ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS OF THREE SELECTED NATIVE TREE SPECIES IN SUBA-SEBETA FOREST: USING BRANCHING APPROACHES.

MSc. THESIS

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APPROVAL SHEET-II

We, the undersigned, members of the Board of examiners of the final open defense by ***Yiheyis Daniel Abebe*** have read and evaluated his thesis entitled ***“Allometric Equations For Estimating Aboveground Biomass of Three Selected Native Tree Species in Suba-Sebeta Forest :Using Branching Approaches”,*** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the Degree of Master of Science in Forestry study with specialization in Forest Resource Assessments and Monitoring.

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Name of main advisor	Signature	Date

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Yiheyis Daniel

JUNE 15, 2018

DECLARATION

I hereby declare that this thesis entitled “***Allometric Equations For Estimating Aboveground Biomass of Three Selected Native Tree Species in Suba-Sebeta Forest: Using Branching Approaches***” submitted in partial fulfillment of the requirements for MSc degree in Forest Resource Assessments and Monitoring at Wondo Genet College of Forestry and Natural Resources, is my own work and, it contains no materials previously published or written by another person and has not been previously submitted or accepted elsewhere to any other university or institute for the award of any other degree.

Name: Yiheyis Daniel Abebe Signature: ________________

Place: Hawassa University, Wondo Genet College of Forestry and Natural Resources.

Date of submission: JUNE 15, 2018

LIST OF ABBREVIATIONS

AGB	Aboveground biomass
BD	Basal diameter
CA	Crown area
CD	Crown diameter
CH	Crown height
EFAP	Ethiopian Forestry Action Plan
FAO	Food and Agricultural organization
FRC	Forest Research Center
GIS	Geographic Information System
GIZ	German International Cooperation
GPS	Global Positioning System
Ha	Hectare
M	Model
IPCC	Intergovernmental panel on climate change
OWFE	Oromia Forest and Wild life Enterprise
MEFCC	Ministry of Environment,Forest and Climate change
REDD+	Reducing Emmisions from deforestation and forest degradation and conservation and enhancement of forest carbon stocks
UNFCCC	United Nations Framework Convention on Climate Change
WBISPP	Woody Biomass Inventory and Strategic Planning Program

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ABSTRACT

The development of allometric models is crucial to assess forest biomass and carbon stocks. However,very few allometric equations have been developed in Ethiopia and as a result generalized allometric equations are often used for forests developed in other study areas.The general objective of this study, therefore, was to develop allometric equations for estimating aboveground biomass of three selected native woody species by using branching method.The three native plants were Dovyalis verrucosa, Ekebergia capensis and Olinia rochetiana of dry evergreen Afromontane forest of Suba-Sebeta forest in centeral highland of Ethiopia. Inventory of woody species was carried out for determining the relative proportion of the three selected woody species in the stand. A total of 36 individual plants (12 from each species) were selected from the diameter categories randomly to trim branch. Sample trees were climbed, basal diameters of small branches were recorded and three branches per tree were removed for further parameters measurement. Plant biometric parameters such as diameter at stump height (DSH), diameter at breast height (DBH), total height (Ht) and crown area (CA) were measured, Woody density of the three selected species were also determined. The best allometric equations were evaluated on the basis of performance statistics (bias, coefficinet of determination (R^2), standard error of estimate (SEE), prediction residuals sum of squares (PRESS), index of agreement between measured and predicted biomass values (D)), The results of the study showed that strongest predictor varaiables for estimating aboveground biomass for Dovyalis verrucosa was DBH($R = 0.97$, $p<0.05$), Ekebergia capensis DSH ($R=0.97$, $p<0.05$) and Olinia rochetiana DBH ($R=0.96$, $p<0.05$).The mean wood density for Dovyalis verrucosa was estimated to 0.483 g cm^{-3},0.353 g cm^{-3} for Ekebergia capensis and 0.434 g cm^{-3} for Olinia rochetiana. The best performing equation for estimating total aboveground biomass of Dovyalis verrucosa explained 98% of the biomass variation (Model 8- $AGB = 0.155 \times (DSH)^{1.164} \times (DBH)^{0.778}$, $R^2=0.98$, $p<0.001$), for E.capensis (Model 8- $AGB = 0.030 \times (DSH)^{0.953} \times (DBH)^{1.840}$, $R^2=0.99$, $p<0.001$) and for O.rochetiana (Model 13- $AGB= 0.242 \times (DBH)^{1.418 \times} (Ht)^{1.085} \times (CA)^{0.036} \times (\bar{\rho})^{1.562}$, $R^2=0.99$, $p<0.001$). It was revealed that using previously published general allometric equations either overestimated or underestimated the aboveground biomass. It was concluded that the equations developed in this study could better estimate the aboveground biomass of D. verrucosa, E. capensis and O. rochetiana in the study region. Furthermore, this study will help to better estimate the three species within reference of dry evergreen Afromontane forest in the study region and agroecologies similar to this study.

Key words: *Allometric equations, Biomass, Ethiopia, native species, predictor variables*

CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justifications

The estimation of biomass components of trees and forests has long been studied to aid the quantification of available forest resources, such as food, fuel, fodder and fiber (Kie and White, 1985). At the present time, forest biomass data can also be used to understand changes in forest structure resulting from succession, or in differentiation between forest types (Gehring et al., 2004; Vargas et al., 2008).

In recent years, the estimation of biomass components has become important for environmental projects, since biomass can be related to carbon stocks and to carbon fluxes when biomass is sequentially measured over time (Brown et al., 1989).

The cycling of carbon in forest ecosystems is a topic of considerable importance with rising atmospheric CO2 concentrations, global climate change, and the poorly defined role that terrestrial ecosystems play in mitigating or improving these phenomena (Dixon *et al.,* 1994).

The carbon sequestered or stored on the forest trees are mostly referred to as the biomass of the tree or forest. The Intergovernmental Panel on Climate Change (IPCC) identified five carbon pools of the terrestrial ecosystem involving biomass, namely the aboveground biomass, below-ground biomass, litter, woody debris and soil organic matter. Among all the carbon pools, the above-ground biomass constitutes the major portion of the carbon pool (IPCC, 2006).

Aboveground biomass is the amount of organic matter in living and dead plant material is a critical component of the carbon cycle in forest ecosystems, providing both short- and long-term carbon sequestrations.Tropical forests, in particular, are major components of the terrestrial carbon cycle, accounting for 26 percent of global carbon storage in biomass and soils (Grace, 2004; Geider *et al.,* 2001).

Tree growth parameters varies considerably with species, site quality, location, climatic regimes, altitude etc. and therefore becomes necessary to obtain accurate and precise tree allometric estimates in order to improve understanding of the role of these carbon sinks in global carbon cycle. An unsuitable application of allometric equation may lead to considerable bias in carbon stocks estimations (Picard et al., 2012).

Allometric regression models are widely used for estimating tree biomass in forests. Broadly, allometry is the linear or non-linear correlation between increases in tree dimensions (Picard et al., 2012).These models are mathematical functions that relate tree dry mass to one or more tree variables.

The most important variables for biomass equations are tree diameter at breast height (DBH) (Brown, 1997; Brown et al., 2001), wood density (WD), and tree height (H) (Ketterings et al., 2001; Chave et al., 2005; Basuki et al., 2009). WD converts volume to weight and varies over a considerable range between species (Chave et al., 2005; Picard et al., 2012). As WD is often not measured in the field, averages at the species level can be associated with trees (Fayolle et al., 2013) and such data is often available in international databases (IPCC, 2006). Furthermore, some authors suggested that crown diameter (CD) or crown area (CA) helps to improve accuracy and reliability of biomass estimates (Henry et al., 2010; Dietz and Kuyah, 2011).

A major challenge lies in developing models that are both accurate and relatively easy to use. It has been argued that models based on large compiled data sets (Brown, 1997; Chave et al., 2005) generally perform better for larger scale assessments than local models because the latter are fitted on a limited number of trees (Chave et al., 2005; Gibbs et al., 2007; Fayolle et al., 2013).

However, results from other studies suggest local models to be more accurate on smaller scales (Basuki et al., 2009; Kenzo et al., 2009; Lima et al., 2012). Numerous publications suggest power models for building allometric equations based on one or more variables (Pearson et al., 2007; Picard et al., 2012).

The most accurate method for the estimation of plant biomass is through cutting of trees and weighing of their parts directly. This “destructive” method is commonly used to validate others, less invasive and costly methods, such as the estimation of biomass and carbon stock using non-destructive in-situ measurements and remote sensing (Wang et al., 2003).

Generally, Allometric equations are a basic tool for non-destructive estimation of biomass in woody vegetation. Equations generated from a small sample of trees are then used to estimate biomass at tree level, plot level and landscape scales. It’s also the convenient and common method to estimate the biomass of a forest or stand (Wang, 2006).

1.2 Statement of the Problem

The recent development of biomass markets and carbon trading has led to increasing interest in obtaining accurate estimates of woody biomass production. The developments of site- and species-specific allometric equations are necessary to achieve higher levels of accuracy (Brown, 1997; Chave et al., 2004; Basuki et.al., 2009).

Tools for biomass estimation remain scarce in the tropics and existing generalized models do not accurately represent biomass in the actual forests (Henry et al., 2011). Most existing models for tropical species were developed in Latin America and Asia. Though great efforts have been made to develop models for several tropical species in recent years, particularly in Africa (Henry et al., 2011; Fayolle et al., 2013), attempts to develop biomass equations for Sub-Saharan Africa have been very limited (Henry et al., 2011).

To obtain precise and accurate biomass estimates in forests, different models must be developed for different species and forest types. Most of the recent biomass models in Africa have been developed for wet or moist forests (Djomo et al., 2010 ; Fayolle et al., 2013), leaving dry forests poorly studied.

According to Henry et al. (2011) review reported biomass equations for only eighteen forest species in Ethiopia. Being part of the tropical forest there is inadequate studies on developing allometric equation on the basis of branching approach conducted to develop site- and species-specific allometric equations for *Dovyalis verrucosa (Hochst.) Warb, Ekebergia capensis Spamn* and *Olinia rochetiana A. Juss* native woody species.

In this study, other high timber value dominant native tree species such as Juniperous *procera and Podocarpus falactus* were not selected because species specific equations were developed by Eyosias and Teshome (2015) in Wof-washa forest of similar agroecology in the same methodological procedure to this study.So we have an opportunity of using these developed equations until site- and species- specific equations will be developed for these species in Suba-Sebeta forest.

Therefore, this study aimed to develop allometric equations for three native tree species in Suba-Sebeta dry evergreen Afromontane forest, with the objective to contribute biomass and carbon estimation models of local species specific allometric equations.

1.3 Objective of the Study

1.3.1 General Objective

The overall objective of this study was to develop allometric equations for estimating aboveground biomass of *Dovyalis verrucosa (Hochst.) Warb, Ekebergia capensis Spamn* and *Olinia rochetiana A. Juss* in Suba-Sebeta Forest using branching approaches.

1.3.2 Specific Objective

The specific objective of this study is:-

- ✓ to determine the dry weight of aboveground biomass components (stem, branches and leaves) of the three selected native species ;
- ✓ to determine wood density of the three selected species;
- ✓ to determine which biometric parameter of the three species best correlates with biomass;
- ✓ to derive various allometric equations to predict aboveground biomass;
- ✓ to evaluate the equations and compare with previously published biomass generic equations.

1.4 Significance of the Study

The knowledge of carbon stocks and fluxes is essential to understand current status and future courses of the carbon cycle in response to changing land uses and climatic conditions (Hollinger, 2008).

Growing carbon trade and the desire to mitigate climate change has brought a number of policies, programs, and legislative actions. For example, forest carbon stocks for many developed and developing nations are reported as part of the overall carbon accounting under the United Nations Framework Convention on Climate Change (Pan, 2003).

Developing site and species-specific allometric equations for selected tree species and applying the scientific fact to estimate their potential and implication on carbon stocks and carbon sequestration is very important and can help to obtain financial rewards for the sequestered carbon or for the CO_2 emission reductions through appropriate management of terrestrial biomass (Henry et al., 2011).

With the development of the REDD+ mechanism and the emphasis put on the possible revenue that could be gained from the conservation of forest carbon stocks, precise and verifiable estimates of forest carbon stocks in Ethiopia are insistently required.

1.5 Organization of the Thesis

This study is organized and presented in five chapters. Chapter one is an introductory part of the thesis to give a background to the research which is briefly described and to the identified statement of the problem being researched and the objective of the study. Chapter two reviews the literature that deals on basic terms, relations and correlation of ideas related to the study that has been conceptualized.

In chapter three, the methodology employed on the samples and the sampling techniques, data collection procedures, model development and data analysis strategies were discussed. Chapter four is concerned with data presentations, analysis and interpretations,results and discussion whereas the last chapter, presents conclusion and recommendations of the study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Forest Resource Assessements and Monitoring in Ethiopia

The definition of forest is still ambiguous. According to FAO (2001) forest is defined as "land with a tree crown cover of more than 10 % and an area of more than 0.5 ha; the trees should be able to reach a minimum height of 5m at maturity". UNFCCC (2006) defined forest as "a minimum land area of 0.05–1 ha, with tree crown cover more than 10–30 % and tree height of 2–5 m at maturity".

According to the revised definition of forest in Ethiopia 'Land spanning at least 0.5 ha covered by trees and bamboo), attaining a height of at least 2m and a canopy cover of at least 20% or trees with the potential to reach these thresholds in situ in due course' (MEFCC, 2015).

Such type of forest definition differs from the definition used for international reporting to the Global Forest Resources Assessment (FRA) and from the forest definition used in the National forest inventory (NFI) which both applied the FAO forest definition.The reason for Ethiopia to change its national forest definition is to better capture dry and lowland-moist vegetation resources. In specific, the reason for lowering the tree height from 5 to 2 m is to capture *Termilania-Combretum* dense woodlands found in Gambella and Benishangul Gumuz Regional States which in its primary state consists of trees reaching a height of around 2-3 m and above (MEFCC, 2015).

Ethiopia owns diverse vegetation resources, from tropical rain and cloud forests in the southwest and on the mountains to the desert scrubs in the east and north east and parkland agroforestry on the central plateau (Teketay,*et al*., 2010).

The country straddle diverse agro-climatic zones, which made the country botanical treasure house, containing about 7000 different flowering plants out of which about 12% are endemic (FAO,2010). Ethiopia's forest resources covers about 50.6% of the country's total land area (1.12 million km^2), which fall into six broad categories (forestlands, woodlands,shrublands,bushlands,plantations and bamboos),however according to WBISPP (2004), Ethiopia has estimated a total high forest area of 4.07 million hectares or about 3.56% of the land area of the country.

There are 92 forests in Ethiopia and out of which 56 are dry evergreen montane forests, 29 moist montane forest, 5 transitional dry moist evergreen montane forests and 2 lowland semi-evergreen forests (EFAP, 1994). WBISPP estimated of the woody vegetation resources was about 59.7 million hectares in Ethiopia with 6.8% forest, 49% woodland, and 44.2% shrub land (WBISPP, 2004).

Ethiopia's forests have been subjected to human pressure over the course of its history and anthropogenic pressures have continued to increase significantly over the last century (Teketay et al., 2010). An estimated 97% of the natural vegetation of Ethiopian highlands has been lost, with humans having significant impacts on an estimated 95% of the natural vegetation in the Horn of Africa. It is declining for at least two centuries, based on original forest estimates and anecdotal evidence (Bishaw, 2001; Henze, 2000).

The data on forest resources of Ethiopia reported in FAO (2010) puts Ethiopia among countries with forest cover of 10-30%. According to this report, Ethiopia's forest cover is 12.2 million ha (11%).

The FAO (2010) FRA data is based on a reclassification, calibration and linear extrapolation of data from WBISPP (2004). However; recent unpublished reports claim that the Ethiopian forest cover has reached about 15% (MEFCC, 2015).

2.2 Methods for Estimating Above-ground Biomass

The accurate assessment of biomass estimates of a forest is important for many applications such as timber extraction, tracking changes in the carbon stocks of forest and global carbon cycle (Ravindranate and Ostwald, 2008).

The accurate and precise measurement of carbon stocks over time, by means of consistent approaches would provide the much-needed information in the determination of changes in carbon stocks (Brown, 2002). Knowledge of the amount of biomass in an ecosystem is often the starting point in biomass carbon estimation. As asserted by Brown and Lugo(1992), most researchers have relied on tree biomass inventory as a reliable way of estimating forest biomass because it accounts for the largest fraction of biomass in that ecosystem.

There is no single method for estimating biomass stocks, but there are number of methods depending on the scale accuracy considered (Gibbs et al., 2007). There are two main common methods for estimation of biomass namely ground based and remote-sensing. Ground based biomass can be either aboveground or both above and below ground biomass estimation.The above and below ground biomass estimation can either be destructive or non-destructive methods. The non-destructive method estimates biomass as a product of volume and wood basic density where tree volume is a function of basal area and tree total height. Non-destructive method also may involve remote sensing technology. The remote sensing methods provide broad geographic coverage; they are reliant on good quality of ground-truthing data for calibration and verification (Mitchard et al., 2011).

To develop allometric equation for biomass measurement from individual species, different sampling methods can be applied; The major ones are destructive and non-destructive method.

2.2.1 Destructive Method

According to Gibbs et al. (2007) among all the available biomass estimation method, the destructive method, also known as the harvest method is the most direct method for estimation of above-ground biomass and the carbon stocks stored in the forest ecosystems.

This method involves harvesting of all the trees in the known area and measuring the weight of the different components of the harvested tree like the tree trunk, leaves and branches (Xiao and Ceulemans, 2004; Ravindranate and Ostwald, 2008) and measuring the weight of these components after they are oven dried.

This method of biomass estimation is limited to a small area or small tree sample sizes. Although this method determines the biomass accurately for a particular area, it is time and resource consuming, strenuous, destructive and expensive, and it is not feasible for a large scale analysis.

This method is also not applicable for degraded forests containing threatened species (Montès et al., 2000). Usually, this method is used for developing biomass equation to be applied for assessing biomass on a larger-scale (Segura and Kanninen, 2005; Navar, 2009).

2.2.2 Non-Destructive Method

This method can be used either non-destructive ground based field measurement and remote sensing (GIS) or the combination of the two methods. In general, it include deductions derived from remote sensing, use of biomass conversion and estimation factors, and estimation by use of allometric equations (Bombelli et al., 2009).

The non-destructive methods used for plant biomass estimation is applicable for those ecosystems with rare or protected tree species where harvesting of such species is not very practical or feasible.The biomass of the individual tree was estimated by taking into account the tree shape (by taking two photographs of the tree at orthogonal angles), physical samples of different components of the trees like branches and leaves and dendrometric measurements (volume and bulk density) of the different components. Although it is a non-destructive method, to validate the estimated biomass, the trees had to be harvested and weighted (Picard et al 2012).

Another way of estimating the above-ground forest biomass by non-destructive method is by climbing the tree to measure the various parts (Aboal et al., 2005) or by simply measuring the diameter at breast height, height of the tree, volume of the tree and wood density (Ravindranate and Ostwald, 2008) and calculate the biomass using allometric equations (Brown et al., 1989; Hughes et al., 1999). Since these methods do not involve felling of tree species, it is not easy to validate the reliability of this method. These methods can also involve a lot of labour and time and climbing can be troublesome.

2.3 Allometric Biomass Equation

The term ‘allometry’ was invented by Huxley and Teissier (1936) ‘‘to denote growth of a part at a different rate from that of body as a whole”.Allometry also implies relationships between body sizes, such as biomass, dbh and height for a tree. Tree biomass can be quantified by either destructive harvest (direct method) or allometric equations (indirect method) that are initially developed based on harvested trees (Brown, 1997; Chave et al., 2005). In general, there are two types of allometric equation namely, general and species - specific allometric equation.

2.3.1 General Allometric Equations

General allometric equation or mixed species allometric equations are equations,which are developed using many species as one component. This means, estimation of biomass of a particular forest by measuring of trees compartment like trunk, branch, leave etc. Using these compartments estimation of biomass needs to measure density of a particular species and general allometric equation assumes that one species' individual have similar density (Singh et al., 2011).

For accounting of biomass and carbon stocks from forests general allometric equation have been frequently used. This is because of the presence of many species and large number of individuals found in one forest which is difficult to deal with all species and individuals and also seeks massive destruction on the forest. In order to resolve this problem scientists formulate allometric equation or model which has a capacity to minimize cost and time. Estimates of biomass are largely results of a common equation applied over a large area (Houghton, 1999).

The advantage of applying general allometric equations is that the equations are derived from a large number of trees with a wide range of DBH. This could improve the accuracy of the biomass estimation (Brown, 2002).

Usage of allometric equations is the standard methodology for the estimation of tree, plot, and regional aboveground biomass beneficial in an area. Its which harboral so high species diversity like tropical, grouping all species together and using generalized allometric relationships that are stratified by broad forest types or ecological zones that has been highly effective in the tropics (Brown, 2002).

Instead of developing and applying an allometric equation for each species which is time consuming and expensive (Litton and Boone, 2008). Several biomass-prediction equations have been developed for mixtures of tropical species (Chave et al., 2005), yet most are not validated for the region. Existing allometric equations in East Africa are mainly developed for distinct land use systems such as forestry and agroforestry. In addition, most existing equations have under represented certain vegetation types and tree size (Kieth et al., 1999).

Applying such equation for a broader geographic area may cause bias, mostly overestimation. Because biomass varies depending upon a variety of factors i.e. age of the stand, species and topography. Generalized allometric equations do not accurately predict aboveground biomass (Litton et al., 2006) and yet the use of generalized equations can lead to a bias in estimating biomass for a particular species (Pilli et al., 2006).

In general, some authors have proposed the use of existing generalized equations to estimate aboveground biomass for African tropical forests (e.g., Brown et al., 1989; Brown and Lugo 1992; Chave et al., 2005), while others reported that generalized models are unsuitable for African tropical forests (e.g., Henry et al., 2010; Ngomanda et al., 2014). So, the use of site-and species-specific equations are encouraged (Cairns et al., 2003; Henry et al., 2011).

2.3.2 Species-Specific Allometric Equations

Species specific allometric equations are used to estimate tree and stand biomass, based on easily measured tree variables such height, diameters and crown. Such equations are specific to sites, species, tree age and management practice to the tree (Picard et al., 2012; Chave et al., 2014).

To reduce uncertainty accurate carbon accounting method is required.So,the development of new, species-specific allometric equations is necessary to achieve higher level of accuracy (Basuki et al., 2009).

Moreover, the use of general allometric equation can lead to bias in estimating of biomass for a particular species due to wood density variation among species and within species and also it excludes architectural differences (Kuyah et al., 2012).

Therefore,using species-specific allometric equation is more preferable than general once in terms of accuracy and it is easy for forests which have low variety of species. The reason behind this accuracy is because architecture and density have great variation among species and within the same species. As a result allometric equation development through single species based components have significant accuracy to estimate the biomass of- a particular tree (Ketterings et al., 2001; Henry et al., 2011).

Even though, species based allometric equation has such kind of importance but some authors like Brown recommend to use general allometric equation for stratified broad forests and it is highly effective in tropical forests (Brown, 2002).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location of the Study Area

The study site, Suba-Sebeta forest, is located about 45 km far away in southwest of Capital city of Ethiopia, Addis Ababa. Geographically, it is situated between $38^0$28' and $38^0$36' East and $8^0$56' and $9^0$02' North in the West Shewa Administrative Zone of Wolemera Woreda, Central Ethiopia (Figure 1).

The study area found at altitudinal range of 2200 to 3000 m.a.s.l. The area characterized by moderate climate, traditionally known as Dega and it has a unimodal rainfall distribution. The area receives total annual rainfall ranging between 900 and 1500 mm. The mean monthly temperature is about 14.3^0c (ranging 1.6^0c -24.5^0c). The hottest temperature is from January to May and the least is during December (Demissew, 1988; Adugna et al., 2015; Yehualashet, 2017).

The soil profile in the study area consists of about 3 cm thick litter layer, about 15 cm mollic A horizon and under argic B horizon. The soil texture varies from silt clay loams in the surface soils to clay or silt clay loams in the B horizon (Eshetu, 2000).

3.1.2 Vegetation

The vegetation type is categorized under dry evergreen Afromontane forest. The forest covers 3,679 hectare of both natural and plantation forests (OFWE, 2013). Of which, 2,500 hectare is natural forest in which this study was covered and 1,179 hectare is plantation established after 1973.

Some of the dominant species of the natural forest are *Olea africana, Allophylus abyssinicus, Maytenus spp., Euphorbia ampliphylla, Podocarpus falcatus, Juniperus procera, Erica arborea, Rosa abyssinica, Olinia rochetiana, Dovyalis verrucosa, Jasminum stans, Lobelia gibberoa, Solanecio gigas and Scadoxus multiflorus (Demissew, 1988; Tamirat, 1993; Senbeta and Teketay, 2001).*

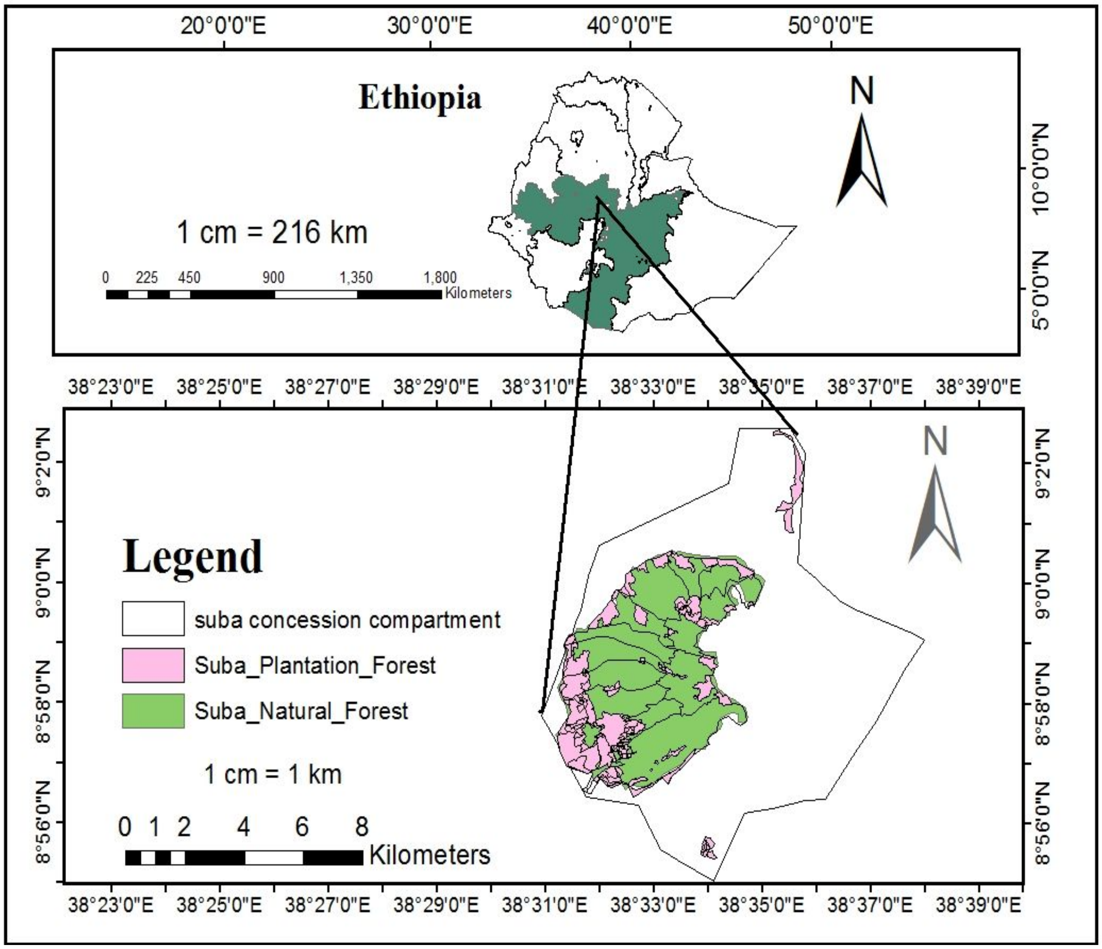

Figure 1: Geographical location of Suba_Sebeta Forest (Source,OFWE,2017)

3.2 Description of the Studied Species

3.2.1 Dovyalis verrucosa (Hochst) Warb

D.verrucosa is a species in the *Flacourtiaceae* family. Its vernacular name is Menedem, Menhetem or Fentoflas in Amharic and Akukkuu,akoko, hokoku or Likme in Afan Oromo. The life form is shrub or small tree up to 4 m tall, spiny or not; barks grey to dark brown, branchlets puberulous. Petiole 1-3 mm long, glabrous to very sparsely puberulous; blade ovate, elliptic, oblong or narrowly so, up to 7.5 x 3 cm, apex rounded to retuse; margin entire (rarely serrulate); reticulation conspicuously raised. It reproduced by seed (Edwards, 2000).

D. verrucosa is grown in dry upland *Juniperus, Olea* and *Podocarpus* forest, sometimes on degraded to steep rocky slopes with scattered shrubs on elevation range of 1700-3200 m.a.s.l. It occurs widely in Gonder, Welo, Gojjam, Shewa upland, Sidamo and Hararge. *D. verrucosa* is used as Firewood, tool handles, fodder (leaves), soil conservation, and windbreak (Edwards, 2000).

3.2.2 Ekebergia capensis Spamn

E.capensis is a species in the Meliaceae family. Its vernacular name in Amharic is Lol/Sombo and Duduna or Sombo in Afan Oromo.

The life form is an evergreen or semi-deciduous, medium-sized to large tree, 7-20 (max. 35) m tall. Its bark is grey-brown and rough with age. The leaves are compound, mostly crowded at the ends of branches on stalks to 30 cm long, leaveslets 3-6 pairs plus one, leaves blades unequal-sided. Its flowers are in loose sprays, up to 8 cm, each flower constitute small and white colored with heavily scented. Its fruits are rounded, 1 up to 2 cm long, thin-skinned and orange on long stalks, drying and splitting to set free 2-4 seeds.

E. capensis occurs in a variety of habitats including high-altitude evergreen forests, riverine forests and coastal sandveld. In Ethiopia; it is widely distributed in a variety of habitats, often used as a shady meeting place in open grassland. It occurs in Dry, Moist and Wet Weyna Dega and Dega agroclimatic zones in all regions on elevation range of 1,600–3,000 m.a.s.l.

E.capensis is propagated by seedlings. Trees are fairly fast-growing. Young trees should be protected from cattle for the first 2 years. This is a fast growing species with a growth rate of up to 1 m/year and it responds well to watering. *E. capensis* is used as Firewood, timber, poles, tool handles, medicine, fodder (leaves), bee forage, shade, ornamental, soil conservation, and windbreak (Azene et al., 1993; Azene, 2007; Orwa et al., 2009).

3.2.3 Olinia rochetiana A. Juss

O. rochetiana is a species in the *Oliniaceae* family. Its vernacular name is Beye or Tife in Amharic and Dalecho, Guna, Kedida or Nolle in Afan Oromo.

The life form is usually a small shrub or tree 4-9 m, occasionally to 20 m and having grey-light brown, smooth or finely grooved bark, but old trunks with thin yellow flakes.Its leaves are opposite, bright red when young, long oval, to 7 cm long, wider at the tip, blunt or notched, edge rolled under, base narrowed into a short grooved stalk, often pink, underside with fine net of veins. Its flowers are white fading to pink or cream, very small, in dense rounded heads to 5 cm across, shorter than the leaves. Its fruits are thinly fleshy, pink then red-brown when ripe, less than 1 cm, in heavy bunches (Azene et al., 1993).

A tree distributed in tropical Africa and in the mountains of eastern Transvaal in South Africa. In Ethiopia, it is commonly found in patches of dry evergreen forest and on riverine fringes, in montane *Juniperus*, *Podocarpus*, *Hagenia* and *Nuxia* forest in Moist and Wet Weyna Dega and Dega agroclimatic zones of Welo, Gonder, Gojam, Wolega, Shoa, Arsi, Bale, Kefa, and Sidamo on elevation range of 1,200–3,500 m.a.s.l.

O.rochetiana is propagated by seedlings and its management practice is coppice management and pollarding. It is used as firewood, timber, farm tools, walking sticks, ornamental, fencing material (Azene et al., 1993; Azene, 2007; Orwa et al., 2009).

3.3 Sampling Techniques and Design

Field data collection was carried out between October, 2017 and January, 2017. First, reconnaissance survey was conducted to collect baseline information, observe vegetation distribution, get an impression of the site condition and identify possible sampling sites.

To obtain information on the tree species and size distribution for guiding the selection of sample trees,inventory data carried out by GIZ project between September-December,2017 in the study site was used.

The GIZ project established 301 nested circular plots of radius 1 m (area 3.14m^2), 3 m (28.27 m^2) and10 m (314m^2) to sample the saplings,shrubs and tree respectively on a systematic grid over the entire area of the natural forest.The distance between transect lines and between sample plots was 300m (Figure 2).

In this study, a total of 30 plots were randomly selected to obtain a representative sample within the study area.

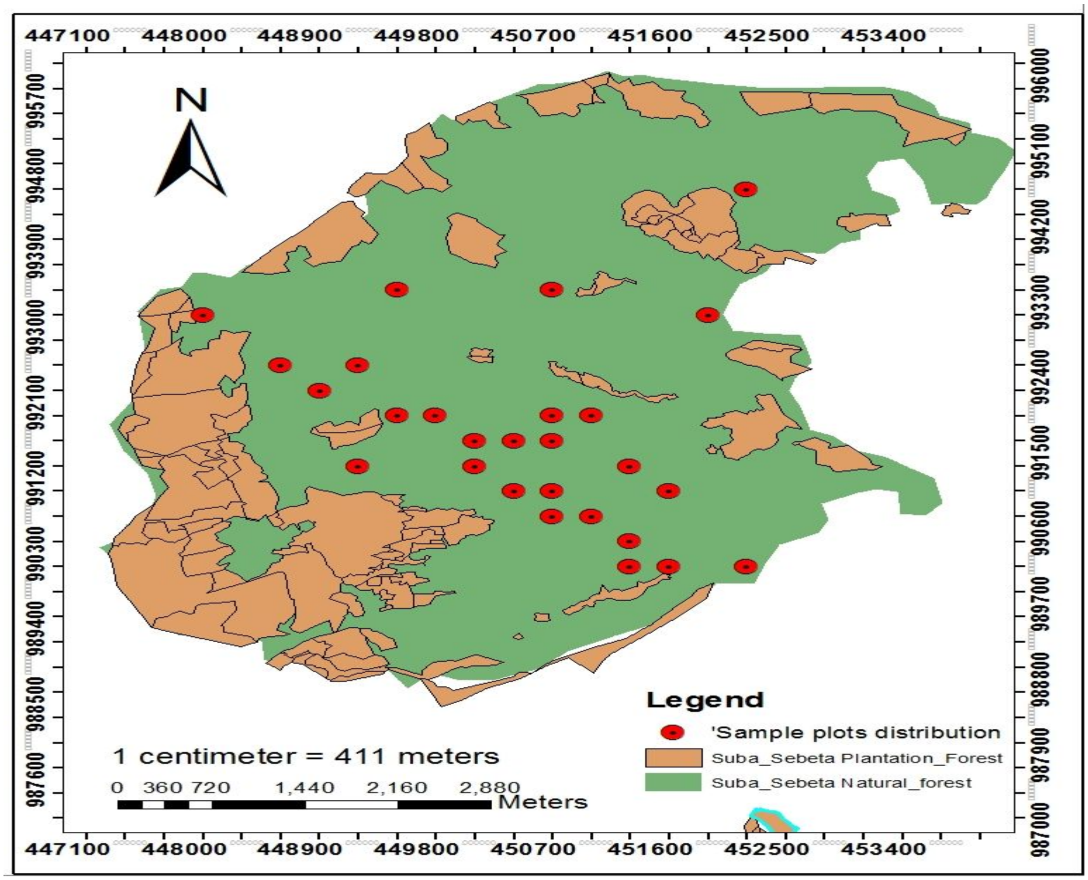

Figure 2: Sampling design for inventory plots

3.4 Data Collection Methods

3.4.1 Inventory of Woody Plant Species

All woody species whose DBH ≥ 2.5 cm were inventoried in the sample plot to take cognisance of diameter at breast height (DBH) range, species frequency to reflect the structure of the study species in the forest and subsequently to facilitate selection of sample trees. Based on inventory out comes, individuals of targeted three species categorized in to the following diameter classes (Table 1).

Table 1: Frequency of the three studied species across diameter classes (n=30)

DBH classes, cm	*D.verrucosa*	*E.capensis*	*O.rochetiana*
2.50-5.00	119	11	61
5.00-7.50	49	4	27
7.50-10.00	17	4	10
10.00-12.50	9	2	8
12.50-15.00	1	2	5
≥ 15	1		15

The total basal area for *D.verrucosa, O. rochetiana and E.capensis* were estimated to 0.50, 1.53, 0.09 m^2 ha^{-1} and stem density 224, 135, 26 stems ha^{-1}, respectively.

3.4.2 Sampling of Individual Plants

Studies shown few trees are harvested for constructing biomass tables on species basis (8-15 individual plants) (Russell, 1983; Brown et al., 1995; Deans et al., 1996; Ebuy et al., 2011). Thus, in this study a total of 12 sample plants were taken for each species, making 36 sample plants for the three selected species. Trees were selected proportionally per diameter class until completing 12 trees per species for allometric equations development. Only trees of good health (not diseased, rotten or dry) and vigour are liable for selection and measurement.

The following biometric parameters were measured for the sampled plants: diameter at stump height 30cm (DSH), diameter at breast height 1.30m (DBH), total tree height (Ht), Crown diameter (CD) (measuring 2 trends of North-South and East-West), and Crown height (CH). GPS was used for indicating the direction and point of sampling.

Table 2**:** Summary for each of the predictor and the response variables of the non-destructively (n=12) sampled trees of the three studied species

Biometric parameters	*D.verrucosa (n=12)*		*E.capensis (n=12)*		*O.rochetiana (n=12)*	
	Mean	Ranges (min-max)	Mean	Ranges (min-max)	Mean	Ranges (min-max)
DSH, cm	6.5	3.5-10.6	8.4	4.3-18.5	9.1	3.0-26.0
DBH, cm	5.2	2.5-10.0	6.4	3.0-13.6	7.8	2.5-25.4
Ht, m	4.7	3.0-6.3	6.5	2.7-13.0	7.9	3.5-16.0
CA, m^2	6.0	1.0-14.2	2.3	0.4-8.3	10.0	1.2-38.5

Tree species identification was done in the field using key informants , plant identification field guide book written by Azene (2007) and Flora of Ethiopia and Eriteria by Edwards, (2000).

3.4.3 Biomass Measurement and Harvesting Method

The trees were divided into separate architectural elements as trimmed small branch (BD $\leq$ 10cm), untrimmed small branch, untrimmed large branch and trunk for the purposes of measurement and analysis (Figure 3). Generally, three small branches per individual plant were cut down and trimmed. Trunk and large branches weights were estimated from serial measurements of height, diameter and section volume using parabolic estimation of trunk shape (Picard et. al., 2012).

It was assumed that the sections cut are considered to be cylinders and density is considered to be the same in all the compartments of the tree, fresh biomass of the trimmed small branches, measured by weighing.

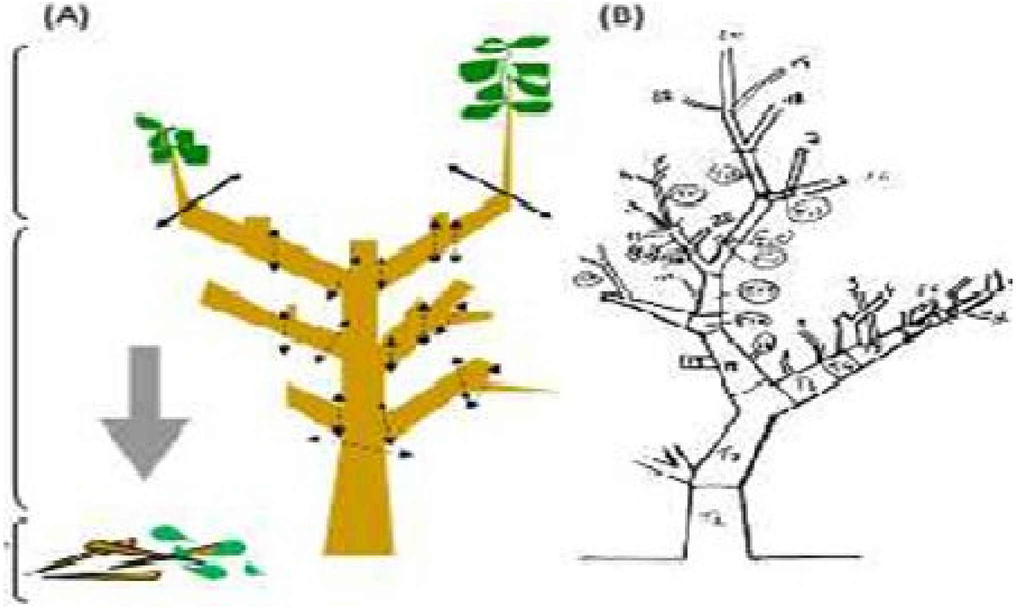

Figure 3: Separation and measurement of trimmed and untrimmed biomass (3A) and numbering of the sections and branches measured on a trimmed tree (3B).

As it was indicated in Figure 3B above, trunk was represented by (T1, T2...), large brances were indicated by numbers given in circle and small untrimmed branches were indicated by numbers without circle.

3.4.3.1 Measurement of Trimmed Fresh Biomass

The diameter at the base of each branch was determined using a diameter tape. Three small branches of basal diameter (BD) $\leq$ 10cm from each tree were trimmed from different direction (East, West, North, South) and position (base, middle and top of the crown). A total of 108 samples from each trimmed branch and leaf were harvested separately, valuing 216 samples for the 36 selected sample trees.

Leaves trimmed from the trimmed branches and determined the fresh biomass of the leaves from the trimmed branches ($B_{\text{trimmed fresh leaf}}$) and the fresh biomass of the wood from the trimmed branches ($B_{\text{trimmed fresh wood}}$) (Appendix 2, 3 and 4).

Random sample of the leaves from the trimmed branches were taken and measured for its fresh weight ($B_{\text{aliquot fresh leaf}}$) in g. At least three sub-samples of leaves from three different branches were generally required constituting the aliquot(Picard et al., 2015) (Figure 4 (C). Similarly, an aliquot of the wood at random from the trimmed branches was taken without debarking and measured for its fresh weight ($B_{\text{aliquot fresh wood}}$) in g, immediately after cutting. Then, aliquots were kept in numbered plastic bags and taken to Ethiopian Environment and Forest Research Institute (EEFRI) laboratory in Addis Ababa for fresh volume, moisture and dry weight determination. The weight of the bag was deducted from the weight of the sub-sample.

Figure 4: Tree DBH measurement (A),separation of sample leaves and branches (B), sample weight measurement (C) and oven drying subsamples (D)

The volume of aliquot fresh wood branch was measured ($V_{\text{fresh wood aliquot}}$) from the wood aliquot taken from the trimmed compartments. This volume was measured with the most commonly employed measurement of volume which is water displaced when the sample is immersed in water.

The volume of water displaced was measured using a graduated tube of 100ml (Figure 5) and the value used to determine mean wood specific density $(\bar{\rho})$. Secondly, both leaf and wood aliquots were oven dried at a temperature of 70ºC for leaves and 105ºC for wood up to net dry mass was obtained (Picard *et al*., 2012).

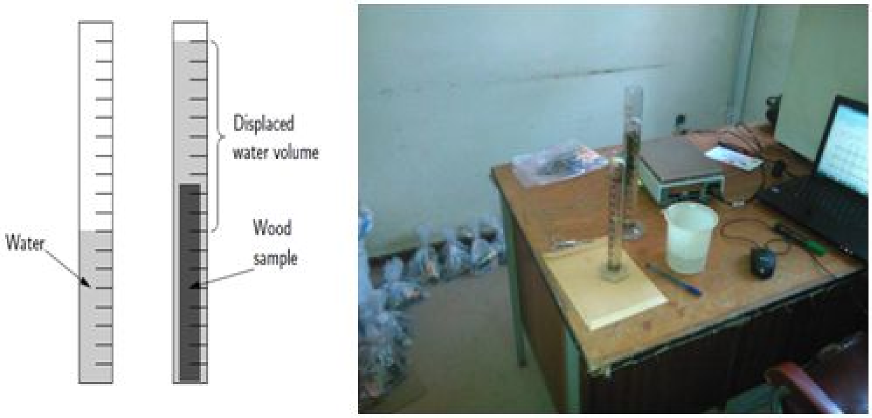

Figure 5: Measurement of sample fresh branch wood volume by water displacement.

3.4.3.2 Measurement of Untrimmed Fresh Biomass

Untrimmed biomass was measured indirectly as non-destructive. The different branches in the trimmed tree were first numbered. The small untrimmed branches are processed differently from the large branches and the trunk. For the small branches, only basal diameter was measured. The biomass of these small untrimmed branches was estimated from the relationship between their basal diameter and their mass. The biomass of the trunk and the large branches was estimated from measurements of volumes (Vi in cm^3) and mean wood specific density ($\bar{\rho}$ in g cm^{-3}). The large branches and trunk should be divided virtually into sections that were then materialized by marking the tree.

The volume Vi of each section i was obtained by measuring its diameter and its length. Section interval was fixed at 1m using graduated stick to consider diameter variations along the length of the trunk and large branches branches (Picard et al., 2012).

3.4.3.3 Calculation of Trimmed and Untrimmed Biomass

Calculating Aboveground Dry Biomass

The aboveground dry biomass of the tree (stem, branches and leaves) obtained by the sum of the trimmed dry biomass and the untrimmed dry biomass:

$$B_{\mathrm{dry}}=B_{\mathrm{trimmed\ dry}}+B_{\mathrm{untrimmed\ dry}}\cdots\cdots \text{equ.1}$$

Where, B_{dry} is total aboveground dry biomass (kg/plant), $B_{\mathrm{trimmed\ dry}}$ is trimmed dry biomass (branches plus leaves), $B_{\mathrm{untrimmed\ dry}}$ is untrimmed dry biomass.

Calculating Trimmed Fresh Biomass

From the fresh biomass $B_{\mathrm{aliquot\ fresh\ wood},i}$ of a wood aliquot and its dry biomass $B_{\mathrm{aliquot\ dry\ wood},i}$, the moisture content of the wood is calculated as follow:

$$X_{\mathrm{wood},i}=\frac{B\ \mathrm{aliquot\ dry\ wood},i}{B\ \mathrm{aliquot\ fresh\ wood},i}\cdots\cdots \text{equ.2}$$

Where $X_{\mathrm{wood},i}$ is moisture content of the wood in the sample of i.

Likewise, the moisture content of the leaves is calculated from the fresh biomass $B_{\mathrm{aliquot\ fresh\ leaf},i}$ of the leaves aliquot and its dry biomass $B_{\mathrm{aliquot\ dry\ leaf},i}$ as follow:

$$X_{leaf,i}=\frac{B\ \mathrm{aliquot\ dry\ leaf},i}{B\ \mathrm{aliquot\ fresh\ leaf},i}\cdots\cdots \text{equ.3}$$

where, $X_{\mathrm{leaf},i}$ is moisture content of the leaves in the sample of i.

Total trimmed dry biomass can then calculated:

$$B_{\mathrm{dry}}^{\mathrm{trimmed}} = B_{\mathrm{fresh\ wood}}^{\mathrm{trimmed}}\times X_{\mathrm{wood}} + B_{\mathrm{fresh\ leaf}}^{\mathrm{trimmed}}\times X_{\mathrm{leaf}}\cdots\cdots \text{equ.4}$$

Where $B_{\mathrm{trimmed\ fresh\ leaf}}$ is the fresh biomass of the leaves stripped from the trimmed branches and $B_{\mathrm{trimmed\ fresh\ wood}}$ is the fresh biomass of the wood in the trimmed branches.

Calculating Untrimmed Fresh Biomass

Two calculations are required to calculate the dry biomass of the untrimmed part (i.e. that still standing): one for the small branches (leaves and branch wood), the other for the large branches and the trunk. The untrimmed biomass is the sum of the two results:

$$B_{\text{untrimmed dry}} = B_{\text{dry branch}}^{\text{untrimmed}} + B_{\text{dry section}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equ.5}$$

Where $B_{\text{untrimmed dry}}$ is the untrimmed dry biomass of the small untrimmed, branches, trunk and large branches, $B_{\text{untrimmed dry branch}}$ is the untrimmed dry biomass of small untrimmed branches (leaves and branch wood) and where, $B_{\text{dry section}}$ is the trunk and large branches.

Each section i of the trunk and the large branches may be considered to be a cylinder of volume (Newton's formula or truncated cone volume formula).Then, the volume of each section is calculated as follows:

$$Vi = \frac{\pi}{8} Li\left(D_{1i}^{2} + D_{2i}^{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equ.6}$$

where, V_i is the volume of the section i, Li its length, and D_{1i} and D_{2i} are the diameters of the two extremities of section i.

According to FAO (Picard et.al.2012) mean wood specific density is calculated by:

$$\bar{\rho} = \frac{\text{B dry wood aliquot}}{\text{V fresh wood aliquot}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equ.7}$$

where, $\bar{\rho}$ is mean wood specific density expressed g/cm^3, $B_{\text{dry wood aliquot}}$ is dry biomass of wood aliquot in g and $V_{\text{freshwood aliquot}}$ is fresh volume of wood aliquot in cm^3.

The dry biomass of the large branches and trunk will be the product of mean wood specific density and total volume of the large branches and trunk.

$$B_{\text{dry section}} = \bar{\rho} \times \sum_{i} Vi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equ.8}$$

Where, $\sum_i Vi$ is the sum corresponds to all the sections in the large branches and the trunk.

Care is taken to use consistent measurement units. For example, if mean wood specific density $\bar{\rho}$ (see equ.7 above) is expressed in g/cm^3, then volume V_i must be expressed in cm^3, meaning that both length Li and diameters D_{1i} and D2i must also be expressed in cm. Biomass in this case is therefore expressed in g.

The dry biomass of the untrimmed small branches (leaves and branch wood) will be calculated using a model between dry biomass of trimmed branches and basal diameter, using a power regression equation:

$B_{\text{dry branch}} = (BD)^b$……………………………………………………………........equ.9

Where a and b are model parameters and BD (branch basal diameter). Using a model of this type, the dry biomass of the untrimmed branches (leaves and branch wood) is:

$B^{\text{untrimmed}}_{\text{dry branch}} = \Sigma_j \, (aBD^b{}_j)$ ……………………………...equ.10

Where the sum was all the untrimmed small branches and `Dj is the basal diameter of the branch.

Crown area (m^2) of a tree is calculated using Huy et al. (2016)

$CA = \frac{\pi * (CD)2}{4}$……………………………………………………………………..equ.11

Where, CD is average crown diameter.

3.5 Data Analysis

Data of the species of *D.verrucosa, E.capensis* and *O.rochetiana* measured in the forests were accomplished by organizing and recording on the excel data sheet. Dry aboveground biomass (AGB) of sample trees was obtained by summing up dry weight of stem wood,branches and leaves. Microsfot excel 2007 and Statistical Package R software version R 3.2.3 was employed to develop allometric equations.

3.5.1 Parameterization and Model Selection

The purpose of a regression analysis is to develop a model that can be used to predict response variable within specific species and similar ecological sites. Power equations were fitted to the measured and estimated data to characterize the relationship between the aboveground biomass (kg dry matter/plant) with either stem diameter alone (DBH or DSH) or combined with total height (Ht), crown area (CA) and mean wood specific density ($\overline{\rho}$).

In this study, crown area and wood density variables were considered for biomass equation development in order to improve the accuracy of the biomass estimate as proven by the previous authors (e.g. Huy, 2012; Huy et al., 2016) even if it required extra time and cost for field work to obtain reliable data.

The non-linear power equation was also performed. Non-linear power equations have previously been shown to yield good results for predictions of this sort (Návar, 2010; Návar-Cháidez et al., 2013). The biomass equations used for model fitting are presented in Table 3. The best one was selected based on performance statistics calculated for each equation.

Table 3: Tested biomass equations for the three studied species

Model no.	Equation
M1	$y= b1x\ (DBH)^{b2}$
M2	$y=b1x\ (DSH)^{b2}$
M3	$y=b1x\ (DBH^{2})$
M4	$y=b1x\ (DSH^{2})$
M5	$y=b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}$
M6	$y=b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}$
M7	$y=b1x\ (DBH^{2})^{b2}\ x\ (Ht)^{b3}$
M8	$y=b1x\ (DSH)^{b2}\ x\ (DBH)^{b3}$
M9	$y=b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}\ x\ (\bar{\rho})^{b4}$
M10	$y=b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$
M11	$y=b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (\bar{\rho})^{b4}$
M12	$y=b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$
M13	$y=b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}\ x\ (\bar{\rho})^{b5}$
M14	$y=b1x\ (DSH)^{b2}\ x\ (Ht)^{b3} x\ (CA)^{b4}\ x\ (\bar{\rho})^{b5}$
Chave et al., 2014	$AGB = 0.0673*(WD*DBH^{2}*Ht)^{0.976}$
Brown,1997	$AGB=exp(-1.996+2.32*ln(DBH)$

Where: Y biomass, DSH (diameter at stump height), DBH (diameter at breast height), Ht (Total height), $\bar{\rho}$ (mean wood specific density), CA (crown area), b1, b2, b3, b4 and b5 are parameters. All possible equations were parameterized for each biomass component (leaves, branches, and stem) and total aboveground biomass. Model $AGB = 0.0673*(WD * DBH^{2} * Ht)^{0.976}$ and Model $AGB = exp(-1.996+2.32 * ln (DBH)$ were used for comparision.

Assessments of best fit for biomass equations were evaluated using various goodness-of-fit statistics, namely such as the coefficient of determination (R^2),standard error of estimate (SEE), mean bias (MB), mean absolute bias (MAB), prediction residuals sum of squares (PRESS) and index of agreement (D) (Kozak and Kozak, 2003; Litton and Boone, 2008; Negash et al., 2013).

Performance measuring statistics used biomass equations are as follows:

$$MB = \frac{\sum_{i=1}^{n}(Yi-\hat{Y}i)}{n} \ldots\ldots 12$$

$$R^2 = \frac{SST-SSR}{SST} \ldots\ldots 13$$

$$SSE = \sqrt{SSR/(n-\ k)} \ldots\ldots 14$$

$$MAB = \frac{\sum_{i=1}^{n}|Yi-\hat{Y}i|}{n} \ldots\ldots 15$$

$$PRESS = \sum_{i=1}^{n} \delta i \text{ ^}2 \ldots\ldots 16$$

$$D = 1- \frac{\sum_{i=1}^{N}(Yi-\hat{Y}i)\text{^}2}{\sum_{i=1}^{N}(l\,\widehat{Yi}-\bar{Y}\,l\,)+(Yi-\bar{Y})\text{^}2} \ldots\ldots 17$$

Where SSR=$\sum_{i=1}^{n}(Yi-\ \hat{Y}i)$ ^2; SST=$\sum_{i=1}^{n}(Yi-\ \bar{Y})$; $\delta i = Yi-\ \bar{Y}i,-$i; *i=1, 2… n; n* is the number of observations, k is the number of estimated parameters, Yi the observations of the response variables, $\hat{Y}i$ is the predicted value of the *Yi*,$\bar{Y}i$ is the average of the *Yi*, δi is ith prediction error, $\hat{Y}i$,-i is the prediction of the *i*th data point by a model that did not make use of the *i*th point in the estimation of the parameters.

R^2 is the fraction of the total variation in biomass that is explained by the model. It is a statistical measure of how close the data are to the fitted regression line. $R^2 = 1$ means that all of the variation in the response variable is explained by the explanatory variable, while a value of $R^2 = 0$ means none of the variation in the response variable is explained by variation in the explanatory variable.

Index of agreement (D) to measure agreement between observed and predicted values, i.e. the degree to which the model is error free and value ranges between 0 and 1, *D*=1 implies complete agreement between estimated and observed value whereas D=0 indicates complete disagreement.

The models were ranked according to each goodness-of-fit statistic. The ranks summed and sums ranked to give an overall model performance rank.The model with the best fit was deemed to be that with the highest overall rank with respect to all of the chosen statistical parameters (Appendix 5,6 &7).

A total of 42 equations which fourteen (14) allometric equations for each species biomass components were developed and ranked based on their performance statistics for the studied species. The best equation should have the highest R^2 and D values and lowest mean bias, SEE, MAB and PRESS values.

3.6 Comparison with Previously Published Aboveground Biomass Equations

The first ranked equations for total aboveground biomass were evaluated its reliability by comparing with the following published and commonly used generic models. Total biomass estimates for individual plants derived from the allometric model developed here for the studied species were compared to existing generalized equations for tropical trees (Brown, 1997; Chave *et al.,* 2014) by plotting the models on a common axis, and by estimating biomass in each model across a range of DBHs and calculating average deviation percent difference (S%).

$S\% = 100 * \left(\sum_{i=1}^{n} \left|\frac{Yi-\widehat{Yi}}{Yi}\right| / n\right)$……………………………………………………………18

Where, Yi is the observed value, $\hat{Y}i$ is the predicted value, and n is the number of observations. S% denotes how well the model fits the actual data. The model is optimal when S% is minimum.

The generalized allometric models used to predict total aboveground biomass (kg dry weight) were:

Brown (1997): $AGB = \exp(-1.996+2.32 * \ln(DBH))$……………………………………19

Chave et al. (2014): $AGB = 0.0673 * (WD * DBH^2 * Ht)^{0.976}$……………………………20

CHAPTER FOUR

4. RESULTS and DISCUSSIONS

4.1 Results

4.1.1 Dry Matter Biomass Estimate

The mean wood specific density is 0.483 g cm^{-3} (ranged 0.405-0.550), 0.353 g cm^{-3} (0.245-0.421) and 0.434 g cm^{-3} (0.366-0.463) for *D.verrucosa*, *E.capensis* and *O.rochetiana* respectively.

The total aboveground biomass measured values was estimated 1.246, 0.304 and 3.187 tons ha^{-1} for *D.verrucosa, E.capensis* and *O.rochetiana* respectively. *O.rochetiana* tree had the highest mean total aboveground dry biomass (23.78 ± 13.00 kg tree^{-1}, ranged 2.713-160.673) followed by *E.capensis* (12.158 ± 5.14 kg tree^{-1}, ranged 0.904-59.404) and *D.verrucosa* (5.562 ± 1.15 kg tree^{-1}, ranged 1.211-14.966) (Table 3).

Among the three studied species (Table 4), the biomass proportion of stem was maximum in *Ekebergia capensis* (85%), followed by *Olinia rochetiana* (81%) and *Dovyalis verrucosa* (80%). The biomass proportion of branches was maximum in *Olinia rochetiana* (15.6%), followed by *Ekebergia capensis* (15.5%) and *Dovyalis verrucosa* (15%), while the proportion of the leaves biomass was maximum in *Dovyalis verrucosa* (5%), and followed by *Olinia rochetiana* (3.5%) and *Ekebergia capensis* (2.5%).

The contribution of stem of the total aboveground biomass fallen in the range of 67-86, 56-94, and 64-85% for *D.verrucosa, E.capensis* and *O.rochetiana respectively*. The overall result of the study showed that the biomasses of total aboveground, stems and branches tend to increase with the DBH.

The result of this study indicated that the stem plus branch biomass of *D. verrucosa, E.capensis* and *O. rochetiana* accounted for 95, 97.5, and 96.5% of total aboveground biomass.

Table 4: Summary statistics of dry matter (kg/plant) of total aboveground and biomass components of sampled plants (n=12)

Components	Mean	Standard error(SE)	Minimum	Maximum
D.verrucosa				
Leaves	0.278	0.03	0.108	0.514
Branches	0.832	0.12	0.294	1.513
Stem	4.452	1.01	0.809	12.938
Total AGB	5.562	1.15	1.211	14.966
E.capensis				
Leaves	0.300	0.05	0.117	0.750
Branches	1.522	0.40	0.278	4.956
Stem	10.336	4.79	0.502	55.650
Total AGB	12.158	5.14	0.904	59.404
O.rochetiana				
Leaves	0.823	0.25	0.141	2.610
Branches	3.699	1.68	0.407	20.859
Stem	19.257	11.13	1.745	137.204
Total AGB	23.78	13.00	2.713	160.673

4.1.2 Biomass Predictor Variables

The Spearman correlations between plant biomass and the measured biometric parameters for all studid species are shown in Table 5.

All of the biomass components of the three studied species were strongly and significantly ($p<0.05$) correlated with the predictors variables such as DSH, DBH, and Ht.

The biomass of all components of *Dovyalis verrucosa* was strongly correlated with DSH, DBH, Ht and CA predictor variables, particularly diameter at breast height (DBH). The highest correlation was with stem biomass and total aboveground biomass ($r=0.97$) followed by leaves ($r=0.94$) and branches ($r=0.83$) biomass.

For *Ekebergia capensis* the biomass of all components of was strongly ($p<0.05$) correlated with stem diameter (DSH &DBH) and total height (H), particularly diameter at stump height (DSH). The highest correlation was with total aboveground biomass (R= 0.97) and stem biomass (r=0.96) followed by leaves (r= 0.85) and branches (r= 0.80) biomass. Wood specific density was significantly correlated with stem biomass and total aboveground biomass components both correlates (r= 0.61).

Similarly, in *O.rochetiana* all biomass components were correlated with DSH, DBH, and Ht biometric parameters. The biomass components was strongly ($p<0.05$) correlated with stem diameter (DSH & DBH). The highest correlation was DBH with stem (r=0.96) and total aboveground (r=0.95) biomass.

In this study the predictor variables such as mean wood specific density and crown area were not significantly correlated with all biomass components with few exceptions in all the three studied species.

Table 5: Spearman correlations between biomass components and species biometric parameters (n=12 for each studied species)

Components	DSH(cm)	DBH(cm)	Ht(m)	$\bar{\rho}$ (g/cm^3)	CD(m)	CH(m)	CA(m^2)
D.verrucosa							
leaves	0.94*	0.94*	0.83*	-0.43^{ns}	0.94*	0.73*	0.94*
Branches	0.90*	0.83*	0.70*	-0.34^{ns}	0.94*	0.66*	0.94*
Stem	0.95*	0.97*	0.67*	-0.42^{ns}	0.92*	0.52^{ns}	0.91*
Total AGB	0.95*	0.97*	0.69*	-0.41^{ns}	0.93*	0.55^{ns}	0.90*
E.capensis							
leaves	0.85*	0.85*	0.77*	0.50^{ns}	0.35^{ns}	0.42^{ns}	0.36^{ns}
Branches	0.80*	0.85*	0.69*	0.46^{ns}	0.27^{ns}	0.26^{ns}	0.28^{ns}
Stem	0.96*	0.93*	0.90*	0.61*	-0.05^{ns}	0.42^{ns}	-0.003^{ns}
Total AGB	0.97*	0.94*	0.90*	0.61*	-0.02^{ns}	0.51^{ns}	0.26^{ns}
O.rochetiana							
leaves	0.94*	0.94*	0.95*	0.35^{ns}	0.83*	0.85*	0.76*
Branches	0.97*	0.92*	0.89*	0.33^{ns}	0.65*	0.87*	0.59*
Stem	0.93*	0.95*	0.86*	0.32^{ns}	0.56*	0.85*	0.50^{ns}
Total AGB	0.94*	0.96*	0.87*	0.33^{ns}	0.58*	0.86*	0.52^{ns}

Note: (ns) not significant at 95%, DSH (diameter at stump height), DBH (diameter at breast height), Ht (Total plant height), $\bar{\rho}$ (mean wood specific density), CD (crown diameter), CH (crown height), CA (crown area),(*) p<0.05 indicates significant association between pairs biomass components and predictors.

4.1.3 Allometric Biomass Equations

The power equation M8 fitted the AGB data best and was thus most capable of explaining the relationship between AGB and the predictor variables (DSH&DBH) for *Dovyalis verrucosa* and *Ekebergia capensis* and M13 for *Olinia rochetiana* (DBH,Ht,CA, $\bar{\rho}$).

Power equations that combined DSH and DBH yielded the highest coefficients of determination and index of agreement for *D.verrucosa and E.capensis* species, especially for total AGB and Stem biomass (R^2= 0.977-0.995, D=0.999).

More than 97.7, 99, and 99% of the variance of the total aboveground biomass was explained for *D.verrucosa*, *E.capensis* and *O.rochetiana* respectively by the first ranked equations. For branches and leaf biomasses the three selected fitted models best explained more than 85.9 % and 73.4 % of the variation in biomasses for the studied species (Table 6, 7 and 8).

The result showed that, for *D.verrucosa* the equation M8 (for total aboveground) and, M13 and M10 for branches and leaves biomass was ranked best overall, respectively. The equation M8 (R^2 = 0.977, P<0.000) that 97.7% of variance of the output variable which is total aboveground biomass (AGB) is explained by the variance of DSH and DBH the input variable and the rest of 2.3% variation of the AGB is explained by other factors. The model statistics were highly significant, with a p-value of $2.16\text{x}10^{-06}$ which is very much below p< 0.05.

M8 also underestimated the aboveground biomass by 0.7% and had the lowest PRESS and Bias. The equation M8 explained 98.4% of the variance in plant stems biomass (Table 6).

For *E.capensis* the equation M8 ($R^2 = 0.990$, $P<0.000$) explained 99% of the variance for stem and total aboveground biomass. The equations M10 and M14 explained 94.7 and 92.3 % of the variance in plant branches and leaves biomasses, respectively (Table 7).

For *Olinia rochetiana A. Juss* the equation M13 ($R^2 = 0.990$, $P<0.000$) explained 99% of the variance for stem, branches and total aboveground biomasses. The equation M14 explained 97% of the variance in leaves biomass. Similarly, the overall results show that the combination of DBH, Ht, CA and $\bar{\rho}$ (M13), are best predictors for the branches, stem and total aboveground biomass of *O.rochetiana* (Table 8).

The relationship between total aboveground biomass of the measured versus the predicted biomass components and their corresponding residual plots for *D. verrucosa, E. capensis* and *O.rochetiana* are presented in Figure 6. The result showed that the first ranked selected models have a predicted ability of 97.6, 99.7 and 99.9 % of total aboveground biomass for *D.verrucosa, E.capensis and O.rochetiana* respectively.

Table 6: Selected equations and goodness-of-fit performance statistics for estimating biomass(kg dry matter/plant) of *Dovyalis verrucosa*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	MB	MAB	D	PRESS		
Leaves(Y)														
M10	$Y = b1x(DBH)^{b2}x(Ht)^{b3}x(CA)^{b4}$	0.045**	0.238	0.586*	0.308*		0.960	0.023	0.000	0.018	0.999	0.050	18	1
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.066**	0.171	0.756**	0.352**	0.843"	0.978	0.017	0.000	0.011	0.999	0.490	19	2
M14	$Y= b1x\ (DSH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}x\ (\bar{\rho})^{b5}$	0.059*	0.180	0.850**	0.350*	0.968*	0.975	0.019	0.000	0.014	0.999	0.400	21	3
Branches(y)														
M12	$Y = b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$	0.417	-0.608	0.257	0.841*		0.900	0.128	0.003	0.098	0.998	0.680	27	3
M13	$Y= b1x(\ DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.488"	-0.410	0.692	0.782***	1.636*	0.952	0.089	0.003	0.067	0.999	1.000	17	1
M14	$Y= b1x\ (DSH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}x\ (\bar{\rho})^{b5}$	0.647	-0.283	0.387	0.728*	1.433	0.934	0.104	-0.001	0.085	0.998	1.150	21	2
Stem(y)														
M8	$Y = b1x\ (DSH)^{b2}x(DBH)^{b3}$	0.092*	1.136**	0.986**			0.984	0.446	-0.006	0.334	0.999	0.450	13	1
M10	$Y = b1x\ (DBH)^{b2}x(Ht)^{b3}x(CA)^{b4}$	0.242**	0.957***	0.153	0.561***		0.993	0.302	0.032	0.236	0.999	2.100	25	3
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.327*	0.929***	0.221	0.566***	0.491	0.995	0.259	0.016	0.186	0.999	3.940	19	2
Total AGB(Y)														
M8	$Y = b1x\ (DSH)^{b2}x(DBH)^{b3}$	0.155*	1.164**	0.788*			0.977	0.604	-0.007	0.455	0.999	0.600	17	1
M11	$Y = b1x\ (DSH)^{b2}x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.159"	2.137***	0.311	1.413*		0.977	0.600	-0.010	0.421	0.999	10.760	29	3
M13	$Y = b1x(DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.621**	0.704***	0.304	0.582***	0.720*	0.995	0.287	0.017	0.199	0.999	4.240	18	2

Table 7: Selected equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of *Ekebergia capensis*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	MB	MAB	D	PRESS		
Leaves(Y)														
M8	$Y = b1x\ (DSH)^{b2}x(DBH)^{b3}$	0.040"	0.528	0.479			0.734	0.095	0.000	0.075	0.999	0.100	26	3
M12	$Y = b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$	0.023*	1.624**	-0.566	0.244**		0.923	0.052	0.003	0.037	0.999	0.400	24	2
M14	$Y= b1x\ (DSH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}x\ (\bar{\rho})^{b5}$	0.020	1.644**	-0.567	0.242**	-0.099	0.923	0.052	0.003	0.038	0.997	0.050	22	1
Branches(Y)														
M10	$Y = b1x\ (DBH)^{b2}x(Ht)^{b3}x(CA)^{b4}$	0.075"	3.145***	-1.693*	0.227**		0.947	0.328	0.044	0.244	0.999	2.440	23	1
M12	$Y = b1x\ (DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$	0.039	2.974*	-1.592	0.313**		0.859	0.527	0.024	0.329	0.997	2.500	30	3
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\ \bar{\rho})^{b5}$	0.111	3.112**	-1.718*	0.233**	0.274	0.948	0.326	0.043	0.243	0.998	12.700	26	2
Stem(Y)														
M7	$Y = b1x\ (DBH^2)^{b2}\ x(Ht)^{b3}$	0.011***	1.180***	0.918***			0.994	0.719	0.145	0.583	0.999	0.720	25	3
M8	$Y = b1x\ (DSH)^{b2}x(DBH)^{b3}$	0.013***	1.717***	1.291**			0.990	0.550	0.056	0.445	0.999	0.550	12	1
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\ \bar{\rho})^{b5}$	0.176	2.230***	0.682*	0.046"	2.064	0.990	0.500	0.200	0.406	0.999	4.000	24	2
Total AGB(Y)														
M7	$Y = b1x\ (DBH^2)^{b2}\ x(Ht)^{b3}$	0.028**	1.251***	0.442"			0.990	1.043	0.259	0.855	0.999	1.040	23	2
M8	$Y = b1x\ (DSH)^{b2}x(DBH)^{b3}$	0.030***	0.953*	1.840***			0.990	0.895	0.168	0.743	0.999	0.900	13	1
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\ \bar{\rho})^{b5}$	0.172	2.375***	0.338	0.040	1.390	0.990	0.852	0.321	0.634	0.999	4.870	23	2

Table 8: Selected equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of *Olinia rochetiana*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	MB	MAB	D	PRESS		
Leaves(Y)														
M10	$Y = b1x(DBH)^{b2}x(Ht)^{b3}x(CA)^{b4}$	0.012	-0.219	1.672**	0.497**		0.964	0.163	-0.006	0.122	0.999	2.020	27	3
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.209	-0.317	1.420**	0.653*	3.049	0.972	0.143	-0.003	0.098	0.999	0.970	15	2
M14	$Y= b1x\ (DSH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}x\ (\bar{\rho})^{b5}$	0.242	-0.341	1.399*	0.657*	3.058	0.970	0.147	-0.002	0.104	0.999	0.150	9	1
Branches(Y)														
M5	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}$	0.036**	1.306***	0.775**			0.990	0.309	-0.021	0.231	0.999	0.310	20	2
M7	$Y = b1x\ (DBH^2)^{b2}\ x(Ht)^{b3}$	0.036**	0.653***	0.775***			0.990	0.309	-0.021	0.231	0.999	0.310	20	2
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.100	1.229***	0.723*	0.103	1.230	0.990	0.294	0.005	0.191	0.999	3.420	15	1
Stem(Y)														
M5	$Y = b1x\ (DBH)^{b2}x\ (Ht)^{b3}$	0.022***	1.470***	1.435***			0.990	0.932	0.185	0.654	0.999	0.930	19	2
M7	$Y = b1x\ (DBH^2)^{b2}\ x(Ht)^{b3}$	0.022***	0.735***	1.435***			0.990	0.932	0.185	0.654	0.999	0.930	19	2
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.171	1.489***	1.166***	0.034	1.890	0.990	0.735	0.091	0.509	0.999	10.160	16	1
Total AGB(Y)														
M5	$Y = b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}$	0.047***	1.411***	1.292***			0.990	1.117	0.168	0.828	0.999	1.120	21	3
M9	$Y = b1x\ (DBH)^{b2}\ x\ (Ht)^{b3}\ x\ (\bar{\rho})^{b4}$	0.167	1.440***	1.109***	1.112		0.990	0.944	0.045	0.635	0..999	16.45	20	2
M13	$Y= b1x\ (DBH)^{b2}x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.242	1.418***	1.085***	0.036	1.562	0.990	0.934	0.096	0.629	0.999	11.54	18	1

Note: SEE, Bias, MAB are in kg per plant, n=12, Ydenote biomass in kg,ns denote non significant, DSH (diameter at stamp height), DBH (diameter at breast height), Ht (Total plant height), $\bar{\rho}$ (mean wood density), CA (crown area), Parameters b1, b2, b3, b4 and b5 are the model's fitted parameters, ***p<0.001,**p<0.01,*p<0.05,"P<0.1.

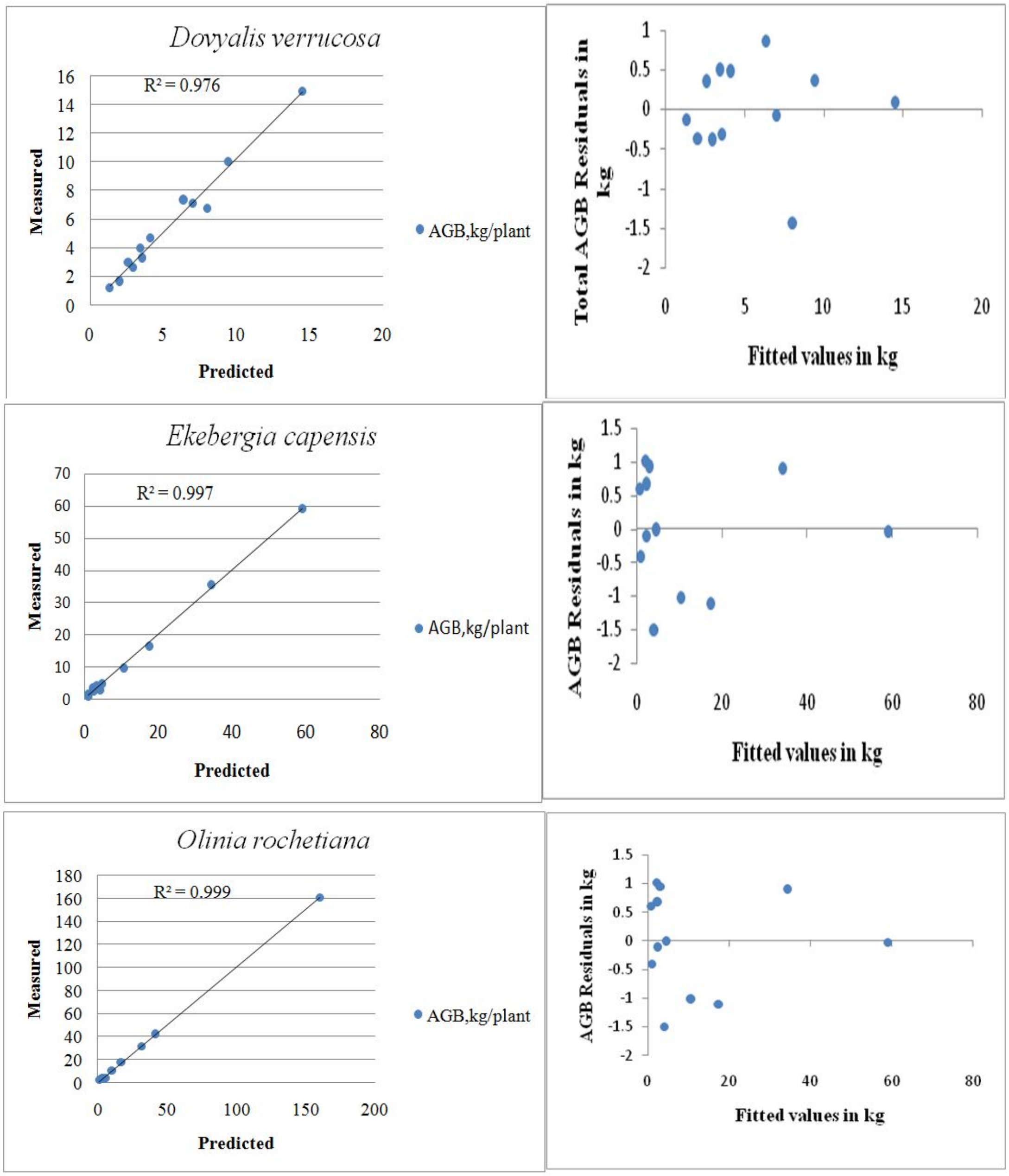

Figure 6: Plots of total aboveground biomass component models:measured versus predicted(left column)and residuals versus Fitted (right column). Equations used for Dovyalis *verrucosa* M8 *(AGB = 0.155 x (DSH)* $^{1.164}$ *x (DBH)* $^{0.778}$), *Ekebergia capensis* M8 (*AGB= 0.030 x (DSH)* $^{0.953x}$ *(DBH)* $^{1.840}$) and *Olinia rochetiana* M13 *AGB= 0.242 x (DBH)* $^{1.418\,x}$ *(Ht)* $^{1.085}$ *x (CA)* $^{0.036}$ *x* $(\overline{\rho})^{1.562}$).

4.1.4 Comparison with Previously Published Biomass Allometric Equations

The total aboveground biomass of each sampled tree (kg/plant) predicted using the best performing site - and species - specific equations (M8 &M13) developed in this study and the most frequently used Tropical dry evergreen general equations developed by Brown (1997) and Chave *et al.* (2014) are presented in Figure 10a, b & c below.

The result showed that Brown (1997) model on averge overestimated the total aboveground biomass per plant from species specific model by 30, 16 and 29 % for *D.verrucosa, E.capensis* and *O.rochetiana* respectively. On the other side, the Chave et al. (2014) model on averge underestimated the total aboveground biomass per plant from species specific model by 17 % and 10 % for *D.verrucosa and E.capensis* respectively and overestimated by 28 % for *O.rochetiana.*

The average deviation (S %) of total aboveground biomass value resulted using the best fitted model from measured value was 11%, 18% and 19% for *D.verrucosa, E.capensis and O.rochetiana* respectively. The overall result shown that the average deviation of the predicted value from the observed value of the three studied species ranged 11-19%, 26-30% and 34-43% by species specific, Chave et al. (2014) and Brown (1997) models respectively.

This indicate that site- and species- specific model has less deviation values than general equations, which means species specific fitted model was preferable for biomass and carbon estimation assessement than the general equations.

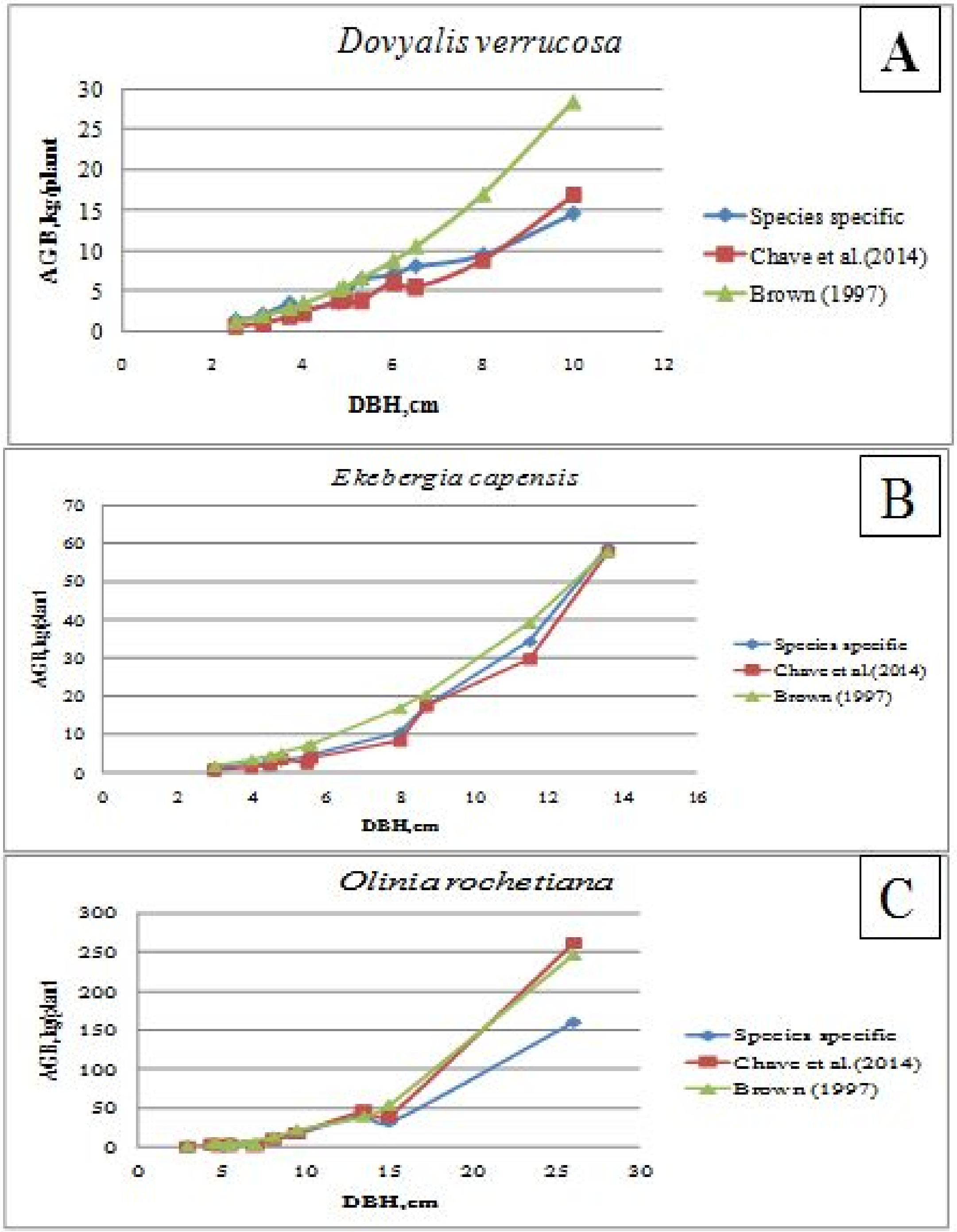

Figure 7: Allometric equations comparison for *Dovyalis verrucosa (A), Ekebergia capensis (B) and Olinia rochetiana* (C) total AGB per plant

4.2 Discussion

4.2.1 Biomass of the Selected Species

There have been very few studies dealing with the biomass of native tree species in Ethiopia.Variability of biomass could be explained by several factors such as Climate, topography, soil fertility, water supply, wood density, distribution of tree species, tree functional types and forest disturbances (Fearnside, 1997; Sicard et al., 2006; Luizão et al., 2004).

For a determined tree species, tree mass is influenced by the size of the tree, its architecture, form, health (e.g. hollow trees) (Fearnside, 1997), social status and variation of the wood density (Patino et al., 2009).

In this study, the proportion of dry mass of the stem wood, which dominated the total aboveground biomass of the tree, was 80%, 85% and 81% for D.verrucosa, *E.capensis* and *O.rochetiana* respectively. This indicates that the stem biomass compartment accumulates more biomass than the branches and foliage in all three studied species. This result was comparable to previous study (Mate et al. (2014) (~46-77%) for three tropical forest species but it was slightly higher than previous studies found by Tesfaye et al. (2016) in Chilimo Gajii forest (~60-70%) for five dry afromontane forest species and Henry et al. (2010) (~70%) for 16 tropical rainforest species in Africa from total aboveground biomass.

The dry biomass proportion of branches in the present study was lower than the proportion reported by the previous studies (≥28%) (Tesfaye et al., 2016; Mate et al., 2014; Henry et al., 2010).

Such variations appeared due to branches are varying greatly due to morphological characteristics of each species.And also branches and foliage, which account for a significant portion, appear apparently different because of their diverse morphological features on different site conditions and terrain (e.g. Chave et al., 2004; Henry et al., 2010).

4.2.2 Biomass Predictor Variables

In this study diameter at stump height (DSH) and diameter at breast height (DBH) were found to be better predictors of the total aboveground biomass. Similarly, previous studies reported for DSH (Negash et al., 2013), for DBH (Chave et al.,2005; Woldeyohanes et al., 2010; Henry et al., 2011; Hung et al., 2012; Negash, et al., 2013; Chave et al., 2014; Tesfaye et al., 2016) were the better predictor of the aboveground biomass.

The present study also showed that total height (Ht) variable was found to be better predictor of total aboveground biomass. This was similar to the previous study reported by Befikadu Nemomsa (2014) but different from other authors (e.g. Negash et al., 2013; Tesfaye et al., 2016).

The present study also revealed that the crown area and mean wood density variables were not significantly correlated to the total aboveground biomass with few exceptions. This result was similar to Tesfaye et al. (2016) for crown variable.

In contrary,other previous studies reported that crown area (Hung et al., 2012; Goodman et al., 2014) and wood density (Chave et al., 2005; Henry et al., 2011; Hung et al., 2012; Chave et al., 2014) were better correlated to total aboveground biomass components. WD is different among species due to forest and tree history, topography, soil fertility, the position of the trees in the landscape and the position on the tree where the samples were taken (Whitmore, 1998; Suzuki, 1999; De Castro et al., 1993).

Further studies will be needed to identify driving factors that influence correlation between crown area and wood density variables with aboveground components in either different or similar species types with similar environmental factors.

4.2.3 Aboveground Biomass Allometric Equations

Best fitted equations such as M5, M7 and M8 which use two predictor variables (DSH & DBH or DSH/DBH &Ht) and M9, M11 and M13 which use more than two variables explained more of the variation in aboveground biomass than did equations M1, M2, M3 and M4 which use use single predictor variable (DSH , DBH , DBH^2 or DSH^2).

The findings in this study agreed with the previous studies (eg. Chave et al., 2005; Basuki et al., 2009; Hung et al., 2012; Chave et al., 2014) as more variables are incorporated in equation development it has increased equation performance but needs extra time and cost for collection of reliable data.

Many authors reported the use of equations with single predictor variable increases efficiency particularly in the case of diameter measurements , accuracy through reducing measurement uncertainity and data collection costs (Chave et al., 2005; Negash et al., 2013; Tesfaye et al., 2016). According to Djomo et al. (2016) for tropical Dry forests, the best model with only dbh gave the best estimator of total wood biomass.

In contrary, the result of this study showed that using the combination of two or more than two variables gave the best estimator of total aboveground biomass.

So, the combination of both stems DSH plus DBH was the best predictor of total aboveground biomass for *Dovyalis verrucosa* and *Ekebergia capensis* and *DBH plus Ht, CA and* $\bar{\rho}$ for *Olinia rochetiana*.

The equations in this study explained between 94.1 and 99.6 % of the variation in total aboveground biomass for all three studied species (Appendix 5, 6 & 7). The findings of the present study was similar to those reported by Huy et al. (2016) and Huy (2012) for estimation of forest above-ground biomass in Viet Nam, Djomo et al. (2016) for estimation of biomass in African tropical forests, Tesfaye et al. (2016) for aboveground biomass estimation of five native tree species in dry tropical afro-montane forest of Ethiopia and Kebede and Soromessa (2018) for aboveground biomass estimation of *Olea europaea L.* subsp. cuspidata in Mana Angetu Forest.

The equations were explained between 94.2- 99.5 %, 57.6- 99.2% and 66.5-97.8% for stem branches and leaves biomasses respectively. The lower prediction potential of the branch and foliage biomass models over the stem model was confirmed in other studies (e.g., Návar, 2009; Ruiz-Peinado et al., 2011; Negash et al., 2013; Tesfaye et al., 2016).

The equations presented are suitable for trees with DBH values ranged between 2.50-12.50 cm, 2.50-15.00 cm and 2.50-26.00 cm for *Dovyalis verrucosa, Ekebergia* capensis and *Olinia rochetiana* respectively.

4.2.4 Comparision with Previously Published Biomass Allometric Equations

This study showed that the total aboveground biomass estimated based on Brown (1997) model overestimated the aboveground of the three studied species by 16-30% while Chave et al. (2014) model underestimated between 10-17% in *D.verrucosa* and *E.capensis* than species specific equation.

Previous studies conducted by Eyosias and Teshome (2014) in Wof-washa forest, Abiy and Teshome (2015) in Menagesha AmbaMariyam forest, and Kebede and Soromessa (2018) in Bale Mena Angetu forest have also reported similarly that, comparison of results obtained from the non-destructive means of biomass estimation with the generalized equations yield higher total amount of biomass than the value estimated by species specific equation.

The disparity in the amount of biomass between the general and species specific equation is mainly due to the fact that general allometric models are developed for a variety of species without considering climate, density, geographical location, soil type and other factors relevant to AGB (Van Breugel, 2011). On the other hand, the variation in biomass and carbon stock estimates of forests can be due to the allometric models selected to calculate the biomass and/or carbon stocks.

In this study,the average deviation of the total aboveground biomass of the three studied species estimated by Brown (1997) and Chave et al. (2014) from measured values resulted 34-43% and 26-30 % respectively.This result was falled in the range of (14-46%) investigated by Tesfaye et al. (2016).

Similarly, Tesfaye et al. (2016) indicated that the generalized allometric models by Brown (1997) and Chave et al. (2014) and species specific equations showed average deviation of 25-45%, 14-46% and 13-29% for AGB predictions of five tree species in Ethiopia.

The species specific fitted models were evaluated and resulted an average deviation (S %) of 11-19 % from the measured biomass values. Hence, it is generally agreed that site - and species - specific allometric models are ideal to estimate both biomass and carbon stocks of forests.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

In this study, the power equation Model-8 fitted the total AGB data best and was thus most capable of explaining the relationship between AGB and the predictor variables (DSH&DBH) for *Dovyalis verrucosa* and *Ekebergia capensis* and Model-13 for *Olinia rochetiana* (DBH plus Ht,CA, $\bar{\rho}$).

The biomass proportion of stem was maximum in *Ekebergia capensis* (85%), followed by *Olinia rochetiana* (81%) and *Dovyalis verrucosa* (80%). The biomass proportion of branches was maximum in *Olinia rochetiana* (15.6%), followed by *Ekebergia capensis* (15.5%) and *Dovyalis verrucosa* (15%), while the proportion of the leaves biomass was maximum in *Dovyalis verrucosa* (5%), and followed by *Olinia rochetiana* (3.5%) and *Ekebergia capensis* (2.5%). This indicates that the stem biomass compartment accumulates more biomass than the branches and foliage fractions in all three studied species.

Diameter at stump height (DSH), diameter at breast height (DBH) and total height (Ht) were found to be better predictors of the total aboveground biomass.The developed models were representing trees of DBH range where the equation of the species resulted from the forest inventory. The allometric models in this study will help to accurately estimate aboveground biomass of the three studied species in the studied forest and beyond for similar agroecolgies and forest types.

The application of generalized models for estimating aboveground biomass produced biased results for the specific species studied. Given the great diversity of species and variability within species characterizing tropical forests, the development of species-specific models is suggested to improve biomass estimation accuracy and reduce uncertainty. And also, it better ensure accurate reporting of forest reference level for REDD+ schemes and carbon financing.

In conclusion, this study has produced useful allometric equations that allow prediction of biomass of total aboveground, stem wood, branches and leaves for three studied *native woody* species in dry Afromontane Suba-Sebeta forest and also for similar forest types in Ethiopia.

5.2 Recommendation

Recently there has been a considerable interest in using site and species specific allometric equations for estimating biomass and carbon stocks in the Ethiopia. Based on the issues discussed in this paper, the following recommendations have been made

1) The method selected by this study is environmentally friendly but it is recommended to harvest a few trees and obtain allometric equation to compare the amount of biomass obtained from direct (destructive) and indirect (non-destructive) measurement and to test validity of existing allometric equations.
2) As Ethiopia has diverse tree species, it is recommended to develop comprehensive country site – and species- specific allometric equations for all woody species which are abundant in their distribution and important for economic and environmental purpose for better assessment of biomass and carbon stock to meet national and international reporting requirements for greenhouse gas inventories.

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APPENDICES

Appendix 1: Field collection data format of tree species

Tree number	DSH(cm)	DBH(cm)	Total height(m)	Crown width(m)			Crown height(m)	Diameter of main Trunk(cm) -Length of the trunk is 1m		Diameter of big branches(cm) in 1m interval		Basal diameter of untrimmed small branches (cm)	Coordinate UTM zone 37N,WGS84	
				W1(EW)	W2(NS)	Average Width		Dbot(cm)	Dtop(cm)	Dbot(cm)	Dtop(cm)		Northing (X)	Easting (Y)

Appendix 2: Summary of the trimmed fresh and dry samples of *Dovyalis verrucosa*

Tree No.	Basal diameter(cm)	Fresh wood weight (g)	Fresh wood aliquot (g)	Volume of the aliquot (cm^3)	Dry wood aliquot (g)	x wood moisture (%)	Dry wood weight (g)	Fresh leaves weight (g)	Fresh leaves aliquot (g)	Dry leaves alqiuot(g)	x leaves moisture (%)	Dry leaves weight (g)	Mean wood density (gcm^{-3})
1	2	3	4	5	6	7	8=3*7	9	10	11	12	13=9*12	15=6/5
1	2.90	203.10	73.60	75.00	36.20	0.49	99.84	99.10	32.80	9.40	0.29	28.46	0.482
2	2.90	156.40	67.50	67.00	32.80	0.48	75.29	145.40	39.00	11.80	0.30	43.98	0.486
3	3.90	252.70	58.50	70.00	27.60	0.47	119.66	180.30	30.60	9.40	0.31	55.95	0.405
4	4.00	264.90	55.60	57.50	26.50	0.48	125.84	241.90	30.40	7.40	0.24	58.86	0.459
5	4.30	247.30	81.90	84.00	40.00	0.49	120.58	153.30	31.20	9.00	0.29	43.89	0.475
6	4.10	158.70	50.20	52.00	25.80	0.51	81.35	202.00	19.60	4.50	0.23	46.02	0.492
7	4.40	267.60	34.70	37.50	16.40	0.47	126.97	164.50	15.60	3.80	0.24	40.29	0.439
8	3.20	142.50	45.20	47.00	23.10	0.51	72.86	132.10	24.60	7.40	0.30	39.71	0.491
9	3.20	260.80	62.40	60.00	32.70	0.53	137.21	170.10	33.40	9.20	0.27	46.66	0.546
10	3.40	223.10	51.50	53.00	25.90	0.50	112.20	98.60	18.40	5.30	0.28	27.78	0.491
11	3.10	177.20	56.30	58.50	28.10	0.50	88.48	96.50	14.60	4.60	0.31	30.07	0.481
12	3.60	243.60	88.30	82.00	45.10	0.51	124.53	137.00	21.20	6.20	0.29	40.27	0.550

Appendix 3: Summary of the trimmed fresh and dry samples of *Ekebergia capensis Spamn*

Tree No.	Basal diameter (cm)	Fresh wood weight (g)	Fresh wood aliquot (g)	Volume of the aliquot (cm^3)	Dry wood aliquot (g)	x wood moisture (%)	Dry wood weight(g)	Fresh leaves weight (g)	Fresh leaves aliquot (g)	Dry leaves aliquot (g)	x leaves moisture (%)	Dry leaves weight (g)	Mean wood density (gcm^{-3})
1	2	3	4	5	6	7	8=3*7	9	10	11	12	13=9*12	15=6/5
1	10.00	2059.70	106.00	103.50	44.70	0.41	850.06	1105.00	29.00	3.80	0.13	142.32	0.421
2	6.00	1049.80	47.40	47.00	17.60	0.36	376.09	445.00	29.30	4.40	0.15	66.95	0.360
3	7.50	1368.40	91.10	91.00	14.20	0.39	528.42	817.50	28.50	4.40	0.14	113.25	0.386
4	5.70	572.90	48.30	49.00	19.00	0.39	221.32	479.70	42.70	7.40	0.17	83.80	0.382
5	6.80	1164.10	56.90	56.00	17.80	0.32	368.37	696.18	35.30	5.20	0.15	101.52	0.315
6	5.80	743.70	64.30	64.00	22.70	0.33	244.96	600.30	28.90	4.30	0.14	86.44	0.330
7	6.20	775.30	88.10	83.50	31.50	0.36	276.95	350.50	55.70	11.10	0.20	69.47	0.378
8	7.70	1218.10	86.60	84.00	32.80	0.38	463.21	567.80	45.20	9.20	0.20	115.86	0.392
9	4.00	372.40	68.20	128.50	22.00	0.31	116.80	216.90	50.00	8.60	0.17	36.38	0.245
10	4.00	500.20	48.50	47.50	17.90	0.37	182.94	281.70	62.80	15.30	0.24	68.56	0.372
11	4.50	556.10	69.10	69.00	24.00	0.34	191.84	208.80	44.90	8.00	0.18	37.32	0.346
12	4.20	461.70	42.20	49.00	15.20	0.36	165.70	192.70	34.50	6.50	0.19	36.46	0.308

Appendix 4: Summary of the trimmed fresh and dry samples of *Olinia rochetiana A. Juss*

Tree No.	Basal diameter (cm)	Fresh wood weight (g)	Fresh wood alqiuot(g)	Volume of the aliquot (cm^3)	Dry wood alqiuot(g)	x wood moisture (%)	Dry wood weight (g)	Fresh leaves weight (g)	Fresh leaves aliquot(g)	Dry leaves alqiuot (g)	x leaves moisture (%)	Dry leaves weight (g)	Mean wood density (gcm^{-3})
1	2	3	4	5	6	7	8=3*7	9	10	11	12	13=9*12	15=6/5
1	4.60	714.90	39.10	39.20	17.70	0.45	323.31	544.90	27.30	5.20	0.19	102.30	0.451
2	3.40	338.70	31.70	34.50	12.80	0.40	135.24	199.10	28.20	5.30	0.18	36.56	0.366
3	3.50	361.70	43.10	46.00	19.60	0.44	159.63	162.30	24.80	4.90	0.20	31.65	0.410
4	3.30	371.40	29.60	30.10	14.00	0.47	174.54	143.60	16.60	4.60	0.28	39.77	0.463
5	5.50	993.50	63.50	65.00	29.40	0.46	461.33	558.70	42.30	10.40	0.25	137.20	0.453
6	5.10	838.20	43.60	45.00	18.70	0.43	359.72	546.90	37.30	10.90	0.29	158.79	0.417
7	3.50	328.70	42.70	45.00	19.80	0.46	152.43	291.10	35.30	9.40	0.27	77.34	0.440
8	3.00	215.10	36.80	38.50	17.10	0.46	98.51	119.30	19.20	4.80	0.25	29.62	0.436
9	3.00	194.20	37.90	40.80	16.60	0.44	84.84	166.50	18.40	3.90	0.21	35.20	0.407
10	3.40	385.00	57.20	57.90	26.50	0.46	177.55	226.20	32.90	9.40	0.28	64.09	0.454
11	7.10	1,146.80	81.90	85.00	39.40	0.48	550.53	650.80	40.10	11.60	0.29	187.01	0.460
12	4.50	665.20	75.00	78.50	35.50	0.47	315.90	502.80	29.10	8.80	0.30	149.19	0.454

Appendix 5: Equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of *Dovyalis verrucosa*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
Leaves(Y)														
	Trimmed leaf biomass=b1(BD)^b2	0.011***	1.090***											
M1	$Y = b1x(DBH)^{b2}$	0.058***	0.947***				0.884	0.040	-0.001	0.035	0.999	0.040	44	11
M2	$Y = b1x(DSH)^{b2}$	0.030**	1.185***				0.877	0.041	0.000	0.033	0.996	0.050	54	12
M3	$Y = b1x(DBH^2)$	0.007***					0.805	0.114	0.061	0.099	0.996	0.142	79	14
M4	$Y = b1x(DSH^2)$	0.005***					0.864	0.075	0.031	0.057	0.992	0.079	74	13
M5	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$	0.033*	0.747***	0.568			0.913	0.035	-0.001	0.027	0.997	0.030	39	8
M6	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$	0.019*	0.896***	0.641"			0.921	0.033	0.000	0.028	0.998	0.030	30	4
M7	$Y = b1x(DBH^2)^{b2}$ x $(Ht)^{b3}$	0.033*	0.374***	0.568			0.837	0.035	-0.001	0.027	0.997	0.030	38	7
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.041*	0.579	0.507			0.907	0.036	-0.001	0.029	0.999	0.040	40	10
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.039"	0.752**	0.632	0.361		0.917	0.034	-0.001	0.026	0.997	0.040	39	8
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.045**	0.238	0.586*	0.308*		0.960	0.023	0.000	0.018	0.999	0.050	18	1
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.029*	0.967***	0.782*	1.070*		0.954	0.025	-0.001	0.019	0.999	0.290	32	5
M12	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$ x $(CA)^{b4}$	0.047"	-0.054	0.739*	0.431*		0.953	0.026	0.001	0.018	0.998	0.100	36	6
M13	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$x $(CA)^{b4}$ x$(\bar{\rho})^{b5}$	0.066**	0.171	0.756**	0.352**	0.843"	0.978	0.017	0.000	0.011	0.999	0.490	19	2
M14	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$x $(CA)^{b4}$x $(\bar{\rho})^{b5}$	0.059*	0.18	0.850**	0.350*	0.968*	0.975	0.019	0.000	0.014	0.999	0.400	21	3
Branches(Y)														
	Trimmed branch biomass=b1 (BD)^b2	0.030***	1.210***											
M1	$Y = b1x(DBH)^{b2}$	0.179*	0.936**				0.687	0.227	-0.005	0.155	0.987	3.850	69	13
M2	$Y = b1x(DSH)^{b2}$	0.075"	1.280***				0.808	0.178	-0.003	0.13	0.994	8.410	44	8
M3	$Y = b1x(DBH^2)$	0.020***					0.597	0.400	0.185	0.309	0.981	0.479	77	14

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
M4	$Y = b1x(DSH^2)$	0.016***					0.781	0.245	0.079	0.191	0.992	0.273	63	12
M5	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$	0.130	0.82*	0.324			0.693	0.224	-0.005	0.142	0.988	0.220	51	10
M6	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$	0.072	1.254**	0.054			0.808	0.178	-0.003	0.127	0.994	0.180	32	6
M7	$Y = b1x(DBH^2)^{b2}$ x $(Ht)^{b3}$	0.130	0.410*	0.324			0.630	0.224	-0.005	0.142	0.988	0.220	53	11
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.062	1.607*	-0.266			0.813	0.175	-0.002	0.13	0.994	0.170	28	5
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.169	0.832*	0.413	0.570		0.702	0.221	-0.005	0.142	0.990	0.250	49	9
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.234"	-0.368	0.374	0.753**		0.907	0.124	0.005	0.091	0.998	0.540	27	3
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.146	1.364**	0.203	1.540		0.865	0.149	-0.006	0.111	0.999	1.670	40	7
M12	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$ x $(CA)^{b4}$	0.417	-0.608	0.257	0.841*		0.900	0.128	0.003	0.098	0.998	0.680	27	3
M13	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3} x$ $(CA)^{b4}$ $x(\bar{\rho})^{b5}$	0.488"	-0.41	0.692	0.782***	1.636*	0.952	0.089	0.003	0.067	0.999	1.000	17	1
M14	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3} x$ $(CA)^{b4} x$ $(\bar{\rho})^{b5}$	0.647	-0.283	0.387	0.728*	1.433	0.934	0.104	-0.001	0.085	0.998	1.150	21	2
Stem(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.205**	1.802***				0.963	0.674	-0.021	0.497	0.999	0.730	30	4
M2	$Y = b1x(DSH)^{b2}$	0.035"	2.486***				0.954	0.760	0.055	0.539	0.999	1.010	58	12
M3	$Y = b1x(DBH^2)$	0.136***					0.960	0.754	0.168	0.498	0.998	0.810	61	13
M4	$Y = b1x(DSH^2)$	0.100					0.942	0.943	-0.215	0.740	0.997	1.139	78	14
M5	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$	0.218"	1.819***	-0.057			0.963	0.674	-0.022	0.504	0.999	0.670	31	6
M6	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$	0.033	2.444***	0.088			0.954	0.758	0.054	0.533	0.999	0.760	52	11
M7	$Y = b1x(DBH^2)^{b2}$ x $(Ht)^{b3}$	0.218"	0.909***	-0.057			0.964	0.674	-0.022	0.504	0.999	0.670	30	4
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.092*	1.136**	0.986**			0.984	0.446	-0.006	0.334	0.999	0.450	13	1
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.225	1.818***	-0.051	0.052		0.963	0.674	-0.024	0.505	0.999	1.550	42	9
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.242**	0.957***	0.153	0.561***		0.993	0.302	0.032	0.236	0.999	2.100	25	3
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.076	2.371***	0.298	1.334"		0.971	0.592	-0.001	0.376	0.999	8.040	31	6

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.081	0.882	0.597	0.713"		0.971	0.622	0.116	0.509	0.999	3.840	46	10
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x(\bar{\rho})^{b5}$	0.327*	0.929***	0.221	0.566***	0.491	0.995	0.259	0.016	0.186	0.999	3.940	19	2
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	0.117	1.46	0.544	0.411	1.088	0.977	0.538	0.038	0.346	0.999	6.620	35	8
Total AGB(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.350**	1.630***				0.949	0.895	-0.026	0.662	0.998	0.970	49	11
M2	$Y = b1x(DSH)^{b2}$	0.077*	2.215***				0.953	0.866	0.047	0.613	0.999	1.130	42	7
M3	$Y = b1x(DBH^2)$	0.163***					0.941	1.185	0.415	0.799	0.997	1.352	77	14
M4	$Y = b1x(DSH^2)$	0.122***					0.949	0.921	-0.106	0.706	0.998	1.074	62	13
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.346	1.627***	0.010			0.949	0.895	-0.026	0.659	0.998	0.900	45	7
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.072"	2.169***	0.098			0.953	0.863	0.045	0.596	0.999	0.860	34	5
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.346	0.814***	0.010			0.949	0.895	-0.026	0.659	0.998	0.900	45	7
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.155*	1.164**	0.788*			0.977	0.604	-0.007	0.455	0.999	0.600	17	1
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.385	1.625***	0.035	0.191		0.950	0.891	-0.03	0.654	0.998	1.410	51	12
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(CA)^{b4}$	0.412**	0.746**	0.190	0.569***		0.990	0.402	0.040	0.316	0.900	2.590	39	6
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.159"	2.137***	0.311	1.41341*		0.977	0.600	-0.010	0.421	0.999	10.760	29	3
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.179	0.716	0.524	0.660"		0.974	0.677	0.113	0.534	0.999	4.280	44	10
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x(\bar{\rho})^{b5}$	0.621**	0.704***	0.304	0.582***	0.720*	0.995	0.287	0.017	0.199	0.999	4.240	18	2
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	0.266"	1.231"	0.534	0.404	1.219*	0.984	0.500	0.030	0.342	0.999	8.140	30	4

Appendix 6: Equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of *Ekebergia capensis*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
Leaves(Y)														
	Trimmed leaf biomass=b1(BD)^b2	0.009***	1.576***											
M1	$Y = b1x(DBH)^{b2}$	0.045"	1.020***				0.726	0.097	0.002	0.076	0.999	0.140	41	7
M2	$Y = b1x(DSH)^{b2}$	0.037	0.987***				0.728	0.097	-0.001	0.073	0.989	0.150	45	10
M3	$Y = b1x(DBH^2)$	0.004***					0.725	0.151	0.079	0.120	0.999	0.202	61	13
M4	$Y = b1x(DSH^2)$	0.002***					0.676	0.164	0.088	0.135	0.983	0.244	79	14
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.046"	1.152"	-0.147			0.728	0.097	0.002	0.076	0.990	0.100	44	9
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.036"	1.358"	-0.404			0.738	0.095	-0.001	0.072	0.989	0.090	35	6
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.046"	0.576"	-0.147			0.665	0.097	0.002	0.076	0.990	0.100	50	12
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.040"	0.528	0.479			0.734	0.095	0.000	0.075	0.999	0.100	26	3
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.045	1.155	-0.146	-0.016		0.728	0.097	0.002	0.076	0.999	2.470	45	10
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.032*	1.161*	-0.037	0.216*		0.873	0.067	0.006	0.051	0.998	0.420	42	8
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.15	1.556"	-0.487	-0.555		0.746	0.093	0.000	0.075	0.999	0.720	32	5
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.023*	1.624**	-0.566	0.244**		0.923	0.052	0.003	0.037	0.999	0.400	24	2
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3} x (CA)^{b4} x(\bar{\rho})^{b5}$	0.053	1.130*	-0.084	0.220*	0.366	0.876	0.066	0.006	0.048	0.995	0.070	31	4
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4} x (\bar{\rho})^{b5}$	0.020	1.644**	-0.567	0.242**	-0.099	0.923	0.052	0.003	0.038	0.997	0.050	22	1
Branches(Y)														
	Trimmed branch biomass=b1 (BD)^b2	0.021***	2.145***											
M1	$Y = b1x(DBH)^{b2}$	0.105	1.410**				0.718	0.744	-0.014	0.55	0.989	134.370	42	8
M2	$Y = b1x(DSH)^{b2}$	0.103	1.258**				0.622	0.862	-0.032	0.615	0.983	118.990	70	13

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRES S		
M3	$Y = b1x(DBH^2)$	0.025***					0.697	0.837	0.225	0.589	0.989	1.211	59	12
M4	$Y = b1x(DSH^2)$	0.014***					0.576	1.012	0.309	0.705	0.984	1.463	75	14
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.091	3.495**	-2.086*			0.845	0.557	0.057	0.446	0.995	0.560	34	4
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.078	2.537	-1.335			0.666	0.809	-0.014	0.574	0.986	0.810	49	11
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.091	1.748**	-2.086*			0.606	0.557	0.057	0.446	0.995	0.560	41	7
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.095	-2.702"	4.451*			0.812	0.617	0.074	0.458	0.994	0.620	46	9
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.036	3.613**	-2.055*	-0.605		0.851	0.55	0.065	0.436	0.999	6.470	39	6
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.075"	3.145***	-1.693*	0.227**		0.947	0.328	0.044	0.244	0.999	2.440	23	1
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.009	3.171	-1.659	-1.382		0.686	0.783	0.006	0.596	0.989	0.990	46	9
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.039	2.974*	-1.592	0.313**		0.859	0.527	0.024	0.329	0.997	2.500	30	3
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3} x (CA)^{b4} x(\bar{\rho})^{b5}$	0.111	3.112**	-1.718*	0.233**	0.274	0.948	0.326	0.043	0.243	0.998	12.700	26	2
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4} x (\bar{\rho})^{b5}$	0.022	3.060*	-1.605	0.305*	-0.386	0.945	0.331	0.044	0.240	0.984	4.690	38	5
Stem(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.009*	3.324***				0.993	1.423	0.325	1.157	0.999	2.440	45	12
M2	$Y = b1x(DSH)^{b2}$	0.013**	2.858***				0.990	1.045	-0.059	0.78	0.999	2.100	35	9
M3	$Y = b1x(DBH^2)$	0.249***					0.954	5.024	-2.426	4.038	0.996	7.200	80	14
M4	$Y = b1x(DSH^2)$	0.144***					0.983	3.934	-2.309	3.367	0.997	5.628	73	13
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.011***	2.360***	0.918***			0.990	0.719	0.145	0.583	0.999	0.720	27	4
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.013**	3.596***	-0.827			0.990	0.812	-0.053	0.671	0.999	0.810	28	6
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.011***	1.180***	0.918***			0.994	0.719	0.145	0.583	0.999	0.720	25	3
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.013***	1.717***	1.291**			0.990	0.550	0.056	0.445	0.999	0.550	12	1
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.046	2.347***	0.682*	0.899		0.990	0.644	0.108	0.497	0.999	261.980	31	7

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(CA)^{b4}$	0.010*	2.308***	1.036**	0.016		0.990	0.694	0.191	0.541	0.999	28.810	36	10
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.013	3.594***	-0.830"	0.015		0.990	0.812	-0.054	0.670	0.999	68.670	37	11
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.010**	3.510***	-0.602	0.031		0.990	0.710	0.059	0.603	0.999	26.790	33	8
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x(\bar{\rho})^{b5}$	0.176	2.230***	0.682*	0.046"	2.064	0.990	0.500	0.200	0.406	0.999	4.000	24	2
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	0.043	3.404***	-0.706	0.049	1.079	0.990	0.653	0.073	0.515	0.999	5.770	27	4
Total AGB(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.026**	2.960***				0.990	1.271	0.361	1.021	0.999	1.56	37	12
M2	$Y = b1x(DSH)^{b2}$	0.032*	2.580***				0.990	1.795	-0.052	1.228	0.999	3.17	35	10
M3	$Y = b1x(DBH^2)$	0.278***					0.969	4.414	-2.122	3.448	0.997	6.10	79	14
M4	$Y = b1x(DSH^2)$	0.160***					0.984	3.540	-1.912	2.989	0.998	4.62	72	13
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.028**	2.503***	0.442"			0.990	1.043	0.259	0.855	0.999	1.04	23	2
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.030**	3.664***	-1.198*			0.990	1.320	-0.033	1.133	0.999	1.32	30	7
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.028**	1.251***	0.442"			0.990	1.043	0.259	0.855	0.999	1.04	23	2
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.030***	0.953*	1.840***			0.990	0.895	0.168	0.743	0.999	0.90	13	1
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.075	2.482***	0.292	0.631		0.990	0.992	0.227	0.774	0.999	227.73	29	5
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(CA)^{b4}$	0.024	2.446***	0.566"	0.020		0.990	0.997	0.318	0.791	0.999	31.15	32	8
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.017	3.720***	-1.164*	-0.38		0.990	1.301	-0.011	1.132	0.999	47.25	36	11
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.022*	3.593***	-0.992"	0.044		0.990	1.104	0.128	0.887	0.999	29.27	33	9
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x(\bar{\rho})^{b5}$	0.172	2.375***	0.338	0.04	1.39	0.990	0.852	0.321	0.634	0.999	4.87	23	2
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	0.04	3.540***	-1.021"	0.052	0.447	0.996	1.089	0.136	0.850	0.999	6.73	29	5

Appendix 7: Equations and goodness-of-fit performance statistics for estimating biomass (kg dry matter/plant) of *Olinia rochetiana A. Juss*

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
Leaves(Y)														
	Trimmed leaf biomass=b1(BD)^b2	0.017***	1.489***											
M1	$Y = b1x(DBH)^{b2}$	0.105*	1.023***				0.873	0.312	-0.043	0.224	0.999	1.000	53	11
M2	$Y = b1x(DSH)^{b2}$	0.060"	1.190***				0.868	0.316	-0.041	0.242	0.995	0.930	66	12
M3	$Y = b1x(DBH^2)$	0.005***					0.709	0.599	0.319	0.428	0.998	1.619	75	13
M4	$Y = b1x(DSH^2)$	0.005***					0.758	0.515	0.237	0.358	0.989	1.147	76	14
M5	$Y = b1x(DBH)^{b2}\ x\ (Ht)^{b3}$	0.030	0.370	1.215"			0.904	0.270	-0.036	0.217	0.996	0.270	35	5
M6	$Y = b1x(DSH)^{b2}\ x\ (Ht)^{b3}$	0.0240	0.415	1.235"			0.904	0.271	-0.036	0.221	0.996	0.270	40	7
M7	$Y = b1x(DBH^2)^{b2}\ x\ (Ht)^{b3}$	0.0300	0.185	1.215"			0.716	0.270	-0.036	0.217	0.996	0.270	42	8
M8	$Y = b1x(DSH)^{b2}\ x(DBH)^{b3}$	0.084	0.512	0.580			0.878	0.307	-0.044	0.229	0.999	0.310	48	10
M9	$Y = b1x(DBH)^{b2}\ x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.016	0.391	1.237	-0.652		0.905	0.269	-0.035	0.219	0.997	0.840	37	6
M10	$Y = b1x(DBH)^{b2}\ x(Ht)^{b3}x(CA)^{b4}$	0.012	-0.219	1.672**	0.497**		0.964	0.163	-0.006	0.122	0.999	2.020	27	3
M11	$Y = b1x(DSH)^{b2}\ x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.022	0.414	1.246	-0.107		0.904	0.271	-0.035	0.221	0.996	0.520	42	8
M12	$Y = b1x(DSH)^{b2}\ x\ (Ht)^{b3}\ x\ (CA)^{b4}$	0.013	-0.214	1.632**	0.489**		0.960	0.165	-0.006	0.125	0.999	1.940	29	4
M13	$Y = b1x(DBH)^{b2}\ x\ (Ht)^{b3}x\ (CA)^{b4}\ x(\bar{\rho})^{b5}$	0.209	-0.317	1.420**	0.653*	3.049	0.972	0.143	-0.003	0.098	0.999	0.970	15	2
M14	$Y = b1x(DSH)^{b2}\ x\ (Ht)^{b3}x\ (CA)^{b4}x\ (\bar{\rho})^{b5}$	0.2421	-0.3405	1.3987*	0.6569*	3.0578	0.970	0.147	-0.002	0.104	0.999	0.150	9	1
Branches(Y)														
	Trimmed branch biomass=b1 (BD)^b2	0.047***	1.656***											
M1	$Y = b1x(DBH)^{b2}$	0.079***	1.725***				0.992	0.534	-0.027	0.383	0.999	9.230	45	12
M2	$Y = b1x(DSH)^{b2}$	0.030**	2.007***				0.990	0.594	-0.012	0.437	0.999	13.320	45	12
M3	$Y = b1x(DBH^2)$	0.033***					0.987	0.804	0.377	0.502	0.999	1.712	63	14

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
M4	$Y = b1x(DSH^2)$	0.031***					0.990	0.595	-0.022	0.437	0.999	0.596	43	11
M5	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$	0.036**	1.306***	0.775**			0.990	0.309	-0.021	0.231	0.999	0.310	20	2
M6	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$	0.018**	1.535***	0.748*			0.990	0.412	-0.007	0.288	0.999	0.410	28	6
M7	$Y = b1x(DBH^2)^{b2}$ x $(Ht)^{b3}$	0.036**	0.653***	0.775***			0.990	0.309	-0.021	0.231	0.999	0.310	20	2
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.057*	0.739	1.077			0.992	0.507	-0.03	0.367	0.999	0.510	38	8
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.041	1.309***	0.758*	0.113		0.990	0.309	-0.023	0.234	0.999	2.790	31	7
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.032*	1.269***	0.821**	0.033		0.990	0.305	-0.006	0.211	0.999	72.250	26	5
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.094	1.598***	0.485	1.488		0.990	0.368	-0.040	0.258	0.999	8.360	40	10
M12	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$ x $(CA)^{b4}$	0.016*	1.483***	0.804*	0.039		0.990	0.406	0.011	0.301	0.999	66.990	39	9
M13	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$x $(CA)^{b4} *(\bar{\rho})^{b5}$	0.010	1.229***	0.723*	0.103	1.230	0.990	0.294	0.005	0.191	0.999	3.420	15	1
M14	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$x $(CA)^{b4}$x $(\bar{\rho})^{b5}$	0.419	1.451***	0.416	0.179	3.249	0.990	0.304	0.006	0.207	0.999	57.900	22	4
Stem(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.100*	2.232***				0.990	3.834	0.156	1.984	0.999	9.980	37	11
M2	$Y = b1x(DSH)^{b2}$	0.028"	2.607***				0.990	3.915	0.263	2.416	0.999	11.620	46	12
M3	$Y = b1x(DBH^2)$	0.208***					0.988	4.593	-1.440	3.031	0.999	8.594	57	13
M4	$Y = b1x(DSH^2)$	0.190***					0.978	7.378	-3.647	5.233	0.998	15.762	67	14
M5	$Y = b1x(DBH)^{b2}$ x $(Ht)^{b3}$	0.022***	1.470***	1.435***			0.990	0.932	0.185	0.654	0.999	0.930	19	2
M6	$Y = b1x(DSH)^{b2}$ x $(Ht)^{b3}$	0.010**	1.762***	1.374***			0.990	1.553	0.301	1.032	0.999	1.550	36	9
M7	$Y = b1x(DBH^2)^{b2}$ x $(Ht)^{b3}$	0.022***	0.735***	1.435***			0.990	0.932	0.185	0.654	0.999	0.930	19	2
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.062	1.069	1.304			0.990	3.767	0.189	1.836	0.999	3.770	36	9
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.119	1.509***	1.190***	1.456"		0.990	0.739	0.058	0.528	0.999	31.480	20	4
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3} x(CA)^{b4}$	0.031**	1.546***	1.317***	-0.081		0.990	0.814	0.011	0.574	0.999	645.880	24	5
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3} x(\bar{\rho})^{b4}$	0.314	1.875***	0.818**	2.962**		0.990	1.009	-0.008	0.692	0.999	256.510	28	6

Model no.	Equation	Coefficient					Performance statistics						Sum	Rank
		b1	b2	b3	b4	b5	R^2	SEE	Bias	MAB	D	PRESS		
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.014*	1.875***	1.219***	-0.096		0.990	1.439	0.081	0.915	0.999	643.930	35	8
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x(\bar{\rho})^{b5}$	0.171	1.489***	1.166***	0.034	1.890	0.990	0.735	0.091	0.509	0.999	10.160	16	1
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	1.023	1.802***	0.739*	0.11	4.330"	0.990	0.955	0.095	0.726	0.999	10.250	29	7
Total AGB(Y)														
M1	$Y = b1x(DBH)^{b2}$	0.180*	2.099***				0.990	4.450	0.123	2.384	0.999	9.610	38	11
M2	$Y = b1x(DSH)^{b2}$	0.055*	2.448***				0.990	4.591	0.242	2.919	0.999	11.520	47	13
M3	$Y = b1x(DBH^2)$	0.246***					0.990	4.65	-0.744	2.888	0.999	6.301	46	12
M4	$Y = b1x(DSH^2)$	0.225***					0.982	7.387	-3.432	5.057	0.998	14.932	67	14
M5	$Y = b1x(DBH)^{b2} x (Ht)^{b3}$	0.047***	1.411***	1.292***			0.990	1.117	0.168	0.828	0.999	1.120	21	3
M6	$Y = b1x(DSH)^{b2} x (Ht)^{b3}$	0.022**	1.686***	1.235***			0.990	1.930	0.297	1.340	0.999	1.930	36	9
M7	$Y = b1x(DBH^2)^{b2} x (Ht)^{b3}$	0.047***	0.705***	1.292***			0.990	1.117	0.168	0.828	0.999	1.120	21	3
M8	$Y = b1x(DSH)^{b2} x(DBH)^{b3}$	0.116	0.990	1.237			0.991	4.348	0.147	2.211	0.999	4.350	34	8
M9	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.167	1.440***	1.109***	1.112		0.990	0.944	0.045	0.635	0..999	16.45	20	2
M10	$Y = b1x(DBH)^{b2} x(Ht)^{b3}x(CA)^{b4}$	0.058**	1.465***	1.212***	-0.056		0.990	1.030	0.010	0.712	0.999	706.87	24	5
M11	$Y = b1x(DSH)^{b2} x(Ht)^{b3}x(\bar{\rho})^{b4}$	0.420	1.785***	0.762**	2.558*		0.990	1.298	-0.047	0.953	0.999	208.09	32	7
M12	$Y = b1x(DSH)^{b2} x (Ht)^{b3} x (CA)^{b4}$	0.027*	1.763***	1.135**	-0.065		0.990	1.852	0.106	1.210	0.999	689.32	37	10
M13	$Y = b1x(DBH)^{b2} x (Ht)^{b3}x (CA)^{b4} x (\bar{\rho})^{b5}$	0.242	1.418***	1.085***	0.036	1.562	0.990	0.934	0.096	0.629	0.999	11.54	18	1
M14	$Y = b1x(DSH)^{b2} x (Ht)^{b3}x (CA)^{b4}x (\bar{\rho})^{b5}$	1.3538	1.7058***	0.688*	0.1152	3.9209*	0.990	1.186	0.107	0.936	0.999	11.12	28	6