	122.62	168.284	201.71
12	3	37.48	17.615	7.496	3.5231	7.83	3.6801	5.08	2.3876	1.46	0.6862	227.36	59.346	255.25
13	1	87.53	41.139	17.506	8.2278	1.42	0.6674	3.91	1.8377	1.2	0.564	40.47	111.566	92.906
14	4	185.8	87.326	37.16	17.465	14.83	6.9701	3.16	1.4852	23.84	11.2048	308.38	264.79	432.83
15	3	45.28	21.281	9.056	4.2563	11.74	5.5178	5.13	2.4111	0	0	284.68	71.206	318.14

16	4	45.14	21.215	9.028	4.2431	7.69	3.6143	3.74	1.7578	2.24	1.0528	220.53	67.838	252.41
17	5	110.8	52.113	22.176	10.427	6.11	2.8717	1.74	0.8178	11.46	5.3862	89.42	152.366	161.03
18	4	188.2	88.477	37.65	17.695	16.28	7.6516	3.07	1.4429	27.93	13.1271	356.49	273.18	484.88
19	3	253.9	119.35	50.788	23.870	8.93	4.1971	2.78	1.3066	37.91	17.8177	142.35	354.348	308.89
20	5	90.52	42.544	18.104	8.5088	4.37	2.0539	1.86	0.8742	6.28	2.9516	74.82	121.134	131.75
21	3	302.6	142.22	60.52	28.444	10.83	5.0901	2.86	1.3442	38.48	18.0856	147.65	415.29	342.83
22	5	115.6	54.369	23.136	10.873	5.24	2.4628	1.66	0.7802	10.84	5.0948	86.37	156.556	159.95
23	3	200.2	94.131	40.056	18.826	8.66	4.0702	2.31	1.0857	40.62	19.0914	275.52	291.926	412.72
24	2	307.3	144.46	61.474	28.892	10.93	5.1371	3.04	1.4288	26.47	12.4409	152.13	409.284	344.49
25	4	230.8	108.50	46.174	21.701	9.06	4.2582	1.04	0.4888	34.62	16.2714	232.04	321.764	383.26
26	5	120.6	56.705	24.13	11.341	3.18	1.4946	1.64	0.7708	5.11	2.4017	61.04	154.71	133.75
27	6	112.4	52.860	22.494	10.572	3.74	1.7578	2.69	1.2643	4.67	2.1949	58.54	146.064	127.19
28	4	200.1	94.079	40.034	18.815	11.53	5.4191	3.27	1.5369	36.88	17.3336	224.71	291.884	361.89
29	3	340.6	160.12	68.138	32.024	9.96	4.6812	3.66	1.7202	30.52	14.3444	149.53	452.968	362.42
30	5	113.6	53.401	22.724	10.680	2.42	1.1374	1.25	0.5875	16.89	7.9383	64.61	156.904	138.35
31	1	103.6	48.696	20.722	9.7393	4.72	2.2184	2.81	1.3207	0.78	0.3666	36.38	132.642	98.721
32	3	287.1	134.97	57.438	26.995	7.94	3.7318	2.68	1.2596	28.66	13.4702	132.99	383.908	313.42
33	3	157.6	74.109	31.536	14.821	3.98	1.8706	3.13	1.4711	14.93	7.0171	105.84	211.256	205.13
34	3	263.7	123.94	52.742	24.788	11.74	5.5178	4.71	2.2137	24.22	11.3834	116.52	357.122	284.36
35	5	157.6	74.109	31.536	14.821	12.39	5.8233	3.94	1.8518	26.04	12.2388	284.77	231.586	393.61
36	4	240.3	112.98	48.078	22.596	14.93	7.0171	2.11	0.9917	44.83	21.0701	267.8	350.338	432.45
37	2	248.7	116.90	49.746	23.380	11.04	5.1888	3.11	1.4617	32.74	15.3878	158.84	345.366	321.16
38	4	136.5	64.164	27.304	12.832	10.63	4.9961	1.03	0.4841	38.62	18.1514	238.38	214.104	339.00
39	4	168.9	79.401	33.788	15.880	13.82	6.4954	3.21	1.5087	34.86	16.3842	296.16	254.618	415.83
40	1	82.94	38.981	16.588	7.7963	1.47	0.6909	4.18	1.9646	0	0	41.56	105.178	90.993
41	2	166.9	78.443	33.38	15.688	6.64	3.1208	1.92	0.9024	32.54	15.2938	218.84	241.38	332.28
42	4	233.9	109.94	46.786	21.989	7.87	3.6989	2.17	1.0199	26.67	12.5349	252.31	317.426	401.50
43	3	37.25	17.507	7.45	3.5015	6.99	3.2853	4.18	1.9646	0	0	231.33	55.87	257.58
44	4	130.6	61.405	26.13	12.281	9.73	4.5731	3.75	1.7625	8.68	4.0796	111.48	178.94	195.58

45	3	210.4	98.916	42.092	19.783	9.27	4.3569	3.94	1.8518	26.49	12.4503	128.16	292.252	265.51
46	3	330.2	155.23	66.056	31.046	10.64	5.0008	2.53	1.1891	28.52	13.4044	126.53	438.026	332.40
47	1	101.4	47.695	20.296	9.5391	3.11	1.4617	3.36	1.5792	1.23	0.5781	52.34	129.476	113.19
48	4	255.7	120.19	51.148	24.039	11.75	5.5225	2.83	1.3301	30.8	14.476	283.55	352.268	449.11
49	1	378.4	177.89	75.698	35.578	7.48	3.5156	3.75	1.7625	25.17	11.8299	108.69	490.588	339.26
50	3	30.6	14.382	6.12	2.8764	5.24	2.4628	3.16	1.4852	0	0	210.26	45.12	231.46
51	2	267.3	125.64	53.464	25.128	9.88	4.6436	2.66	1.2502	36.92	17.3524	164.81	370.244	338.82
52	4	120.7	56.761	24.154	11.352	9.31	4.3757	4.87	2.2889	29.74	13.9778	255.34	188.844	344.09
53	5	90.45	42.511	18.09	8.5023	4.26	2.0022	1.93	0.9071	24.48	11.5056	73.59	139.21	139.01
54	2	240.8	113.17	48.16	22.635	9.99	4.6953	3.89	1.8283	32.35	15.2045	182.05	335.19	339.58
55	2	140.8	66.213	28.176	13.242	4.33	2.0351	3.07	1.4429	12.64	5.9408	93.71	189.096	182.58
56	3	210.3	98.869	42.072	19.773	10.63	4.9961	2.64	1.2408	29.53	13.8791	166.62	295.232	305.37
57	2	318.3	149.63	63.676	29.927	12.84	6.0348	2.85	1.3395	31.36	14.7392	159.43	429.106	361.10
58	1	99.36	46.699	19.872	9.3398	2.78	1.3066	2.88	1.3536	1.53	0.7191	50.06	126.422	109.47
59	5	89.35	41.994	17.87	8.3989	6.33	2.9751	2.74	1.2878	8.98	4.2206	75.8	125.27	134.67
60	2	288.5	135.60	57.704	27.120	10.85	5.0995	3.01	1.4147	33.6	15.792	121.59	393.684	306.62
61	2	286.7	134.76	57.346	26.952	13.68	6.4296	3.11	1.4617	28.28	13.2916	118.5	389.146	301.39
62	2	170.3	80.055	34.066	16.011	11.95	5.6165	2.63	1.2361	28.89	13.5783	109.47	247.866	225.96
63	3	270.3	127.04	54.062	25.409	5.84	2.7448	2.55	1.1985	24.36	11.4492	204.87	357.122	372.71
64	3	382.7	179.88	76.546	35.976	14.6	6.862	2.9	1.363	33.7	15.839	153.05	510.476	392.97
65	5	96.36	45.289	19.272	9.0578	2.48	1.1656	1.03	0.4841	6.64	3.1208	48.02	125.782	107.13
66	2	265.4	124.78	53.098	24.956	8.92	4.1924	2.04	0.9588	28.74	13.5078	142.86	358.288	311.25
67	4	236.6	111.23	47.332	22.246	8.45	3.9715	2.63	1.2361	27.75	13.0425	258.18	322.822	409.90
68	2	288.3	135.53	57.676	27.107	9.42	4.4274	2.46	1.1562	29.14	13.6958	174.93	387.076	356.85
69	1	87.62	41.181	17.524	8.2362	0.88	0.4136	5.37	2.5239	0	0	42.73	111.394	95.085
70	3	285.7	134.31	57.156	26.863	6.98	3.2806	2.74	1.2878	22.63	10.6361	168.93	375.286	345.31
71	3	170.4	80.102	34.086	16.020	8.92	4.1924	2.08	0.9776	28.7	13.489	185.93	244.216	300.71
72	2	267.8	125.90	53.578	25.181	12.04	5.6588	2.99	1.4053	28.98	13.6206	178.6	365.478	350.37
73	5	169.3	79.594	33.87	15.918	12.43	5.8421	3.04	1.4288	31.46	14.7862	263.53	250.15	381.10

74	4	208.6	98.070	41.732	19.614	7.16	3.3652	2.15	1.0105	34.08	16.0176	251.83	293.782	389.90
75	5	116.6	54.802	23.32	10.960	4.24	1.9928	1.92	0.9024	12.42	5.8374	62.71	158.5	137.20
76	4	268.4	126.10	53.694	25.236	8.63	4.0561	2.07	0.9729	38.78	18.2266	194.6	371.644	369.27
77	5	104.5	49.143	20.912	9.8286	4.29	2.0163	2.17	1.0199	8.64	4.0608	65.93	140.572	131.99
78	2	260.8	122.61	52.178	24.523	11.85	5.5695	2.62	1.2314	27.94	13.1318	164.02	355.478	331.09
79	2	266.9	125.45	53.386	25.091	10.63	4.9961	3.86	1.8142	26.15	12.2905	145.51	360.956	315.15
80	2	235.1	110.53	47.036	22.106	7.44	3.4968	2.34	1.0998	28.42	13.3574	242.94	320.416	393.53
81	4	242.7	114.08	48.548	22.817	9.56	4.4932	2.11	0.9917	31.88	14.9836	263.04	334.838	420.41
82	2	230.6	108.38	46.122	21.677	13.77	6.4719	2.03	0.9541	34.35	16.1445	155.37	326.882	309.00
83	3	48.83	22.950	9.766	4.5900	14.63	6.8761	5.64	2.6508	1.26	0.5922	242.55	80.126	280.20
84	2	232.8	109.45	46.578	21.891	9.58	4.5026	2.64	1.2408	31.41	14.7627	179.51	323.098	331.36
85	2	125.4	58.970	25.094	11.794	8.01	3.7647	4.11	1.9317	11.6	5.452	135.14	174.284	217.05
86	2	254.8	119.76	50.964	23.953	11.84	5.5648	2.17	1.0199	28.58	13.4326	123.73	348.374	287.46
87	4	175.5	82.503	35.108	16.500	15.38	7.2286	2.94	1.3818	32.85	15.4395	275.48	261.818	398.53
88	2	250.8	117.89	50.166	23.57802	10.85	5.0995	2.53	1.1891	28.12	13.2164	134.01	342.496	294.98
89	1	240.8	113.19	48.166	22.63802	6.86	3.2242	2.13	1.0011	2.03	0.9541	72.88	300.016	213.88
90	5	98.67	46.374	19.734	9.27498	5.85	2.7495	2.63	1.2361	10.85	5.0995	84.37	137.734	149.10
Average		189.2	88.92	37.84	17.7845	8.501	4.01	2.925	1.374	21.36	10.0400	162.6938	259.825	284.81

Appendix 27. Bulk density calculation and soil organic carbon storage in Sele-Nono forest at each sample plots

Plot No.	Depth (cm)	V (cm^3)	Mass of oven-dry bulk soil (gm)	C content of SOC of the composite soil (%)	Bulk density (gcm^{-3})	SOC (t/ha)
1	30	98	115.90	6.41	1.18	227.60
2	30	98	51.41	4.22	0.52	66.58
3	30	98	148.03	5.46	1.51	247.89
4	30	98	61.341	3.42	0.62	64.40
5	30	98	158.36	3.58	1.61	174.02
6	30	98	89.22	9.03	0.91	246.82

7	30	98	39.68	4.28	0.40	52.11
8	30	98	126.14	6.78	1.28	262.04
9	30	98	100.06	6.02	1.02	184.60
10	30	98	63.20	10.75	0.64	208.17
11	30	98	55.87	7.16	0.57	122.62
12	30	98	230.68	3.21	2.35	227.36
13	30	98	11.61	11.37	0.11	40.47
14	30	98	109.30	9.21	1.11	308.38
15	30	98	110.50	8.41	1.12	284.68
16	30	98	237.76	3.02	2.42	220.53
17	30	98	30.91	9.44	0.31	89.42
18	30	98	126.35	9.21	1.28	356.49
19	30	98	82.60	5.62	0.84	142.35
20	30	98	30.07	8.12	0.30	74.82
21	30	98	73.65	6.54	0.75	147.65
22	30	98	34.79	8.10	0.35	86.37
23	30	98	135.76	6.62	1.38	275.52
24	30	98	115.84	4.28	1.18	152.13
25	30	98	105.14	7.20	1.07	232.04
26	30	98	91.89	2.16	0.93	61.04
27	30	98	41.12	4.64	0.41	58.54
28	30	98	221.10	3.31	2.25	224.71
29	30	98	83.54	5.84	0.85	149.53
30	30	98	51.48	4.09	0.52	64.61
31	30	98	20.08	5.91	0.20	36.38
32	30	98	95.27	4.55	0.97	132.99
33	30	98	52.79	6.54	0.53	105.84
34	30	98	65.96	5.76	0.67	116.52
35	30	98	156.17	5.95	1.59	284.77

36	30	98	92.30	9.47	0.94	267.80
37	30	98	97.91	5.29	0.99	158.84
38	30	98	116.44	6.68	1.18	238.38
39	30	98	117.63	8.22	1.20	296.16
40	30	98	29.51	4.59	0.30	41.56
41	30	98	112.04	6.38	1.14	218.84
42	30	98	114.97	7.16	1.17	252.31
43	30	98	80.92	9.33	0.82	231.33
44	30	98	46.47	7.83	0.47	111.48
45	30	98	94.72	4.41	0.96	128.16
46	30	98	110.52	3.73	1.12	126.53
47	30	98	29.63	5.76	0.30	52.34
48	30	98	215.92	4.28	2.20	283.55
49	30	98	60.73	5.84	0.61	108.69
50	30	98	558.59	1.22	5.69	210.26
51	30	98	91.00	5.91	0.92	164.81
52	30	98	98.77	8.44	1.00	255.34
53	30	98	28.86	8.32	0.29	73.59
54	30	98	129.28	4.59	1.31	182.05
55	30	98	55.05	5.55	0.56	93.71
56	30	98	71.20	7.64	0.72	166.62
57	30	98	97.90	5.31	0.99	159.43
58	30	98	41.50	3.93	0.42	50.06
59	30	98	72.61	3.40	0.74	75.80
60	30	98	66.68	5.95	0.68	121.59
61	30	98	85.64	4.51	0.87	118.50
62	30	98	77.24	4.62	0.78	109.47
63	30	98	100.86	6.63	1.02	204.87
64	30	98	91.57	5.45	0.93	153.05

65	30	98	23.95	6.54	0.24	48.02
66	30	98	101.01	4.61	1.03	142.86
67	30	98	194.34	4.33	1.98	258.18
68	30	98	161.43	3.53	1.64	174.93
69	30	98	27.97	4.98	0.28	42.73
70	30	98	217.27	2.53	2.21	168.93
71	30	98	170.63	3.55	1.74	185.93
72	30	98	150.76	3.86	1.53	178.60
73	30	98	102.29	8.41	1.04	263.53
74	30	98	79.37	10.36	0.80	251.83
75	30	98	57.06	3.58	0.58	62.71
76	30	98	61.33	10.36	0.62	194.60
77	30	98	32.26	6.67	0.32	65.93
78	30	98	77.36	6.92	0.78	164.02
79	30	98	81.70	5.81	0.83	145.51
80	30	98	97.87	8.10	0.99	242.94
81	30	98	133.95	6.41	1.36	263.04
82	30	98	106.18	4.77	1.08	155.37
83	30	98	120.99	6.54	1.23	242.55
84	30	98	136.70	4.28	1.39	179.51
85	30	98	75.50	5.84	0.77	135.14
86	30	98	56.38	7.16	0.57	123.73
87	30	98	95.24	9.44	0.97	275.48
88	30	98	101.10	4.32	1.03	134.01
89	30	98	56.15	4.23	0.57	72.88
90	30	98	32.50	8.47	0.33	84.37
Averag.	**30**	**98**	**98.46**	**6.03**	**1.00**	**162.69**

Appendix 28. Dendrometric and biomass data for formulating allometric models for biomass estimation of trees in Sele-Nono forest

Appendix 28A. Data for developing allometric equation for biomass estimation of *Albizia gummifera* in Sele-Nono forest (Ag-Albizia gummifera)

code	DBH	Height	Wood density	Stump biomass	Bole Biomass	Large branch biomass	Small branch biomass	Leaves biomass	Total AGB (kg)
Ag1	45	19	0.57	0.276695	3.629801	15.93397	12.70133	1.342	33.8838
Ag2	50	21	0.43	0.256107	2.890768	31.36705	14.23693	2.98367	51.73452
Ag3	43	18	0.44	0.196088	2.192526	20.67004	11.27824	1.4398	35.77669
Ag4	67	23	0.43	0.47255	5.837463	51.52856	25.71975	3.5643	87.12263
Ag5	67	22	0.46	0.511172	6.443427	30.90905	22.336	2.4263	62.62595
Ag6	62	21	0.42	0.398452	3.395794	27.8649	15.22584	2.6584	49.54338
Ag7	83	24	0.55	0.911058	14.36351	86.92619	31.55909	2.91563	136.6755
Ag8	55	20	0.47	0.344466	4.510129	19.49644	12.753	1.984	39.08804
Ag9	44	19	0.45	0.216565	2.610539	24.03754	11.85684	1.6453	40.36678
Ag10	35	17	0.5	0.147472	1.426506	10.62539	9.249943	1.3794	22.82871
Ag11	85	25	0.54	0.937261	14.9366	72.77244	42.994	1.95463	133.5949
Ag12	54	20	0.51	0.370198	4.48484	20.72362	13.40133	0.9849	39.96489
Ag13	95	26	0.54	1.181165	20.80844	120.2352	45.00816	4.3546	191.5876
Ag14	35	18	0.47	0.135199	1.307788	7.728716	11.13885	0.8767	21.18725
Ag15	48	19	0.46	0.258293	7.177298	19.57251	14.94152	0.9941	42.94372
Ag16	38	17	0.47	0.162815	1.55841	15.01613	10.54638	1.0453	28.32903
Ag17	50	19	0.45	0.267286	3.222174	15.11306	15.68471	1.6588	35.94603
Ag18	70	23	0.44	0.514555	7.988438	35.9105	23.75086	1.53422	69.69857
Ag19	43	18	0.44	0.197495	4.256366	10.09448	8.81888	0.6676	24.03482
Ag20	88	25	0.45	0.808529	14.52721	45.55631	26.41714	2.9998	90.30899
Ag21	55	20	0.32	0.239493	2.945352	11.47227	8.1848	0.8744	23.71631
Ag22	75	24	0.49	0.664696	9.429691	38.07079	17.199	1.0332	66.39737
Ag23	34	18	0.51	0.146573	1.343752	9.460615	6.2352	1.0034	18.18954
Ag24	58	20	0.47	0.389951	4.81558	21.05867	17.94857	1.2321	45.44487
Ag25	54	21	0.49	0.35125	4.315703	16.90828	11.328	1.6575	34.56073

Ag26	46.5	17	0.44	0.232752	2.206981	9.943356	5.36848	1.212	18.96357
Ag27	94	25	0.45	0.939399	16.96767	61.04893	45.9425	3.7489	128.6474
Ag28	38	16	0.53	0.183184	1.167801	12.81974	10.71093	1.2343	26.11596
Ag29	49	20	0.47	0.268956	3.268779	17.49862	11.44133	1.85683	34.33452
Ag30	55	22	0.42	0.292854	3.561437	20.25093	13.83467	1.453	39.39288

Appendix 28B. Data for developing allometric equation for biomass estimation of *Mimusops kummel* in Sele-Nono forest (Mk-Mimusops kummel)

Code	DBH	Height	Wood density	Stump biomass	Bole biomass	Large branch biomass	Small branch biomass (including foliage)	Total AGB (Kg)
Mk1	37	18	0.566667	20.31109	195.5176	286.0292	173.16	675.0178528
Mk2	18	10	0.6619	5.931137	37.80028	101.5464	202.3168	347.5945834
Mk3	46	20	0.569444	31.57483	359.5914	837.751	106.72	1335.637173
Mk4	52	23	0.579605	39.07228	409.7864	823.7346	183.9797	1456.573008
Mk5	63	25	0.576667	57.39119	1031.552	730.8357	254.1	2073.879078
Mk6	64	25	0.642188	63.89685	1300.843	1075.687	119.592	2560.018264
Mk7	44	17	0.620269	29.57983	317.1469	398.7702	199.459	944.9559617
Mk8	59	24	0.571939	48.48898	1046.389	324.1398	93.84533	1512.862718
Mk9	29	14	0.578655	12.2646	131.1066	106.6752	136.9547	387.0011152
Mk10	33	16	0.597297	16.74599	164.3489	96.94436	178.9363	456.9755852
Mk11	24	8	0.591591	8.707479	96.29078	89.38749	271.674	466.0597543
Mk12	39	18	0.672	26.61866	405.0884	251.0362	84.65657	767.3998589
Mk13	44	20	0.669048	33.3556	692.0965	262.3459	169.0443	1156.842312
Mk14	39	15	0.605489	22.81483	343.7957	221.7174	84.97543	673.3033622
Mk15	52	23	0.604127	41.50071	661.7849	300.1392	141.2775	1144.702275
Mk16	39	17	0.621667	24.6249	262.1691	254.6232	114.1538	655.5709354
Mk17	27	13	0.630909	11.6486	65.35004	158.9608	55.0935	291.0529448
Mk18	24	10	0.626571	9.222348	94.17862	135.6821	158.3589	397.4419634
Mk19	48	20	0.553571	31.94621	524.7864	377.9843	345.5617	1280.278577
Mk20	39	15	0.732143	27.58714	298.4469	329.6187	376.134	1031.786704

Mk21	14	8	0.611373	3.23951	22.31279	48.13672	378.324	452.0130207
Mk22	30	15	0.628434	14.68863	213.7498	157.6851	298.5086	684.6321198
Mk23	24	8	0.549286	8.414659	59.75421	108.6015	112.1505	288.9208596
Mk24	30	15	0.664167	16.03215	155.6774	589.7486	170.2925	931.7506918
Mk25	21	6	0.626813	7.144542	48.43847	94.45852	136.7925	286.834034
Mk26	19	5	0.62625	5.899275	38.69924	91.11184	78.0192	213.7295633
Mk27	14	4	0.604545	3.203335	12.48708	61.5439	112.0871	189.3213606
Mk28	22	6	0.572851	7.13655	29.24322	139.6079	80.5609	256.5485805
Mk29	29	15	0.634167	13.44116	133.2527	241.3605	34.4	422.4543265
Mk30	26	15	0.669444	11.49299	83.10477	153.0128	248.8909	496.5014922

Appendix 28C. Data for developing allometric equation for biomass estimation of *Syzygium guineense* in Sele-Nono forest (Sy- Syzygium guineense)

Code	DBH	Height	Wood density	Stump biomass	Bole biomass	Large branch biomass	Small branch biomass (including foliage)	Total AGB (Kg)
Sy1	64	20	0.470513	46.81544	577.6905	1760.888	19.7575	2405.151782
Sy2	59	30	0.498205	42.23783	650.0871	4042.268	164.094	4898.686884
Sy3	62	25	0.536218	51.73664	672.2785	1765.148	243.648	2732.811371
Sy4	59	15	0.544902	50.20693	709.2062	3474.571	92.5164	4326.500163
Sy5	59	25	0.526407	48.50281	854.1452	1616.579	20.61295	2539.840384
Sy6	67	22	0.499426	54.38508	926.2899	2864.038	77.85414	3922.566777
Sy7	64	18	0.61	60.69424	1451.586	1529.695	48.3784	3090.353232
Sy8	49	20	0.590833	34.78531	625.971	722.477	48.1609	1431.39421
Sy9	74	25	0.67243	92.7103	2680.821	2793.244	198.3873	5765.162402
Sy10	77	34	0.496707	71.16733	1632.684	4270.719	98.41313	6072.984004
Sy11	60	26	0.65	58.85734	1768.7	2351.337	52.332	4231.225924
Sy12	59	26	0.537	45.52686	1037.178	2047.168	48.052	3177.924562
Sy13	64	27	0.577381	59.24353	1444.187	2036.55	65.15139	3605.132439
Sy14	76	30	0.552381	80.19134	2105.399	1875.294	33.544	4094.428659
Sy15	62	18	0.567931	54.79646	1477.853	1238.281	70.12883	2841.059162

Sy16	49	15	0.542391	33.23617	557.7681	827.0722	109.2843	1527.360749
Sy17	43	17	0.607692	28.34324	413.3085	969.2885	83.75833	1494.698569
Sy18	39	15	0.463462	18.82209	237.8565	324.5505	10.78457	592.0136449
Sy19	36	13	0.458333	14.77664	177.5518	615.8734	16.8091	825.0109198
Sy20	51	16	0.494173	31.46854	555.0725	2591.581	18.12378	3196.245456
Sy21	49	15	0.523077	30.79615	744.9354	1451.212	26.3872	2253.330995
Sy22	44	13	0.483636	23.06401	385.9748	679.3842	22.15478	1110.577857
Sy23	34	12	0.561667	16.20338	178.5128	1101.499	23.6901	1319.905486
Sy24	31	12	0.570833	13.76576	160.7327	616.961	28.34421	819.8037176
Sy25	47	15	0.537677	29.78803	577.0508	1529.213	21.448	2157.499991
Sy26	44	14	0.539712	25.73817	496.22	1553.278	22.38261	2097.619158
Sy27	39	12	0.777405	30.79386	685.0902	1131.821	48.3105	1896.015365
Sy28	39	13	0.669632	25.23173	476.6253	1150.519	25.49662	1677.872398
Sy29	29	10	0.738101	15.64405	164.4839	595.0303	55.5345	830.6927298
Sy30	36	12	0.666163	22.06537	392.5823	835.636	27.59894	1277.882669

Appendix 29. Validation data sets for verifying formulated allometric equations in Sele-Nono forest

Appendix 29A. Observed and predicted biomass of *Albizia gummifera* in Sele-Nono forest

Code	Parameters			Observed AGB (Kg)	Predicted AGB (Kg) by different models					
	DBH	H	ẟ		Present Model	Brown	Chave1	Chave2	WBISPP	Djomo
Ag31	51	22	0.41	21.39	38.4422	3039.	119.4	111.0	671.9	1.516
Ag32	72	24	0.47	67.82	81.4391	7500.	297.6	270.7	1421.	3.847
Ag33	75	23	0.48	66.37	83.5433	8347.	316.0	287.1	1553.	4.206
Ag34	83	24	0.51	89.77	109.452	10886	429.1	387.0	1937.	5.666
Ag35	91	25	0.55	158.9	144.120	13854	579.5	518.8	2368.	7.557
Ag36	86	24	0.52	130.4	117.686	11947	469.8	422.7	2093.	6.236
Ag37	64	22	0.48	67.46	63.8921	5509.	220.1	201.7	1099.	2.877
Ag38	48	16	0.43	20.13	24.8143	2592.	80.68	75.73	589.2	1.183
Ag39	96	25	0.54	181.8	150.965	15938	633.2	565.7	2661.	8.405
Ag40	37	16	0.31	19.02	11.4219	1310.	34.56	33.10	335.9	0.505

Appendix 29B. Observed and predicted biomass of *Mimusops kummel* in Sele-Nono forest

Code	Parameters			Observed AGB (Kg)	Predicted AGB (Kg) by different models					
	DBH	H	ẟ		Present model	Brown	Chave1	Chave2	WBISPP	Djomo
Mk31	34	13	0.55	365.351	592.477	1050.	42.07	40.11	280.1	0.599
Mk32	40	16	0.64	752.939	854.369	1608.	83.39	78.21	397.4	1.077
Mk33	45	18	0.64	1124.432	1007.92	2189.	118.7	110.4	512.4	1.486
Mk34	51	22	0.6	1170.148	1210.73	3039.	174.7	161.0	671.9	2.058
Mk35	39	15	0.53	672.361	702.744	1504.	61.54	58.14	376.3	0.848
Mk36	49	22	0.58	1384.85	1149.54	2736.	155.9	144.0	616.1	1.829
Mk37	30	13	0.61	902.83	583.556	756.7	36.32	34.75	214.2	0.490
Mk38	20	5	0.51	250.548	198.065	261.5	5.191	5.204	90.62	0.108
Mk39	62	24	0.6	2035.084	1475.96	5069.	281.7	256.6	1026.	3.336
Mk40	64	25	0.65	2580.13	1642.78	5509.	338.7	307.2	1099.	3.896

Appendix 29C. Observed and predicted biomass of *Syzygium guineense* in Sele-Nono forest

Code	Parameters			Observed biomass (Kg)	Predicted AGB (Kg) by different models					
	DBH	H	ẟ		Present model	Brown	Chave1	Chave2	WBISPP	Djomo
Sy31	60	21	0.5	2694.23	2840.43	4652.	192.4	176.8	955.9	2.513
Sy32	70	25	0.51	6012.64	4030.49	6967.	317.9	288.8	1336.	3.928
Sy33	61	26	0.64	4167.84	3818.52	4858.	315.1	286.3	990.9	3.515
Sy34	74	27	0.56	4006.46	4991.94	8059	421.4	380.1	1508.	4.978
Sy35	62	17	0.56	2738.55	3362.35	5069.	186.2	171.3	1026.	2.685
Sy36	63	22	0.45	2512.815	2834.51	5286.	200.0	183.6	1062.	2.636
Sy37	64	20	0.6	3142.72	3888.13	5509.	250.1	228.5	1099.	3.290
Sy38	34	10	0.54	1316.73	904.111	1050.	31.77	30.49	280.1	0.522
Sy39	48	15	0.46	3102.46	1611.40	2592.	80.91	75.94	589.2	1.211
Sy40	65	20	0.47	3884.698	3140.43	5737.	202.1	185.6	1137.	2.802

Appendix 30. Method of quality assurance/quality control implemented during the life span of this study in Sele-Nono forest

S/N	Kind of error	Source of error	Actions applied to reduce the error
1	Sampling error	Selection of forest plots	Plot shape and size for each component of carbon pools were made following a design developed by a group of scientists on the area (Walker *et al.*, 2012). Placements of plots were made using stratified sampling method to adequately represent the forest (MacDicken 1997, Pearson *et al.*, 2005)
2	Field measurement error	Measurements of relevant parameters for all C-pools	Literate crew members were hired both by the researchers and District administrators. They were trained how to measure an accurate data like DBH in the field. A pilot field measurement near the study forest was made before actual data collection to see the outcome of the training. Possible potential errors were identified and corrections were made for the actual field measurement in Sele-Nono forest. It was ensured that all carbon pools were measured according to the state of the art and was certain that trees were not measured twice or dead trees counted as living.
3	Data taking and entry error	Filling the data sheet and entering them into a computer	Recording all the field data in the computer were made by the researcher with great patience and care. Data entry was also made by the researcher himself immediately after a return to the office. Data entry for each plot was rechecked with the original hard copy data sheet before we entered data for the next plot.
4	Estimation error	Application of allometric equations	Model validation which we think can work better to the study area were checked using local data; and the best models with lower errors bias were used for this study. The errors attributable to the allometric equation was estimated at 10% following the suggestion of Clark and Clark (2000), Keller *et al.* (2001) and Walker *et al.* (2012)..
		Application of wet-dry mass ratio technique for biomass estimation	All balances for measuring sub sample fresh weights in the field and dry weight in the lab were calibrated against known weights in Ecophysiology lab, AAU.
		Biomass estimation at plot level	Biomass density at plot level were estimated using the appropriate techniques and conversion to hectare basis was done using slope corrected area so as to report the biomass on horizontal projection levels following the SOP manual (Walker *et al.*, 2012).
		Application biomass to carbon ratio	The IPCC (2006) presents a default value of 0.47 for tropical forests. This is an improvement on 0.5 suggested by Brown (1997), MacDicken (1997) and Pearson *et al.* (2005).