EFFECT OF FOREST MANAGEMENT ON WOODY BIOMASS, SOIL ORGANIC CARBON AND WOODY SPECIES DIVERSITY OF ZEGE NATURAL FOREST IN BAHIR DAR ZURIA WEREDA, WEST-GOJJAM ZONE

LAKACHEW YALEW

HAWASSA UNIVERSITY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCES, SCHOOL OF GRATUATE STUDDIES, WONDO GENET, ETHIOPIA

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LAKACHEW YALEW

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Approval Sheet-I

This is to certify that the thesis entitled "Effect of forest management on woody species biomass, soil organic carbon and woody species diversity of Zege Natural Forest in Bahir-dar Zuria Woreda, West-Gojjam Zone, Ethiopia" submitted in partial fulfillment of the requirements for the degree of Master of Sciences in **Forestry** with specialization in **Forest Resource Assessment and Monitoring** of the Graduate Program of the Department of Forestry and Natural Resources, Wondo Genet College of Forestry and Natural Resources, and is a record of original research carried out by **Lakachew Yalew Wubie Id. № MSc/010/09**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

Amare Tesfaye (PhD)	________________________	__________________
Name of Major advisor	Signature	Date

Approval sheet-II

We, the undersigned, members of the Board of examiners of the final open defense by **Lakachew Yalew Wubie** have read and evaluated his thesis entitled "Effect of Forest Management on woody species biomass, Soil organic carbon and Woody species diversity of Zege natural forest in Bahir-Dar Zuria woreda, West-Gojjam zone, Ethiopia", 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 Masters of Science in Forestry with specialization in Forest Resource Assessment and Monitoring.

Name of the Chairperson	Signature	Date
Name of advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date

DECLARATION

I, the undersigned declare that this Thesis is my original work and it has not been presented in other Universities, Colleges or Institutes for a degree or other purpose. All sources of the materials used have been duly acknowledged.

Name: Lakachew Yalew Signature: ___________________ Date: ______________

This work has been done under my supervision.

Principal Supervisor

Amare Tesfaye (PhD): Signature: __________________ Date: ________________

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Aboveground Biomass
AGWB	Aboveground Woody Biomass
BEF	Biomass Expansion Factor
BGB	Below Ground Biomass
BGWB	Below Ground Woody Biomass
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CO2	Carbon dioxide
DBH	Diameter at Breast Height
DSH	Diameter of Stump Height
EWNHS	Ethiopia Wildlife and Natural History Society
FAO	Food and Agriculture Organization of the United Nations
GHGS	Green House Gasses
GPS	Geographical Position System
IPCC	Intergovernmental Panel on Climate Change
NBP	Net Biomass Production
NEP	Net Ecosystem Production
SOC	Soil Organic Carbon
REDD	Reducing Emission from Deforestation and Forest Degradation
TBGS	Total Biomass Carbon Stocks
IUCN	International Union for Conservation Nature and Natural Resources
UNDESA	United Nation Development Environmental Strategic Action
WBISPP	Woody Biomass Inventory and Strategic Plan Project

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ABSTRACT

In Ethiopia, forests have been widespread in diverse agro-ecologies of the country and known to provide various products and ecosystem services especially for smallholder farmers. However few studies have been made on the effects of forest management on woody biomass, soil organic carbon and woody species diversity in different regions of Ethiopia. There is no such study at Zege Natural Forest as well. The overall objective of this study was to identify the effect of forest management on woody biomass, soil organic carbon and woody species diversity of Zege natural forest. 62 Sample plots were laid along line transects in which sample plots of 20m×20m were used for data collection. A systematic sampling method was conducted to estimate carbon stock. The data was collected from the field by measuring plants with a DBH of ≥ 5 cm and data were analyzed for species diversity. The carbon stock of each plant was analyzed by using allometric equations. The soil samples (0 -20 cm and 20 -40 cm) were collected. Accordingly, the total woody species recorded in the wood -based forest 58 and coffee based forest 47. The Shannon diversity index, Simpson's diversity and evenness of wood based and coffee-based forest were (H=3.74, D=2.85 and E=0.15) and (H=2.85, D=0.75 and E=0.11) respectively. From this study the mean total carbon stock of Zege forest was 237.5±40.1t/ha, of which the above and belowground carbon, litter carbon and soil organic carbon. The one way ANOVA showed that there is a significant difference in carbon between coffee based and wood based forests. The highest above ground and soil carbon stock was found in wood based forest while the least stock was found in coffee based forest. This implies that forests store high amount of carbon, which can play an important role in climate change mitigation. Finally, data of current study can be used as a baseline to make inferences about the effect of forest management on woody biomass, soil organic carbon and woody species diversity.

Key Words: Aboveground biomass carbon, allometric equation, Basal area, Carbon stock,

Coffee based forest

1. INTRODUCTION

1.1. Background of the study

Climate change is one of the most widely recognized environmental issues today. A consensus in the climate science research community has emerged that continued emission of greenhouse gases resulted further warming and long-lasting changes (IPCC, 2014). Emissions of GHGs into the atmosphere are likely to increase the earth's mean surface temperature, thereby affecting physical and biological systems (Rosenzweig *et al*., 2008). The effects of temperature threats to natural phenomena, societal disturbances and threats to economic growth (IPCC, 2007 a; UNFCCC, 2011). Forests are play in regulating the global climate; (as) both sinks and sources of carbon dioxide. Globally, forests approximately 80 % of terrestrial above-ground and 40 % of terrestrial belowground biomass (Kirschbaum, 1996) in the form of aboveground biomass, belowground biomass dead wood, and litter and soil organic carbon. Therefore, forest biomass placed on important role in carbon sequestration. Forests used to quantify carbon pools and fluxes of greenhouse gases (GHGs) from the terrestrial biosphere associated with land use land cover changes (Cairns *et al*., 2003). Moreover, forests are thought to provide a more cost-effective means of reducing global CO_2 emissions than other sectors (IPCC, 2007) and also sustainable forest development and forested landscape expansion was one of the key approaches for reducing atmospheric carbon concentration (Siry *et al*., 2006). The goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al*., 1996).

In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of the soil, generally in the partially decomposed vegetation (humus) on the surface and in the upper soil layers, in the microbial organisms that decompose organic matter (decomposers) and in the living or dead wood (Gorte, 2009). The amount of carbon sequestered in forest soils varies widely, depending on the environment and the history of the site. Carbon accumulated in the soil as dead vegetation is added to the surface and decomposers respond, slowly releasing it in to the atmosphere. In addition, carbon is also injected in to the soil as the root biomass grows (Harper *et al,* 2005).

The vegetation of Ethiopia was been described by various scientists such as (Hawas *et al*., 2001, and Yeshitila & Bekele, 2002) are some of the vegetation surveys made in different parts of the country. Vegetation types in Ethiopia are highly diverse, due to variation in ecological conditions (EPA, 1997). Over population growth resulted in deforestation and land degradation. They occurred gradual resource depletion in the country, particularly in the central highlands of Ethiopia. Productivity has already declined and environmental resources are deteriorating. Although information on the severity of the situation, the problems have not been studied and clearly identified.

In Ethiopia, varies research on the effect of forest management on woody biomass, soil organic carbon and diversity have been conducted in different parts of the country. However in Western Gojjam, Bahir-Dar woreda, Zege natural forest there is research has been out concerning effect of forest management on woody biomass, soil organic carbon and woody diversity.

1.2. Problem of the statement

Ethiopia losses it's biologically diverse forest resource from time to time due to various human induced pressures such as: expansion of agricultural land, overgrazing, fire and settlements. Coffee production in many parts of Ethiopia is purely organic in that it is either collected from forest/ semi-forest systems or produced in gardens of small-scale farmers with little capital to use inorganic agricultural inputs. However, increasing demand for wood, forest management for high coffee yield, changing to settlement is likely to cause over-exploitation of some highly valued secondary forest and climax tree species. In this regard, the role of forest coffee in the conservation of the forests and coffee forest management impacts of South-west Ethiopia has been studied (Schmitt *et al.*, 2005; Schmitt, 2006; Feyera Senbeta, 2006; Tesfaye Gonfa, 2009).

The ever increasing demands for forest products and forestland driven by human population growth result in forest depletion. Particularly, trees are being cut in large numbers for fuel wood that is sold in the nearby town of Bahir-Dar. Timber became increasingly important in order to generate additional income and to offset the crop losses. As an additional income generation, firewood and timber are taken illegally and sold in local markets. This production system covers huge amount of forest land and served as a base of household economy for the community around in Zege.

To change this status quo, the Amhara Regional State has Introduced the Participatory Forest Management in 200l, in which majority of the forest resources were partitioned and distributed to households, so that, they can manage and utilize the resources in a sustainable way. However, a change in the management system was having an effect on ecosystem services like woody biomass, soil carbon stocks and woody species diversity.

1.3. Objectives

1.3.1. General objective

The general objective of the study was to identify the effect of forest management on woody biomass, soil organic carbon and woody species diversity of Zege natural forest, West-Gojjam zone

1.3.2. Specific objectives

The specific objectives of this study were:

- To identify woody species diversity of the Zege natural forest
- To estimate the above and below ground woody biomass carbon stock
- To estimate the soil organic carbon stock

1.4. Research questions

How does forest management affect?

- Woody species diversity of the Zege natural forest
- Above and below ground woody biomass carbon of the Zege natural forest
- Soil organic carbon stock of the Zege natural forest

1.5. Significance of the study

This study investigated the effect of forest management practice on woody biomass, soil organic carbon and woody species diversity of Zege natural forest, West-Gojjam. This can services sources researchers and other stake holders to understand the effect of forest management on carbon stock and woody species diversity of Zege natural forest, in climate change mitigation. From this study, quantified reliable carbon stock may be used as important source of data for regional and global data sets such as: CDM, $REDD^+$ and voluntary carbon markets. The study has also a contribution to the conservation of forest resources and promotes the ecosystem services they provide to the local communities in addition to their direct economic benefit.

2. LITERATURE REVIEW

2.1. Overview of the climate change

Climate change is any significant change in measures of climate (temperature, precipitation) for an extended period of time typically decades (IPCC, 2007). The global temperatures have increased since the past 400,000 years (USEPA, 2007). Even if preventing and minimizing climate change by limiting anthropogenic emissions of greenhouse and enhancing greenhouse gas sinks is essential (UN, 1992), earth is currently warmer than it has been in its recent past. The assessment of the global climate by the Intergovernmental Panel on Climate Change (IPCC) from 1995– 2006 indicates that most of the global average temperatures increase when the anthropogenic greenhouse gas concentrations increase. Due to this, accurate and precise measurement of the carbon in forests is gaining global attention globally (Brown, 2002).

The (IPPC, 2007) highlighted that Africa is be one of the continents affected by climate change due to an increased temperature and water scarcity. Yet Africa represents only 3.6 of emissions. The IPCC Report pointed out that there is “very high confidence” that agricultural production and food security in many African countries could be severely affected by climate change and variability. In Africa, the yields of crops in some countries could be reduced as much as 50 by 2020, with smallholders being the most affected (FAO, 2011). Ethiopia is one of the developing countries, which are more vulnerable to climate variability and change (NMA, 2001; FAO, 2011). Low level of socio-economic development, inadequate infrastructure, lack of institutional capacity and a higher dependency on natural resources base make the country more vulnerable to climatic factors including climate variability and extreme climate events. Ethiopia is particularly vulnerable to global climate change, given its massive reliance on agriculture (FAO, 2011).

2.2. Major carbon pools in forest ecosystem

2.2.1. Aboveground biomass carbon (AGBC)

Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements (Pearson *et al.*, 2005). First directly estimates biomass density through biomass regression equations then convert wood volume estimates to biomass density using biomass expansion factors (Brown, 1997). This means; the AGB contains 47 % carbon which is “all biomass of livening vegetation both woody and herbaceous” above the soil including; stem, bark, branches, twigs and needles (IPCC, 2007). Carbon stock values can be expressed either as t/ha or tco_2/ha. The conversion factor 3.67 is used to convert t/c to tco_2 is obtained by dividing the molecular weight of carbon.

2.2.2. Belowground biomass carbon

The BGB carbon pool consists of the biomass contained within live roots, which predict root biomass based on above-ground biomass carbon (Brown, 2002). Many studies covering tropical, temperate, boreal forests, and find a mean root-to-shoot (RS) ratio of 0.26, ranging between 0.18 and 0.30. However, the estimation of BGB is more efficient and effective using a conservative ratio for the shoot: root (5:1) based on AGB carbon (MacDicken, 1997; Watson, 2008).

2.2.3. Litter carbon stock

Carbon is stored in trees in the form of AGB, BGB, litter, dead wood and soils. The mechanism of species driven carbon sequestration in soil is influenced by two major activities, aboveground litter decomposition and belowground root activity (Lemma *et al.*, 2007). Litter decomposition is one of the major sources of SOC and the quality of litter is very important in this regard (Mafongoya *et al*., 1998; Isaac and Nair, 2006 ; Lemma *et al*., 2007). In the systems with high plant diversity, litters are present with different degrees of chemical resistance, creating the possibility of longer residence of carbon through slower decomposition of litters from some species. Lignin in litter is highly resistant to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya *et al*., 1998). In contrast, litter with low lignin, phenols, and high nitrogen content would have faster rate of decomposition (Aber and Mellilo, 1991).

2.2.4. Soil carbon stock

Carbon is accumulated in the soil as dead vegetation is added to the surface and decomposers respond, although it is slowly released to the atmosphere. In addition, carbon is also injected in to the soil as the root biomass grows (Harper *et al.,* 2005). The soil carbon sequestration implies the removal of atmospheric CO_2 by plants and storage of fixed carbon as soil organic matter. It increases SOC stocks through land use change and forest management practices (Post *et al*., 2001; Lal, 2004). Natural vegetation soils are one of the major carbon sinks on earth, because of their higher organic matter content. Soil organic carbon can increase or decrease depending on numerous factors, including climate, vegetation type, nutrient availability, disturbance, and land use and management practice (Baker, 2007).

2.3. Factor affecting carbon stock in forest

Deforestation leads to reductions in forest carbon stock through land clearing. Forest degradation reduction in forest biomass through no sustainable harvest or land-use practices can also result in substantial reductions of forest carbon stocks from selective logging, fire and other anthropogenic disturbances, and fuel wood collection (Asner *et al*., 2005).

All of these factors have also carbon balance implications. Such disturbances affect roughly 100 million ha of forests annually (FAO, 2006). Degradation, defined as decrease of density or increase of disturbance in forest class, affected tropical regions at rate of 2.4million ha/yr. in the1990s according to the Millennium Ecosystem Assessment (2005) scenarios, forest area in industrialized regions will increase between 2000 and 2050 by about 60 to 230 million ha. At the same time, the forest area in the developing regions will decrease by about 200 to 490million ha. The lack of consensus on factors that control the carbon balance is an obstacle to development of effective mitigations strategies.

2.4. Forest structure

The term 'forest structure' encompasses many things and can be described in numerous ways. According to Spies (1998), the essential attributes of forest structure include structural type, size, shape, and spatial distribution (vertical or horizontal) of components. The same author also explained that important components of forest structure include live-tree sizes/age distribution, vertical foliage distributions, and horizontal variation in canopy density, and dead woody debris. The traditional and most common measures of forest structure are the size and age distributions of the trees (Smith, 1986). Because, he also added that size distribution of living trees is closely linked to many other structural features (e.g. foliage distribution, crown attributes) or the potential to produce other features (e.g. dead wood of different sizes).

On the other hand, according to Schmidt (2005), a forest ecologist distinguishes forest ecosystems by the vertical and horizontal structure of tree species, whereas a vegetation ecologist describes forest ecosystems using all visible plant species, i.e. higher plant (cryophyte) taxa, mosses and lichens. Forest structure also characterized primarily by the horizontal and vertical distributions of plant species (http://en.wikipedia.org/wiki/Vegetation). Horizontal distributions refer to the pattern of spacing of plant stems on the ground and three broad categories of spacing are recognized: uniform, random and clumped. Whereas, the vertical distributions of biomass determined by the strata of vegetation from ground cover to the dominant tree.

2.5. Species diversity and richness

Biodiversity has become one of the main topics of many studies in forest condition assessment and management designing. It refers to the diversity of life in all its forms (animals, plants, fungi, and microorganisms) and at all levels of organization (genes, species, and ecosystems) (Hunter, 1999). However, species diversity is considered as one of the key parameters characterizing ecosystems and a key component of ecosystem functioning (Scherer-lorenzen *et al*., 2005). High species diversity reduces the risk of large changes in ecosystem processes in response to directional or stochastic variation in the environment or in response to invasions of pathogens and other species (Holsinger, 2003-2009)

Species diversity has two basic components. The first is species richness: which is a measure of the number of different species present in an ecosystem. The main problem with measuring species richness is that the result depends on the number of individuals recorded (Newton, 2007). The second is species evenness measures the relative abundance of the various populations present in an ecosystem or it assesses the departure of the observed pattern from the expected pattern in a hypothetical assemblage (i.e. all species are equally abundant or broken stick distribution) (Magurran, 2004).

In an ecological survey designed to measure species diversity, the numbers of individuals of each species present in a forest can be determined, and then a "diversity index" would be calculated for the forest. Species diversity for plants can be expressed not only by the total number per whole study areas with different sizes (ha) but also by the mean number of species per ha, which permits a comparison between the investigated sites (Schmidt, 2005). That is, species diversity comparison of the diversity index with that of other areas provides insights into the species diversity and the health of the ecosystem. Of course, a number of factors might affect the species diversity and the proportion of forest related species groups, including site history, management practices, time since cessation of management and the existing site conditions (Schmidt, 2005).

Some commonly used diversity measures of 'diversity index ' are Shannon-Winner Index, Simpson's index, and Shannon evenness, Simpson's Evenness and Log series index (Fisher's alpha index) (Magurran, 2004; Wilsey and Stirling, 2007). According to Magurran (2004) Shannon index is so narrowly constrained in most circumstances that can make interpretation difficult because it confounds two aspects of diversity, species richness and evenness. The interpretation problem is related with that an increase in the index may arise either because of greater richness, or greater evenness, or indeed both

2.6. The effect of forest management practice on plant species diversity

Understanding the effects of forest management practices on plant species diversity was important for achieving ecologically sustainable forest management (Banda *et al*., 2006; Nagaike *et al*., 2006; Tavankar *et al*., 2011). It offer evidence to support management decisions that will eventually improve the ecological health of the forests, increase the flow of ecosystem services, and support livelihoods in rural societies that are dependent on forest resources.

Evaluation of existing ecological parameters was one of the best methods to investigate the effects of different management practices on the composition and diversity of forest vegetation (Rawat *et al*., 2011; Måren *et al*., 2014). Additionally, comparing forest stands that are in proximity and share similar topographic factors provide the ideal conditions for assessing the effects of different management practices on forest structure and diversity (Sitzia *et al*., 2012).

Most researchers suggested that the disturbances by management may increase plant species richness (Boch *et al*. 2013). Species richness and diversity are useful indicators of the effects of forest management practices (Nagaike *et al*. 2006). Poor forest management practices contribute to decline or loss of biodiversity. Ecologically sustainable forestry is the practice of land stewardship that integrates growing and harvesting of trees while protecting soil, water, biodiversity and landscape.

The replacement of wood based tree species by one or two preferred timber tree species during forest management practices may facilitate recruitment of the unique suite of rare species, thus decrease evenness (Saha, 2003). Discouraging the development of monoculture and promoting the recruitment of multiple tree species possibly maintain a sustainable forestry and conserve forest biodiversity (Pandey, Maraseni, *et al*., 2014). Although development of a monoculture can have economic importance it does not necessarily ensure sustainability (Carnus *et al*., 2006).

To address the burgeoning problems with forest degradation and deforestation, different forest management strategies have been adopted in different parts of the world (Tewar, & Rawat, 2011; Måren, Bhattarai, & Chaudhary, 2014). In recent decades, substantial investments have been made to initiate forest management through community participation, called community forestry (Soltani & Eid, 2013; Pinyopusarerk, Tran, & Tran, 2014). Nevertheless, the survival of many species that depend on natural forest habitat remains compromised.

3. MATERIAL AND METHODS

3.1. Description of the study area

The study site, Zege Peninsula forest is located in northwestern Ethiopia, Amhara National Regional State in Bahir_Dar Zuria, which is about 560 km from Addis Ababa. It has altitudinal range of 1770 -1988m.a.s.l. and falls within a geographic coordinate of 11^0 40’ N to 11^0 43’ N latitude and 37^0 19’ E to 37^0 21’ E longitude (Alelign, 2002).

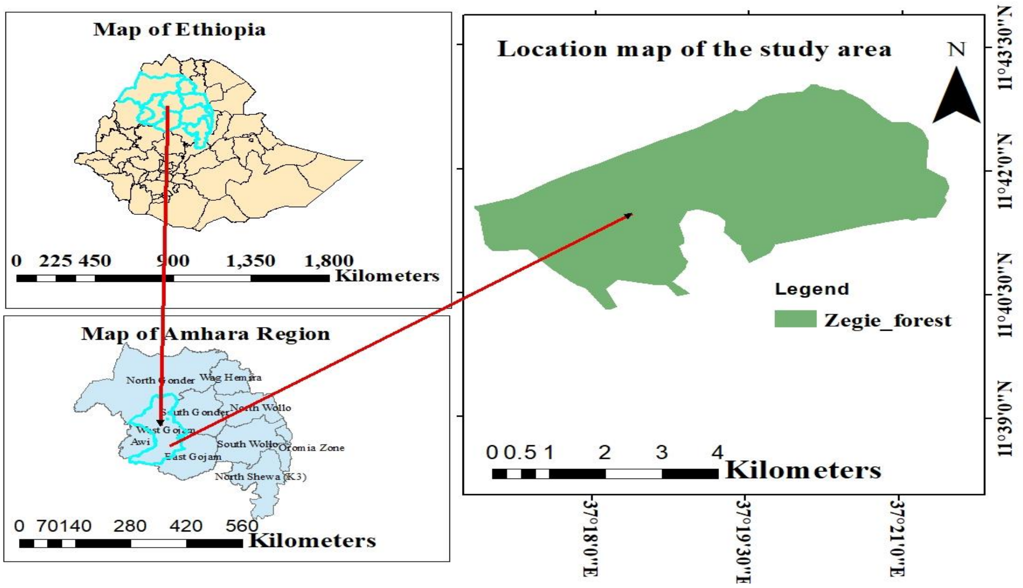

Figure 1 : Location map of the study area

The Zege forest covers about 1219 ha. As the name Peninsula indicates, more than 75% of the circumference of Zege forest is flanked by Lake Tana, which is the largest lake in Ethiopia.

3.1.1. Geology and soil

The soils of Zege Peninsula are predominantly Nitosols with some Luvisols, Vertisols and reddish or brownish ferrisols derived from volcanic parent material. The study area of soil type was Nitosols. The pH of the soil ranges from 5.05 to 6.07 (Deriba, 1993).

3.1.2. Climate

Zege lies in the moist Woina Dega Ago-Climatic-Zone, Based on 8 year-data obtained from the National Meteorological services Agency, the mean minimum and maximum temperatures are 10.3^0 C and 27.7^0 C, respectively, while the average annual rainfall is about 1415 mm.

3.1.3. Vegetation

The total area of Zege natural forest i.e. 1219 ha, 670 ha is being be lived to have been covered once by densely growing forest trees. The area coverage is almost the same, due to over utilization by the local community through species composition and density. Currently, the community is cultivating about 549 ha of coffee based under the shade of forest tree (the whole forest area is divided among the community).

3.2. Delineation and stratification of the study area

Before stratifying the study area reconnaissance survey was conducted to determine the number of transects and number and location of forest stratums. The boundaries of the study forest area were delineated to facilitate accurate measurement and accounting of the forest carbon stock. GPS points were used for delineation of boundary of the study area. In order to maintain homogeneity and minimize the spatial variation of the study area and obtain accurate data from the fieldwork, the study area was stratified by forest canopy coverage. Accordingly, the total forest area categorizes in to two forest stratums. Wood based forest management practice one consists forest structure that is land with relatively continuous cover of trees, for all species (FAO, 2014). The coffee based forest consists of high tree ≥ 5 m tree height and crown tree cover > 20% (FAO, 2014).

3.3. Sampling design

For this study nested plot design was selected in which trees >25cm DBH were measured in 20m×20m plots trees between 5cm to 25cm DBH were measured in 10m×10m subplots and soil, litter seedling and sapling <5cm were measured in 1m×1m sub-plots. So, to reduce the variability and to include more variables nested plot design was important (Pearson *et al*., 2005). Within each stratum, following the systematics sampling method sample plots were laid along the transect line. Distance between consecutive transect lines and between adjacent plots was 500m and 400m respectively. To avoid boarder effect, the first sample plot was established 20m from the boundary of the forest area. The first transect lines were being randomly allocated. Totally square shaped 62 sample plots (20 m × 20 m) were used to collect the tree data. To collect shrub data totally 62 subsample plots which were 10m×10m established within the sample plots. To collect sapling and seedling data totally 62 quadrants of 1m×1m were established within the subsample plot area 10m×10m.

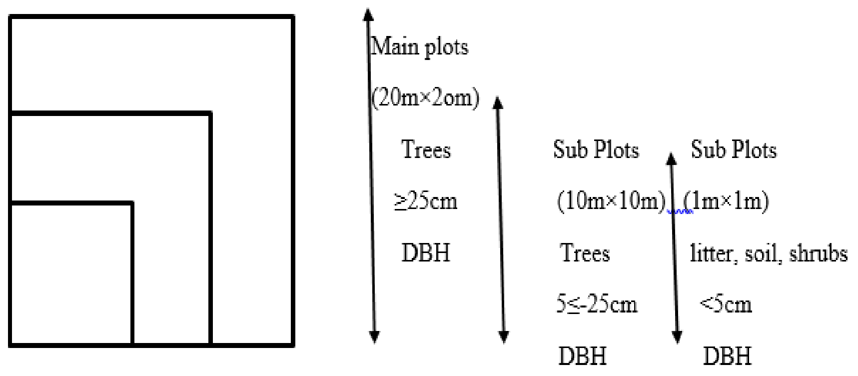

Figure 2: Nested plot design showing the sample plot, subsample plot and quadrants

To collect the litter and soil samples for carbon content analysis, totally 310sub quadrants 1m×1m were established at each corner of the sample plot and center of each sample plots (figure 2). To collect the soil sample for the bulk density determination totally 62 sub quadrants were established at the center of each sample plots.

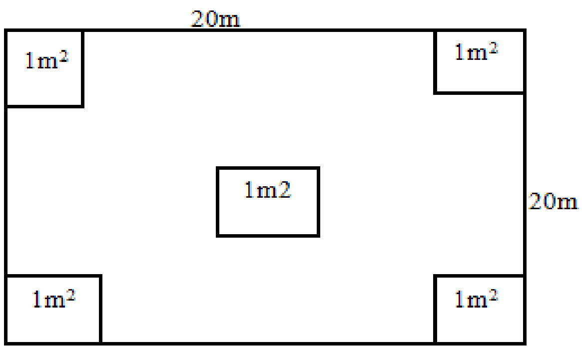

Figure 3: Quadrate designs for litter and soil sample

3.3.1. Vegetation data collection and identification

In each plot all standing living trees and shrubs with a DBH ≥ 5 cm diameter were recorded with in a sample area of 20 m x 20 m. Those trees on the border were included when ≥ 50 % of their basal area fell within the plot and excluded if < 50 % of their basal area fell outside the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included (Bhishma *et al*., 2010). The trees that were found on a slope, always measured on the uphill side. If the tree has fallen but is still alive, were then placed the measuring stick towards the bottom to measure at DBH. Trees are considered alive if there are green leaves present (Pearson *et al.*, 2005).

The diameters were in two perpendicular directions. In the case of multi-stemmed plants (more than 2 stems per plant), each stem was measured and the equivalent diameter of the plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon *et al*., 2002).Plant identification was done in the field by using Flora of Ethiopia and Eritrea (Bekele, 2007)

3.3.2. Litter biomass sampling

. Total of five sub-plots of 1 m × 1 m (four at corners and one in the center) were established and used for litter samples collection. A composite sample of 100 g was taken for laboratory analysis placing in a plastic bag. The total dry weight was determined in the laboratory after oven drying of the sample for 48 hours at 105^{o}C using dry ashing method as per Allen *et al*. (1986). Oven dried samples were taken in pre-weighed crucibles. The samples were ignited at 550^{o}C for one hour in muffle furnace after cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated. Finally, carbon in leaf litter t /ha for each site was determined

3.3.3. Soil sampling

Soil samples were collected from the field with five sub-plots within each primary plot. The samples were collected using auger to a two depth of 0-20 and 20 -40 cm from the four corners and center of each quadrat. Mixing of soils was done properly by taking equal amount of soil from each sub plots to make a composite in order to make homogeneity. The samples were analyzed at Adet Agricultural Center.

Laboratory analysis according to (Pearson *et.al*. 2005) the soil sample collected from each sub-quadrat was air dried. Then dry weight of each sample was taken. The carbon fraction of the sub-sample was measured in the laboratory using Walkley-Black method (1934). Finally, the bulk density, soil organic carbon and soil organic matter were calculated.

3.4. Diversity and similarity indices

The quantitative index of species diversity, richness and evenness was measured using the Shannon- Wiener index (Magurran, 1988) using the formula:

$$H' = -\Sigma \; pi \ln pi \text{ ………………………………………………………. (eq.1)}$$

Where, H' is the Index of Species Diversity;

S = total number of species,

Pi = the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of total cover.

ln = log base n. The minimum value of H' is 0, which is the value for a community with a single. Species, and increases as species richness and evenness increases (Manuel and Molles,
2007).

Species richness (S) is the total number of different woody species recorded in each of the sampled plots (Magurran, 2004). Accordingly, Species richness (number of species) of the study area was determined by the total number of woody species recorded.

Species richness (S) is defined by: $S = \sum n$, Where, n is the number of species in a community.

The species evenness or equitability (J) that measures the equity of species in a given sample area is represented by 0 and 1, where 0 indicates the abundance of few species and

1 indicates the condition where all species are equally abundant (Whittaker, 1975). The following formula was used to calculate species evenness;

$J = \Sigma$ pi lnpi / ln S= H'/lnS = H'/ H_{max}…………………………………………………. (eq2)

Where, Hmax is defined as ln S. J is species evenness. H' is Shannon-Wiener Diversity Index; S is the number of species found when all sample plots are united; Pi is the proportion of total individuals in the i^{th} species, lnS is the natural logarithm of the total number of species evenness (a measure of species abundance).

The degree of community similarity between the study plots was calculated using the Sørensen coefficient of community (Sørensen, 1948) and the Jaccard similarity coefficient (Mueller and Ellenberg 1974):

3.4.1. Forest structure

The structural analysis of the vegetation was also described by using the following components: relative density and DBH and height class distribution were analyzed. Six DBH classes (i.e. 1= 5 ≥- 10 cm, 2= 10 –20 cm, 3= 20 –30 cm, 4=30 -40 cm, 5= 40 -50 cm, 6= >50 cm) and height class (i.e.1=5 - 10 m, 2=10 -15 m, 3= 15 -20 m, 4= 20 -25 m, 5= 25 -30 m, 6= > 30 m) were established by (Kitessa Hundera *et al*., 2007).

Frequency is the number of times a particular species is recorded in the sample area. The frequency distribution of tree species was calculated as follow:

The following structural parameters of the species were analyzed following (Mueller-Dombois and Ellenberg, 1974) and (Martin, 1995).

I) Frequency of a species= the number of plots in which that species occurs/total number of plots

II) Relative frequency= Frequency of species A/ total frequency of all species ×100

III) Density of species= the number of individuals of that species/area sampled

IV) Relative density = Density of species A/total density of all species×100

V) Basal area ($m^{2)}$= $(DBH/200)^2 \pi$ or $BA = \frac{\pi * DBH^2}{4}$

Where π=3.14 and dbh = diameter at breast height (cm) for woody species with DBH≥5

VI) Dominance= Total basal area/area sampled

Relative dominance=Dominance of species A/total dominance of all species×100

VII) Importance Value Index (IVI) =Relative density +Relative frequency +Relative dominance.

Important value index (IVI) is the most important parameter to understand the community organization in relation to the competitive ability (Uniyal *et. al*., 2010). IVI gives a more realistic value figure of dominance from structural stand point (Derero, 2003). The species having highest IVI was identified as dominant and the second highest IVI was defined as co-dominant species (Sagar *et. al*., 2008).

3.5. Estimation of carbon stocks (woody species biomass plus soil organic carbon)

3.5.1. Estimation of above and belowground woody species biomass carbon stock

The above ground biomass consists of all living tree biomass above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The selection of the appropriate allometric equation is crucial in estimating aboveground tree biomass carbon (AGBC). (Bhishma *et al*., 2010) defined allometric equation as a statistical relationship between key describe dimensions of trees that are fairly easy to measure, such as DBH or Height and other properties that are more difficult to assess, such as above ground biomass carbon. There are different allometric equations that have been developed by many researchers to estimate the above ground biomass carbon. These equations are different depending on the types of species, geographical locations, forest stand types, climate and others (Baker *et al*., 2004).

To develop and use of locally developed allometric equations used to generate a reliable estimate of forest carbon stocks for AGB. But to develop allometric relationships a large number of trees needs to be harvested, this makes it time-consuming and expensive (Gibbs *et al.*, 2007). Although, many allometric equations had been developed globally, no African site had been included in previous efforts (Chave *et al*., 2005) except the pan tropical AGB model developed by Chave *et al*. (2014), included sites from Africa by considering 58 study sites of woody vegetation, excluding plantations and agroforestry systems with a total of 4004 trees and DBH ranging from 5 to 212cm, spanning a wide range of climatic conditions and dry tropical forest types. The model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors (Chave *et al*., 2014; Victor, 2015). According to Henry *et al*. (2010), equations that integrate more than one tree dimension improve the reliability of forest biomass estimation. Therefore, the model of Chave *et al*. (2014) was used by many studies and has been the best model for carbon stock assessment in Africa (MEFCC, 2016; Victor, 2015) on the basis of climatic condition, DBH of trees and forest type of the study area to determine biomass of tree species having ≥ 5 cm DBH. This study uses the following equations to calculate AGB (stem plus bark, branches and foliage) of trees. The model that was used to calculate the above ground biomass is given below:

$$AGB\ (kg) = 0.0673 \times (WD \times DBH^{2} \times Ht)^{0.976} \text{ ------------------------------------- eq. (2)}$$

Where AGB = above ground biomass in (kg/tree)

DBH = diameter at breast height in (cm)

WD =wood density, in (gcm^{-3})

Ht =total height of trees in (m)

DBH of trees were measured directly, but total height of trees was measured by regression using DBH of some directly measured tree species as indicated by chave *et al*., (2014). Height of 17 trees was measured directly and the other measured by using linear regression equation of

$$y = 0.2894x + 1.1404 \text{ --- eq. (3)}$$

Where Y = dependent variable (Ht.)

X= independent variable (DBH), therefore the remaining total height of tree was measured using the above equations.

According to IPCC (2006), the biomass stock density of a sampling plot is converted to carbon stock densities by default carbon fraction of 0.47, as the dry biomass contains 47 % organic carbon in the tropical and sub-tropical region.

Below ground biomass estimation is much more difficult and time-consuming than estimating aboveground biomass (Cairns *et al*, 2007). According to (Pearson *et al*, 2007) standard method for estimation of below ground biomass is simply assuming that it constitutes 26% of aboveground tree biomass i.e., the root-to-shoot ratio value of 13:50 is used. Thus, the equation developed by (IPCC *et al*, 2006) to estimate below-ground biomass was done:

$$BGB = AGB \times 0.26 \qquad \text{(eq 6)}$$

Where, BGB is below ground biomass, AGB is above ground biomass, 0.26 (range of 0.18 -0.30) is conversion factor 26 % AGB).

3.5.2. Estimation of in the litter biomass carbon

According to (Pearson *et al*., 2005), estimation of the amount of biomass in the leaf litter can be. Calculated by:

$$LB = \frac{Wfield}{A} \times \frac{Sub\ sample(dry)}{Sub\ sample(fresh)} \text{ x1/10,000} \qquad \text{(eq.7)}$$

Where: LB = Litter (biomass of litter t/ha)

W field = weight of wet field sample of litter sampled within an area of size 1 m^2 (g);

A = size of the area in which litter were collected (ha);

W sub-sample, dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and

W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

$CL=LB\times0.37$………………………………………………………………… (eq.10)

Where,

CL= total carbon stocks in the dead litter in t/ha,

LB =Litter biomass in the dead litter in t/ha

Where, LC is total carbon stocks in the dead litter in ton/ha, 0.37 is carbon fraction (IPCC, 2006), LB is oven dry mass of litter biomass.

3.5.3. Estimation of soil organic carbon (SOC)

The carbon stock of soil was done by using the following formula which was recommended by Pearson *et al*, (2005) from the volume and bulk density of the soil.

$V = h * \Pi r^2$ …………………………...……………………………….....…… (eq.11)

Where, V = volume of the soil in the core sampler in cm^3,

h = height of core sampler in cm, and r is the radius of core sampler in cm Pearson *et al*., (2005). Moreover, the bulk density of a soil sample was calculated as follows:

Bulk density:

BD (g/cm^3) = (oven dry weight of the soil) / (volume of the core) ……………….… (eq.12)

Bulk density soil cores of 2.5 cm is the radius of core sampler and 20 cm is the height (it is modified core sampler) volume=392.5 cm^3 were used for determining the bulk density of the soil samples of each soil layer. The fresh soil samples extracted by bulk density cores were bagged in a plastic bag, sealed and labeled. Then the samples were transported to laboratory for oven dry and the oven dry105^{0}c for bulk density.

SOC = BD * D * % Cx1/100 x (1 - $\frac{frag}{100}$) x100………………………………… (eq.13)

Frag= Cores fragmentation

SOC = soil organic carbon stock per unit area (t/ha), BD = soil bulk density (g cm-^{3}),

D =the total depth which the sample was taken (40 cm), and %C = Carbon concentration (%).

Note In this analyzed was not core fragmentation

3.5.4. Estimation of total carbon stock (Woody species biomass and SOC)

The total carbon stock is calculated by summing the carbon stock woody species biomass and SOC of the individual carbon pools of the stratum using the (Pearson *et al*., 2005) formula. Carbon stock of a study area:

CT = AGC + BGC + LC +SOC………………………………………………… (eq.14)

Where, CT = Total Carbon stock for all pools (t/ha), AGC=above ground carbon stock (t/ha),

BGC= below ground carbon stock (t/ha),

LC=litter carbon stock (t/ha) and

SOC= soil organic carbon (t/ha). The total carbon stock was converted to tons of CO_2 equivalent by multiplying it by 44/12, or 3.67 as indicated by (Pearson *et al*., 2007).

3.6. Data analysis

The data which were collected from the field inventory were organized and recorded in micro soft excel 2010 data sheet. The frequencies of each tree species in all 62 sample plots were analyzed. Biomass of each tree species in all sample area was made using data from diameter class distribution, referred to as above ground biomass. The data obtained from DBH, diameter, height of each species, (W field) weight of wet field sample of litter sampled within an area of size 1 m^2 (g), fresh weight-(FW) weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g) and dry weight (Wdry) of dead litter and soil organic carbon and also soil bulk density were organized by excel 2010 and analyzed using SPSS software version 16. DBH data was arranged in classes applying appropriate model of biomass estimation equation. The relationship between each parameter was tested by descriptive statistics. To test the carbon stock potential one way ANOVA. To test the woody species diversity Shannon diversity index test was used. All of the necessary statistics were evaluated at a 95% confidence level.

4. RESULTS AND DISCUSSION

4.1. Woody species diversity and species richness

A total 103 plant species (57 trees, 36 shrubs, and 10 climbers) were recorded the sample plots (Appendix 1). These species belong to 55 families (30 wood based and 25 coffee-based) forest. Fabaceae is the most species-rich family comprising 9 (8.3%) of the total plant species identified in Zege forest, followed by Euphorbiaceae with 8(7.4%) species. Other dominant families wre Moraceae, Olacaceae and Rutaceae each represented by 5 species and together accounted 13.9% of the total identified species. The remaining 31 families (28.7%) were rare and each represented by a single species (Appendix 2).

When considering the two forest separately, a total of 56 and 47 plant species were recorded in wood based and coffee based forest respectively. Of the total identify families 8.7% were found only in wood based forest and 5.2% in coffee based forest. The tree species diversity indices of Zege forest recorded in the whole forest and in individual forest stratus is presented in (Table 1). The wood based forest had higher values of species richness, evenness and diversity than the coffee based forest.

Table 1: Species richness, Shannon diversity (H') Simpson's diversity (D) and evenness (E) of tree species in wood based and coffee based forest.

	Wood based	Coffee based	Total
Species richness	56	47	79
Shannon diversity(*H)*	3.74	2.85	3.36
Simpson's diversity *(D)*	0.78	0.75	0.79
evenness *(E)*	0.15	0.11	0.26

The overall woody species diversity of Zege forest was found to be H= 3.36 which was higher than Harenna forest (H=2.60) and Maji forest (H=1.54) (Feyera Senbeta, 2006). The number of species (103) recorded in the study area was found to be also higher than the number of species recorded in other Ethiopian Afromontane forests: Chilimo=90 (Tadesse Woldemariam *et al*., 2000); Bonga forest= 51 (Abayneh Derero *et al*., 2003); Belete forest =79 (Kitessa Hundera and Tsegaye Gadissa, 2008); Hugumburda forest=79 (Ermias Aynekulu, 2011). However, the total species number in this study was lower than that reported for Afer-Shala Luqa and South west of lake Chamo=216 species (Teshome Soromessa *et al*., 2004). *Fabaceae* was the family represented by highest number of species in Zege forest. A similar observation has been made for Belete forest (Kitessa Hundera and Tsegaye Gadissa, 2008) and Hugumburda forest (Ermias Aynekulu, 2011). This might be due to agro-ecology similarity of the forests or the adaptation potential of *Fabaceae* families to wider agro-ecologies.

The two patches were differenced due to, factors like human and environmental influences have a strong impact on forest structure, composition and species richness (Espinosa and Cabrera, 2011) though it depends on intensity and persistency of influences (Kuffer and Senn-irlet, 2004). Possible reasons for these differences may also be laid on forest size and landscape fragmentation, the distance to the nearest species pool or microclimatic factors.

4.1.1. Forest structure

The diameter size distribution of all woody species in the two patche of forests showed more or less inverted J-shape, there were greater numbers of individuals in the lower diameter size class (Figure 4). In wood based forest, 69.7% and in coffee based forest 44.3% of individuals were concentrated in the first lower diameter size class (5 -< 10 cm). Only 1.9% in wood based forest and 0.58% in coffee based forest of the total individuals found in the higher diameter size class.

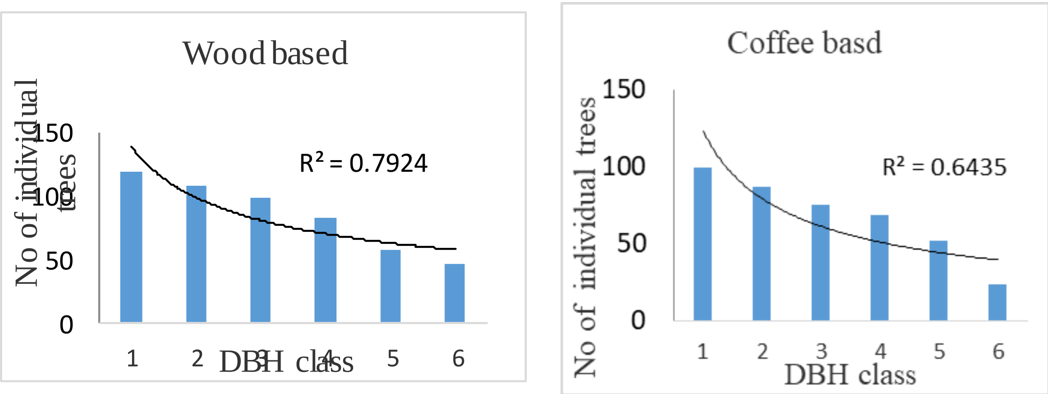

Figure 4: Diameter class distribution of all woody species within wood based and coffee based system

The height class distribution of woody species (Figure 5) revealed that 54.6 % of individuals in wood based forest were found at the lowest height class 1-5 m and gradually decreased as height size increased and only 0.26 % of individuals were recorded at the highest height class 30 m. In the wood based forest, *Ficus vasta* was again the tallest tree with 30 m and *Cupressus lusitanica* with 25 m followed by the majority of tree species 77.8 % with a height of 20 m Similarly, in coffee based forest *Ficus vasta* is the tallest tree with 34m and *Celtis africana* with 32 m is the second followed by *Nuxia congesta* 31 m. Generally many trees have heights of less than 5m, while 21.7 % of the individuals' attain heights between 5 and 10 m.

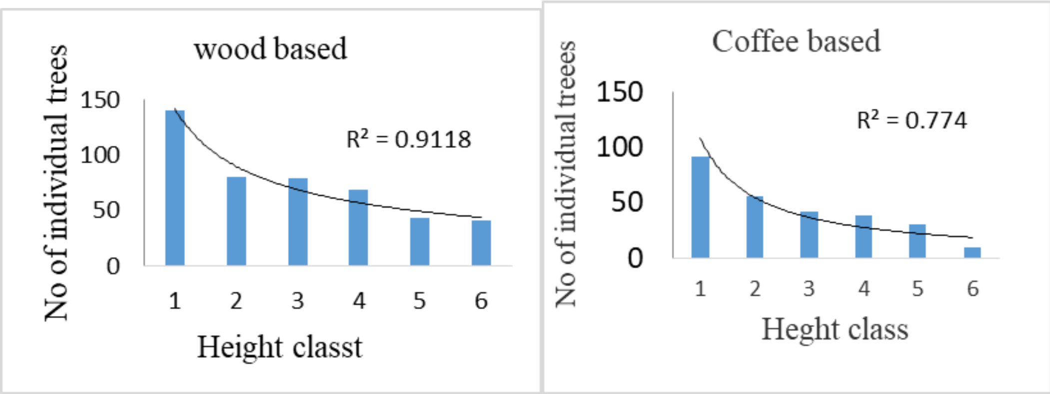

Figure 5: Height class distributions of woody species in wood based and coffee based system.

This indicates that the forest patches were highly disturbed, excessive felling of large trees in the past to meet the demand of firewood and timber, or they were at secondary stage of forest succession (Abayneh Derero *et al.*, 2003). Moreover, the large numbers of individuals in lower diameter size class might be cofounded with large number of shrubby individuals particularly coffee plant in coffee-based forest.

Despite the population structure observed in all woody species, some selected woody species exhibited different structure (Figure 4). The first pattern has inverted J-shape,was due tohigher number of individuals at lower diameter size class with gradual decreasing towards the higher diameter class. Many forest trees show such kind of structure in normal forest condition (Richards, 1996). *Rothmannia urcelliformis* and *Millettia ferruginea* were found under this structure. This implies that these species have good reproduction as well as good seedling and sapling development potential.

The second type was U -shaped structure where the numbers of individuals are higher in lowest and highest DBH classes with more or less low in the intermediate classes, *e.g.*

Albizia schimperiana. This was due to selective cutting or removal of medium sized individuals.

The third structure was Bell- shaped in e.g. *Prunus africana*, which means the species lacks seedling regeneration potential as seen in many mountain forests and suffered from selective cutting of bigger trees (Krauchi *et al*., 2000).

The fourth structure was broken inverted 'J' structure where there is relatively good early recruitment and establishment of seedlings but failure of further development to sapling and mature tree. It also indicates the threat of local extinction of the species since the mature individuals will not be replaced e.g. *Podocarpus falcatus.* Of course, the chance of regeneration of *Podocarpus falcatus* was very little and sensitive under human influenced environment and is always more exploited, and destroyed as a result of intensive logging due to its economic importance Mersha Gebrhiwot (2003).

The fifth structure was broken 'J' structure where there was a failure of reproduction as well as weak seedling and sapling development or poor regeneration as well as high mortality of the small individuals e.g. *Ficus vasta*. The structure was observed on *Prunus africana* and *Ficus vasta* was inline with the findings of Kitessa Hundera and Tsegaye Gadissa (2008) in Belete forest.

Regarding the vertical structure, only six species, *Albizia shimperiana*, *Croton macrostachyus*, *Celtis africana*, *Nuxia congesta*, *Millettia ferruginea* *Ficus vasta*, made the upper canopy of the coffee-based forest. These species were retained to grow to a larger height due to their special uses mainly. However, in wood forest only *Ficus vasta* was found in the upper canopy the rest were almost in the lower strata. Because, the species in the coffee forest were naturally shrub and small tree species that can't grow to higher height level. The low soil depth and relatively sloppy topographic nature might determine plant species existed in wood forest. In wood based forest, almost all studied plots were at higher altitude and 27.0 % of plots were at higher slope relative to plots in coffee-based forest.

4.1.2. Frequency

The frequency distributions of woody species in the study area indicate that *Rothmannia urcelliformis & Millettia ferruginea* 87.14 % frequencies each and *Ritchiea albersii* 67.1 % have highest frequency in wood based. However, only 15.7 % of woody species have a frequency value of >50 % in wood based forest. In coffee based forest- *Rothmannia urcelliformis* and *Ritchiea albersii* had 83.3 % frequencies each and *Ehretia cymosa and Croton macrostachyus* have 69.4 % frequencies each (Appendix 3).

Thus, the result verifies the existence of high degree of floristic heterogeneity in Zege natural forest. According to Lamprecht (1989), frequency was the indicated of homogeneity and heterogeneity of vegetation. High frequency value and in lower frequency classes reveal constant or similar composition. On the other hand, high percentage of number of species in the lower frequency classes and low percentage of number of species in the higher frequency classes indicates a high degree of floristic heterogeneity.

The frequency distribution of woody species in the study area indicates that *Rothmannia urcelliformis & Millettia ferruginea* 87.1 % frequencies each and *Ritchiea albersii* 67.1 % had highest frequency in wood based. However, only 15.7 % of woody species have a frequency value of >50 % in wood based forest. In coffee based forest- *Rothmannia urcelliformis* and *Ritchiea* *albersii* has 83.3% frequencies each and *Ehretia cymosa and Croton macrostachyus* have (69.4 % frequencies each).

4.1.3. Basal area

The total basal area of all woody species in Zege forest with DBH ≥5 cm was 47.87 m^2ha^{-1} - 22.76 $m^2ha^{-1}$was contributed some large sized trees wood based and coffee based forest respectively (Appendix 3). In the wood based forest and coffee based forests, the basal area of all tree species with DBH≥5 cm were 25.21 m^2ha^{-1} and 13.49 m^2ha^{-1} respectively. Ritchiea albersii with 5.102m2ha-1 (21.6%) attained the largest portion of the total tree species basal area in coffee based forest followed by Rothmannia urcelliformis with 4.19 m2ha-1 (17.76%) and Ehretia cymosa with 3.32m2ha-1(14.06%). These three species together with Ritchiea albersii and Rothmannia urcelliformis accounted 66.15 % (15.59m2ha-1) of the total basal area of all tree species in the coffee based forest. In the coffee based forest, Rothmannia urcelliformis has the highest basal area with 4.89 m2ha-1 (36.3%) and next Ritchiea albersii with 1.77 m2ha-1 (13.1%) followed by Albizia lophantha with 1.27 m2ha-1 (9.5%).

The total basal area of woody species in forest wood base forest (25.21 $m^2ha^{-1}$was in the coffee based forest was (13.49 m^2ha^{-1}) This finding disagrees with by (Bhuyan *et al*., 2003) The higher basal area in wood based forest might be due to existence of trees with larger diameter maintained for their coffee shade, lumber and fuel wood production. Thakuri (2010) reported that high basal area indicates the presence of large sized trees and closed canopy. The total stand basal area of the Zege forest (22.76 m^2 ha^{-1}) was far less than that of Belete Forest (90 m^2 ha^{-1}), (Kitessa Hundera and Tsegaye Gadissa, 2008) but higher than Hugumburda forest (9.23 m^2ha^{-1}), (Ermias Aynekulu, 2011).

4.1.4. Importance value index (IVI)

The Importance value indices of thirteen plant species with the high IVI values were summarized for each forest stratus (appendix 3) and the IVI values of all plants were *Ritchiea albersii* is the tree species with the highest IVI value of 19.81 (23.34 %) in the wood based forest. The next is *Rothmannia urcelliformis* with IVI value of 19.54 (13.85 %) followed by *Ehretia cymosa* with 17.61 (12.14 %). With IVI value of 24.11 (12.26 %) was the first followed *by Ritchiea albersii* with 24.63(8.25 %) and 20.44 (7.72 %). *Combertum molle* and *Euclea racemosa* with (0.19 each) in coffee based forest and *Ximenia americana* with 0.5 were plant species with the least IVI value.

Importance value index (IVI) was measured of the relative importance of a species in an area and combines such attributes as relative density, relative frequency and relative dominance (Van Andel, 2003) or an important parameter that reveals the ecological significance of species in a given ecosystem (Lamprecht, 1989).

The high IVI value of *Ehretia cymosa* and *Albizia schimperiana* was because of high basal area. The high IVI value of *Rothmannia urcelliformis* was might due to its high frequency and density while *Millettia ferruginea* was due to its high relative density and dominance.

Similarly, the high IVI value of *Ficus vasta* in Abebaye forest in northern Ethiopia was the result of its high basal area (Haileab Zegeye, 2011). The first four species with high IVI value together in wood based forest accounts higher proportion of IVI value 53.3% in comparing with the first four in the coffee-based 34.8 % (Appendix 3). This designates that there was high human influence in coffee based as to favor certain selected species while disfavoring the rest.

Species with high IVI values were considered more important than those with low IVI value. The IVI values can also be used to prioritize species for conservation, and species with high IVI value need less conservation efforts, whereas, those having low IVI value need high conservation effort (13.49 m^2ha^{-1}).

Generally, factors like human and environmental influences have a strong impact on forest structure, composition and species richness (Espinosa and Cabrera, 2011). Possible reasons for these differences may be laid on forest size and landscape fragmentation, the distance to the nearest species pool or microclimatic factors.

214.2. Biomass carbon stock (Above and belowground)

4.2.1. Above and belowground biomass carbon

The significant (P<0.05) mean values of above ground biomass and carbon in wood based forest management were 168.7±52.3t/ha and 84.4 ± 26.0t/ha respectively and the mean aboveground biomass and carbon value of coffee-based forest management were 123.5±27.5t/h and 43.9±13.6 t/ha respectively (Table 2). The maximum and minimum equivalent carbon dioxide in wood based forest and coffee-based forest were 405.53t/ha and 213.96 t/ha and 251.76 and 101.85 t/ha respectively.

Belowground biomass and carbon of the study site was in wood based forest 43.9±13.6t/ha based forest 22.0±6.8t/ha and belowground biomass carbon coffee based forest 32.1±7.4 t/ha 13.8±3.6 t/ha respectively .The maximum and minimum equivalent carbon dioxide of the study site was wood based 105.69t//ha and 35.78 t/ha and coffee based 68.85t/ha and 27.43 t/ha respectively (Table 2). The mean of aboveground biomass carbon stock study area which are higher than those continental assessments by IPCC (2006) and Brown

(1997). As compared to recent studies the above ground biomass carbon of the study site was lower than Menagasha Suba State Forest (281.53 t/ha), Egdu Forest (614.73 t/ha) and Banja Forest (639.86 t/ha) (Mesfin Sahile, 2011, Adugna Feyissa *et al.*, 2013 Fentahun Abere, 2016) respectively. This differences is might be due to variations in age of the trees, management of the forests, the allometric model used (Lasco *et al.*, 2000). Therefore, forest status was well managed and protected even though there wassome human interference for forest management.

The variation was might be due to large trees have much more potential to produce larger quantities of belowground biomass compared to small trees. Therefore, forest status was well managed and protected even though there is some human interference for forest management.

As compared to recent studies the below ground biomass carbon of the study site was lower tha Tara Gedam forest (61.5 t/ha), Danaba Community Forest, (41.7 t/ha) Egdu forest, (55.3 t/ha) and Menagasha Suba State Forest, (27.0 t/ha) (Mohammed Gedefaw *et al.*, 2014, Muluken Nega *et al*, 2014, Adugna Feyissa *et al.*, 2013 and Mesfin Sahile, 2011).This variation is might be due to the presence large trees much higher potential to produce larger quantities of belowground biomass compared to small trees. The difference might be the DBH, height of trees and the allometric equations.

4.2.2. Litter biomass carbon

The litter biomass of the sample plots showed relatively different values. The minimum value observed with 0.03 t/ha and the maximum value was 0.68 t/ha.

The litter carbon concentration per sample plot in the laboratory analysis was resulted with the in the wood based forest minimum value 0.23t/ha and maximum value 0.41 t/ha and coffee based forest minimum value 0.11t/ha and maximum value 0.28t/ha. Mean total carbon stock of litter of the study site was wood based forest 0.31 ± 0.06 t/ha and coffee based 0.23±0.04 t/ha respectively (Table 2). The equivalent Carbon dioxide of the study site was also resulted in with the maximum and minimum value 1.36 and 0.92 t/ha and 0.99 and 0.69 t/ha, wood based and coffee based forest respectively.

Table 2: One-way ANOVA for wood based and coffee based carbon pools mean ± SD systems of Dry Afromontane forest.

	Wood based forest		Coffee based forest		P-value
	Biomass (t/ha)	Carbon (t/ha)	Biomass (t/ha)	Carbon (t/ha)	
AG (Tree)	168.7 ±52.3	84.4 ±26.1	123.5 ±27.5	61.8 ±6.8	0.003
AG (Litter)	0.66 ±0.12	0.31 ±0.06	0.48 ±0.08	0.23 ±0.04	0.007
BG	43.9 ±13.6	22.0 ±6.8	32.1 ±7.4	13.8 ±3.6	0.003
Total	213.3 ± 66.0	106.7 ±33.0	156.8 ±35.0	75.83 ±10.4	

The present study was lower than Egdu Forest (Adugna Feyissa *et al*., 2013) (3.47 t/ha) and Menagasha Suba State Forest (Mesfin Sahile, 2011) (5.26 t/ha) Tara Gedam Forest (Mohammed Gedefaw *et al*., 2014) (0.92 t/ha). The reason for the small litter carbon stock of in the present study was due to huge closed canopies up to the near ground making the growth of herbs and grasses unsuitable. As the present study area had mountainous manifestation, litter run off occurred and might cause for small carbon account in this pool.

In most parts of Ethiopia tree litter layers are cleared for fuel wood; and this may explain the relatively lower carbon stock observed in the site.

4.3. Soil organic carbon stock

The bulk density of the soil profile found in the study site is ranged from wood based forest 0.39 g cm^3 to 0.95 gcm^3 value with an average value of 0.66 $gcm^3$and also coffee based forest 0.41 $gcm^3$to 1.2 g value with an average value of 0.81 gcm^3. The highest and the lowest soil carbon stock of the Zege forest is in wood based range from 89.86 - 64.68t/ha and coffee based forest range highest to lowest 69.4t/ha and 44.7t/ha respectively. The mean soil carbon stock of the study site is in wood based 161.74±14.80t/ha and in coffee-based 126.72±8.71t/ha. But, there were significant differences soil organic carbon with management practice ($P <0.05$) (Table 3). Wood based top oil 0-20cm contained significantly ($P <0.05$) higher SOC (87.68±9.35t/ha) as compared to the layer 20-40 cm (74.06±7.40t/h. Coffee based top soil 0-20cm contained significantly higher SOC 68.00±7.66t/ha as compared to layer 20-40cm (58.72±7.16t/ha) significant ($P <0.05$). So, there were significant differences of soil organic carbon with depth (Table 3).

Table 3 : SOC Wood based and coffee-based one-way ANOVA results of mean ± SD (t/ha).

Soil depth(cm)	df	Soil organic carbon (tc/ha)		
		Wood based	Coffee based	P-value
0-20	61	87.7 ±7.4	68.0 ±7.7	0.000
20-40	61	74.1 ±7.4	58.7 ±7.2	0.000
Total (0-40)	61	161.8 ±14.8	126.7 ±14.8	0.000

The mean soil bulk density values of wood based (0.72, and 0.79 g cm^{-3}), and coffee based (0.87., and 0.92 g cm^{-3}) was observed in 0-20, and 20-40 soil depths a respectively. This result showed that bulk density values increased with the increasing depths among all stratus.

The litter decomposition was one of the major sources of soil organic carbon and the decomposition process was dependent on the quality of the litter fall (Mafongoya *et al*., 1998) and the plant species (Lemma *et al*., 2007). Litter decomposition rates are also frequently considered to be regulated by soil organisms, environmental conditions and chemical nature of the litter (Gallardo and Merino, 1993). The physical environment, especially soil moisture, temperature and relative humidity are important in litter decomposing as these regulate the biological activity in soil (Sayer, 2006).

4.4. Total carbon stock of the study area

In the present study, the highest carbon stock was contributed by the SOC, which accounted in the 144.23±12.02t/ha four carbon pools. Aboveground carbon73.1 ±16.5 t/ha and the third were recorded in below ground carbon which accounted for 19.6 ±5.2 t/ha and the least carbon pool was in the litter, which 0.27±0.08t/ha. The total carbon stocks of Zege natural forest were 237.50±33.1 t/ha (Table 4).

Table 4: One-way ANOVA results of mean ± SD biomass carbon and SOC stocks of the Zege natural forest.

	Carbon pools (tc/ha)				
Vegetation zone	AGC	BGC	LC	SOC	Total
Wood based	84.4 ±26.1	23.0 ±6.8	0.31 ±0.04	161.7 ±14.8	269.4 ±47.7
Coffee-based	61.8 ±6.8	16.8 ±3.6	0.23 ±0.04	126.7 ±8.7	205.5 ±19.1
Mean total	73.1 ±16.5	19.9 ±5.2	0.27 ±0.08	144.2 ±11.8	237.5 ±33.1

Carbon stocks estimated was lower than Menagesha Suba State forest (281.53 t/ha), Banja forests (639.86 t/ha), Egdu Forest (. 614.73 t/ha) and Tara Gedam Forest (643.1 t/ha) (Mesfin Sahile, 2011, Fentahun Abere, 2016, Adugna Feyissa *et al.*, 2013, Mohammed Gedefaw *et al.*, 2014).

The wood based forest total carbon stock significantly the higher than the total carbon stock coffee based was observed. This is might be due to forest management has aboveground biomass carbon, belowground biomass carbon and litter biomass carbon stock compared to the coffee based forest. So, there was much accumulation of organic matter in wood based forest

There was more carbon stock appeared in forest wood based forest might be due to plants capture CO_2 from the atmosphere through the process of photosynthesis. The standing vegetation, most of which is eventually added to the soil as plant organic litter and then to the soil as SOC by microbial activity. Therefore, the estimation of carbon stock both in the aboveground and in soil becomes imperative to assess the carbon sequestration potential (Ramachandran *et al*., 2007). Generally, this result indicated that the study area had large carbon stock and sequestered large amount of CO_2 contributing to the mitigation of global climate change.

5. CONCLUSIONS AND RECOMMONDATIONS

5.1. Conclusions

Total of 55 (30 in wood based and 25 coffee based) common families with 103 woody species. The dominant species Ritchiea *albersii*, *Rothmannia urcelliformis, Ehretia cymosa* and *Millettia ferruginea* and *Rothmannia urcelliformis*, *Ritchiea albersii*, *Albizia lophantha*, and *Millettia ferruginea* respectivelyin the system. Shrubs accounted the largest proportions followed by trees. Family Fabaceae is the dominant family contributing the large proportion of species.

The density of woody was decrease with increasing DBH classes. The DBH class distribution of Zege forest showed that more or less inverted J shaped which has the capacity for regeneration.

The carbon stock potential the study forest was 237.5 ±40.07 t/ha of carbon, equivalent to 871.63 ±147.67 ton/ha of CO_2. Thus, Zege forest plays an important role for climate change mitigation of the surrounding area. Organic soil carbon pool was also found to have a good reservoir of carbon stock in the Zege natural forest. The other important carbon pool was the litter that contributed for carbon sinks in this forest with comparable carbon density as compared to other Ethiopian and tropical forests.

In general, Zege forest had both the highest stock of carbon and tree species diversity as it has different population structure. Hence, conservation efforts in Zege forest should be targeted to achieve the carbon storage potential of forest, which could help in meeting double objectives of emission reduction from deforestation and biodiversity conservation purposes. Therefore, participatory forest management is crucial to have principal impact in emission reduction, enhancement of regeneration and carbon stock preservation from climate change adaptation and mitigation point of view.

5.2. Recommendations

Based on the findings of the study the following recommendations are forwarded:

- Planting new seedlings, promote natural regeneration and conserving degraded areas with local community participation should be undertaken to sustain the existing carbon stock in the forest and increase its biomass in the future.

- Considering the remnant patch forests like Zege forests as in-situ biodiversity conservation is very paramount crucial.

- The regional government should have to give attention and creating awareness to the local people regarding forest management and sustainable use of natural resources.

- Conducting research on the development of modeling and application of country specific (species specific) allometric equations is recommended. This will increase the reliability and acceptance of the existing data on forest carbon stocks.

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APPENDIX

Appendix 1: Location map of sampling plots

Vegetation zone	Transect line	Plot#	latitude	longitude	Altitude (M)
Wood based forest	1	1	318266.4	1292214.564	1814
		2	318720.5	1292405.12	1804
		3	319184.1	1292599.625	1812
		4	319648.9	1292814.53	1818
		5	320104.6	1292985.822	1814
		6	320568.3	1293180.363	1815
		7	321030.2	1293374.174	1786
		8	321040.8	1293378.621	1806
	2	9	317651.5	1292460.861	1840
		10	318113.4	1292654.672	1842
		11	318575.4	1292848.483	1855
		12	319037.3	1293042.294	1843
		13	319499.2	1293236.104	1844
		14	319961.2	1293429.915	1854
		15	320421.7	1293623.132	1800
		16	320724.3	1293731.423	1813
	3	17	317233.3	1292784.226	1844
		18	317496.2	1292894.569	1850
		19	317958.2	1293088.38	1900
		20	318420.1	1293282.191	1895
		21	318882.1	1293476.002	1890
		22	319344	1293669.813	1865
		23	319805.9	1293863.624	1850
		24	320267.9	1294057.435	1851

		25	320729.8	1294251.246	1800
	4	26	317078.1	1293144.985	1830
		27	317364.2	1293272.95	1850
		28	317826.1	1293466.761	1892
		29	318288.1	1293660.572	1960
		30	318750	1293854.383	1955
		31	319212	1294048.194	1930
		32	319673.9	1294242.005	1873
		33	320135.8	1294435.816	1832
		34	320597.8	1294629.627	1808
Coffee based forest	5	35	316606.4	1293374.268	1814
		36	316773.6	1293447.93	1821
		37	317232.6	1293650.126	1850
		38	317694.1	1293845.142	1904
		39	318156	1294038.953	1948
		40	318618	1294232.764	1979
		41	319079.9	1294426.575	1930
		42	319519.1	1294610.855	1850
		43	320004	1294813.681	1811
	6	44	316302.7	1293676.243	1806
		45	316641.4	1293826.783	1813
		46	317100.4	1294028.978	1853
		47	317562.1	1294223.523	1904
		48	318024	1294417.334	1909
		49	318485.9	1294611.145	1908
		50	318947.9	1294804.956	1879
		51	319409.8	1294998.767	1828
		52	319556.9	1295069.689	1817

	7	53	316506.2	1294214.282	1802
		54	316968.2	1294407.831	1836
		55	317430	1294601.904	1860
		56	317892	1294795.715	1856
		57	318353.9	1294989.526	1846
		58	318815.8	1295183.337	1841
		59	319277.8	1295377.148	1841
		60	317759.9	1295174.096	1813
	8	61	318221.9	1295367.907	1809
		62	318683.8	1295561.718	1805

Appendix 2: List of plant species Vernacular name, Scientific name Family, Plant form and Occurrence(1&2) recorded in Zege natural forest

No	Scientific name	Local name	Family name	Plant form	Occurrence
1	*Acanthus senni* Chiov.	Kosheshela	Acanthaceae	Shrub	2
2.	*Acokanthera schimper*	Merz	Apocynaceae	Tree	1,2
3.	*Albizia grandibracteata* Taub.	Mogne sesa	Fabaceae	Tree	1,2
4	*Albizia lophantha*(Willd) Benth	Sesa mesel	Fabaceae	Tree	1
5	*Albizia malacophylla* (A. Rich.) Walp.	Sendel	Fabaceae	Tree	1,2
6	*Albizia schimperiana* Oliv.	Abat sesa	Fabaceae	Tree	1,2
7	*Allophylus abyssinicus* (Hochst.) Radlk.	Yetota mirak	Sapindaceae	Tree	1
8	*Apodytus dimidiata* E. Mey. ex Arn. var.	Donga	Icacinaceae	Tree	2
9	Bersama abyssinica Fresen. Subsp. Abyssinica	Azamir	Melianthaceae	Tree	2
10	*Bridelia micrantha* (Hochst.) Baill.	Yeneber tifer	Euphorbiaceae	Shrub	2
11	*Brucea antidysenterica* J.F.Miller	Yedega abalo	Simaroubaceae	Shrub	1,2
12	*Buddleja polystachya* Fresen.	Anfar	Loganiaceae	Tree	1,2
13	*Calpurnia aurea* (Ait.) Benth.	Digta	Fabaceae	Shrub	1,2
14	*Capparis tomentosa*	Gumero	Capparidaceae	Shrub	1,2
15	*Carica papaya* L.	Papaya	Caricaceae	Tree	1
16	*Carissa edulis* (Forssk.) Vahl	Agam	Apocynaeae	Shrub	1

17	*Cassipourea malosana* (Bak.) Alston	Qeret	Rhizophoraceae	Shrub	1
18	Catha edulis (Vahl) Forssk. ex Endl.	Chat	Celastraceae	Shrub	1,2
19	*Celtis africana* Burm. f.	Kawa	Ulmmaceae	Tree	1,2
20	*Chionanthus mildbraedii* (Gilg. & Schellenb.)	Yebaria esheh	Oleaceae	Tree	1,2
21	Citrus aurantifolia (Christm.) Swingleb	Lomi	Rutaceae	Tree	1,2
22	*Citrus aurantium* L.b	Behro lomi	Rutaceae	Tree	1,2
23	Citrus medica L.	Tirengo	Rutaceae	Shrub	1,2
24	*Clausena anisata* (Willd.) Benth.	Limich	Rutaceae	Shrub	1
25	*Clematis longicauda* Steud. ex A.	Azohareg	Ranunculaceae	Shrub	1
26	*Clematis simensis* Fresen.	Azoharge	Ranunculaceae	Shrub	1
27	*Coffea arabica* L.	Buna	Rubiaceae	Shrub	1,2
28	*Combretum molle* R. Br. ex G. Don.	Avalo	combretaceae	Tree	1,2
29	*Cordia africana* Lam.	Wanza	Boraginaceae	Tree	1,2
30	*Croton macrostachyus* Del.	Bisana	Euphorbiaceae	Tree	1,2
31	*Cupressus lusitanica*	Yeferenje tide	Cupressaseae	Tree	1
32	*Cussonia ostinii* Chiov.	chakima	Araliaceae	Tree	1,2
33	*Dalbergia lactea* Vatke.	Yezemed lit	Fabaceae	Shrub	1,2
34	Diospyros abyssinica (Hiern) F.White	Selchen	Ebenaceae	Tree	1,2
35	*Dombeya quinqueseta* (Del.) Exell.	Wulkefa	Sterculiaceae	Tree	1,2

36	*Dracaena steudneri* Engl.	Tsepatos	Dracaenaceae	Tree	1,2
37	*Ehretia cymosa* Thonn.	Kindaba	Boraginaceae	Tree	1,2
38	*Ekebergia capensis* Sparm	Lool	Meliaceae	Tree	1,
39	*Entada abyssinica* Steud. ex A. Rich.	Ambleta	Fabaceae	Tree	1,2
40	*Euclea racemosa* subsp. schimperi (A.DC.)	Dedho	Ebenaceae	Shrub	1,2
41	*Euphorbia candelabrum* Kotschy.	Kulkul	Euphorbiaceae	Tree	1
42	*Euphorbia ti*rucalli L.	Kinchib	Euphorbiaceae	Tree	1
43	*Ficus ovata* Vahl	Qef	Moraceae	Tree	1
44	*Ficus sur* Forssk.	Sholla	Moraceae	Tree	1,2
45	*Ficus sycomorus* L	Bamba	Moraceae	Tree	1.2
46	*Ficus thonningii* Blume.	Chibha	Moraceae	Tree	1,2
47	*Ficus vasta* Forssk.	Warka	Moraceae	Tree	1,2
48	*Flacourtia indica* (Burm.f.) Merr.	Enqua	Flacourtaceae	Tree	1,2
49	*Gardenia ternifolia* Schumach. & Thon	Gamibalo	Rubiaceae	Tree	1,2
50	*Grewia bicolor* Juss.	Sefa	Tiliaceae	Tree	1
51	*Grewia ferruginea* Hochst. ex A. Rich	Lenqwata	Tiliaceae	Tree	1,2
52	*Helinus mystacinus* (Ait.) E. Mey. ex Steud	Esat abird	Rhamnaceae	Woody climber	1,2
53	*Hypericum quartiniannum* A.Rich	Telbosh	Hypericaceae	Shrub	1,2
54	*Jacaranda mimosifolia* D.Don	Yetemenja zaf	Boraginaceae	Tree	1

55	*Jasmium abyssinicm*(Hochest.ex) Dc.	Tembellel	Oleaceae	Woody climber	1
56	*Justicia schimperiana* (Hochst. ex Nees)	Smiza	Acanthaceae	Shrub	1,2
57	*Mangifera indica* L.b	Manigo	Anacarddiaceae	Tree	2
58	*Maytenus gracilipes* subsp. arguta (Lees.)	Atat	Celastraceae	Shrub	1,2
59	*Millettia ferruginea* (Hochest.).Back	Birbira	Fabaceae	Tree	1,2
60	*Mimusops kummel* A. DC.	Eshe	Sapotaceae	Tree	1,2
61	*Myrtus communis* Juss	Ades	Myrtaceae	Shrub	1,2
62	*Nuxia congesta* Fresen.	Keskessie	Loganaceae	Shrub	1,2
63	*Olea capensis* subsp.welwitschii (Knobl.)	Qerer	Oleaceae	Tree	2
64	*Olea europaea* subsp. cuspidata (Wall. ex DC.)	Woyra	Oleaceae	Tree	2
65	*Olinia rochetiana* A. Juss.	Woyrer	Oliniaceae	Tree	1,2
66	*Otostegia intergrifolia* Benth.	Tinjit	Lamiceae	Shrub	1
67	*Otostegia tomentosa* subsup.ambigiens(chiov)	Tinijit mesel	Lamiceae	Shrub	1
68	*Pavetta oliveriana* Heirn.	Yebuna msaya	Rubiaceae	Shrub	1
69	*Pergularia daemia* (Forssk.) chiov.	Yahaya qanja	Asclepiadaceae	Shrub	1,2
70	*Persea americana* Mill.	Avocado	Lauraceae	Tree	2
71	*Phragmathera regularis*(Sprague)M.Gilbert	Tekettla	Loranthaceae	Epiphyte	1
72	*Phyllanthus ovaliformis* Forssk.	Zigralava	Euphorbiaceae	shrub	1
73	*Phytolacca dodecandra* L’ Her	Endod	Phytolacaceae	Woody climber	1

74	*Piliostgma thonngii* (Schumach.) Milne-Redh	Lafdi	Fabaceae	Tree	1,2
75	*Pittosporium viridiflorum* Sims	Dingay seber	Pittosporaceae	Tree	1,2
76	*Podocarpus falcatus* (Thunb.) Mirb.	Zigba	Podocarpaceae	Tree	1,2
77	*Premna schimperi* Engler.	Checiho	Verbenaceae	Shrub	1,2
78	*Prunus africana* (Hook.f.) Kalkm.	Akoma	Rosaceae	Tree	1,2
79	*Psidium guajava* L.b	Zeituna	Myrtaceae	Shrub	1,2
80	*Pterolobium stellatum* (Forssk.) Brenan.	Kentef	Fabaceae	Woody climber	1,2
81	*Rhamnus prinoides* L'Herit. a b	Gesho	Rhamnaceae	Tree	1,2
82	*Rhus glutinosa* A. Rich.	Embes qumo	Anacardiaceae	Tree	1,2
83	*Rhus vulgaris* Meikle	Qamo	Anacardiaceae	Tree	1,2
84	*Ritchiea albersii* Gilg.	Kosila	Capparidaceae	Tree	1,2
85	*Rothmannia urcelliformis* (Hiern) Robyns	Barya koba	Rubiaceae	Tree	1,2
86	*Rumex nervosus* Vahl.	Embancho	Polygonaceae	Shrub	1,2
87	*Ruttya speciosa* Engler.	Teje amtit	Acanthaceae	Woody climber	1
88	*Sapium ellipticum* (Hochst. ex Krauss) Pax	Arboje	Euphorbiaceae	Tree	2
89	*Senna petersiana*(Bolle) Lock	Yedha mar	Fabaceae	Shrub	1,2
90	*Senna septentrionalis* (Viv.) Irwin & Barneby c	Yamoraguaya	Fabaceae	Shrub	1,2
91	*Siygium guineense*(Wild) DC.subsp.guineense	Dokma	Myrtaceae	Tree	1,
92	*Solanum gigantum* Jacq. Woody	Dengorita	Solanaceae	Shrub	1

93	*Steganotaenia araliacea* Hochst	Shenkore	Apiaceae	Tree	1,2
94	*Stereospermum kunthianum* Cham.	Zana	Bignoniaceae	Tree	1,2
95	*Tephrosia elata Deflers* Shrub	Woyno	Fabaceae	Shrub	2
96	*Terminalia brownii* Fresen.	Abalo	combretaceae	Tree	1,2
97	*Trema orientalis*(L) Bl	Shumiya	Ulmmaceae	Tree	1,2
98	*Vangueria volkensii* K.Schum	Shembolekita	Rubiaceae	Tree	1,2
99	*Vepris dainelli* (Pichi-Sermolli) Kokwaro	Sila	Rutaceae	Tree	1,2
100	*Vernonia amygdalin*a Del.	Sete girawa	Asteraceae	Shrub	1,2
101	*Vernonia hochstetteri* Sch. Bip. Ex Walp.	Amedmado	Asteraceae	Shrub	1,2
102	*Vernonia myriantha* Hook.f.	Wondo grawa	Asteraceae	Shrub	1,2
103	*Ximenia americana* L.	Enkoy	Olacaceae	Shrub	1

*1=Wood based forest &2=coffe based forest

Appendix 3: Relative Frequency, Relative Density, Relative Dominance and Importance Value Index (IVI) of tree species of wood based Zege natural forest

Botanical name	plant form	Aban dance	occc urence	DBH (m)	Fre	RF (%)	D (ha^{-1})	RD (%)	BA (m^2)	RBA (m^2)	RDO (%)	IVI
Acokanthera schimper	Tree	22	9	0.39	26.5	1.5	16.2	0.9	0.1	2.6	2.6	5.0
Albizia grandibracteata	Tree	87	21	0.29	61.8	3.4	64.0	3.7	0.1	5.7	1.4	8.5
Albizia lophantha(Willd)	Tree	205	29	0.32	85.3	4.7	150.7	8.8	0.1	16.5	1.7	15.2
Albizia malacophylla	Tree	22	10	0.27	29.4	1.6	16.2	0.9	0.1	1.3	1.2	3.8
Albizia schimperiana	Tree	78	21	0.46	61.8	3.4	57.4	3.3	0.2	13.0	3.6	10.3
Allophylus abyssinicus	Tree	19	7	0.26	20.6	1.1	14.0	0.8	0.1	1.0	1.1	3.1
Apodytus dimidiata	Tree	12	3	0.52	8.8	0.5	8.8	0.5	0.2	2.5	4.6	5.6
Bersama abyssinica	Tree	47	19	0.27	55.9	3.1	34.6	2.0	0.1	2.7	1.2	6.3
Carica papaya	Tree	7	7	0.11	20.6	1.1	5.1	0.3	0.0	0.1	0.2	1.6
Celtis africana	Tree	107	27	0.41	79.4	4.4	78.7	4.6	0.1	14.1	2.8	11.8
Citrus aurantifolia	Tree	19	6	0.08	17.6	1.0	14.0	0.8	0.0	0.1	0.1	1.9
Citrus aurantium	Tree	17	9	0.07	26.5	1.5	12.5	0.7	0.0	0.1	0.1	2.3
Combretum molle	Tree	8	4	0.37	11.8	0.6	5.9	0.3	0.1	0.9	2.3	3.3
Cordia africana	Tree	79	21	0.49	61.8	3.4	58.1	3.4	0.2	14.9	4.1	10.8

Croton macrostachyus	Tree	86	29	0.43	85.3	4.7	63.2	3.7	0.1	12.5	3.1	11.5
Ehretia cymosa	Tree	242	30	0.38	88.2	4.8	177.9	10.3	0.1	27.4	2.4	17.6
Ekebergia capensis	Tree	7	4	0.24	11.8	0.6	5.1	0.3	0.0	0.3	1.0	1.9
Entada abyssinica	Tree	7	6	0.37	17.6	1.0	5.1	0.3	0.1	0.8	2.3	3.6
Euphorbia tirucalli	Tree	5	3	0.39	8.8	0.5	3.7	0.2	0.1	0.6	2.6	3.3
Ficus ovata	Tree	5	5	0.31	14.7	0.8	3.7	0.2	0.1	0.4	1.6	2.6
Ficus sur	Tree	6	3	0.41	8.8	0.5	4.4	0.3	0.1	0.8	2.8	3.6
Ficus thonningii	Tree	8	7	0.42	20.6	1.1	5.9	0.3	0.1	1.1	3.0	4.5
Ficus vasta	Tree	6	4	0.47	11.8	0.6	4.4	0.3	0.2	1.0	3.7	4.6
Flacourtia indica	Tree	9	3	0.21	8.8	0.5	6.6	0.4	0.0	0.3	0.7	1.6
Gardenia ternifolia	Tree	33	19	0.23	55.9	3.1	24.3	1.4	0.0	1.4	0.9	5.4
Grewia bicolor	Tree	5	3	0.12	8.8	0.5	3.7	0.2	0.0	0.1	0.2	0.9
Grewia ferruginea	Tree	20	9	0.09	26.5	1.5	14.7	0.9	0.0	0.1	0.1	2.4
Jacaranda mimosifolia	Tree	13	6	0.32	17.6	1.0	9.6	0.6	0.1	1.0	1.7	3.3
Mangifera indica	Tree	8	5	0.09	14.7	0.8	5.9	0.3	0.0	0.1	0.1	1.3
Millettia ferruginea	Tree	189	32	0.47	94.1	5.2	139.0	8.1	0.2	32.8	3.7	17.0
Mimusops kummel	Tree	48	18	0.32	52.9	2.9	35.3	2.0	0.1	3.9	1.7	6.7

Olea capensis	Tree	7	3	0.47	8.8	0.5	5.1	0.3	0.2	1.2	3.7	4.5
Olea europaea	Tree	5	2	0.43	5.9	0.3	3.7	0.2	0.1	0.7	3.1	3.7
Piliostgma thonngi	Tree	2	2	0.28	5.9	0.3	1.5	0.1	0.1	0.1	1.3	1.7
Pittosporium viridiflorum	Tree	6	3	0.39	8.8	0.5	4.4	0.3	0.1	0.7	2.6	3.3
Podocarpus falcatus	Tree	11	7	0.56	20.6	1.1	8.1	0.5	0.2	2.7	5.3	6.9
Prunus africana	Tree	20	9	0.31	26.5	1.5	14.7	0.9	0.1	1.5	1.6	3.9
Rhamnus prinoides	Tree	47	17	0.34	50.0	2.7	34.6	2.0	0.1	4.3	2.0	6.7
Rhus glutinosa	Tree	17	9	0.21	26.5	1.5	12.5	0.7	0.0	0.6	0.7	2.9
Rhus vulgaris	Tree	31	18	0.16	52.9	2.9	22.8	1.3	0.0	0.6	0.4	4.7
Ritchiea albersii	Tree	301	31	0.34	91.2	5.0	221.3	12.9	0.1	27.3	2.0	19.8
Rothmannia urcelliformis	Tree	253	32	0.46	94.1	5.2	186.0	10.8	0.2	42.0	3.6	19.5
Sapium ellipticum	Tree	2	2	0.31	5.9	0.3	1.5	0.1	0.1	0.2	1.6	2.0
Siygium guineense	Tree	12	9	0.28	26.5	1.5	8.8	0.5	0.1	0.7	1.3	3.3
Steganotaenia araliacea	Tree	13	9	0.28	26.5	1.5	9.6	0.6	0.1	0.8	1.3	3.3
Stereospermum kunthian	Tree	83	28	0.43	82.4	4.5	61.0	3.5	0.1	12.0	3.1	11.2
Terminalia brownii	Tree	18	14	0.34	41.2	2.3	13.2	0.8	0.1	1.6	2.0	5.0
Trema orientalis	Tree	7	4	0.32	11.8	0.6	5.1	0.3	0.1	0.6	1.7	2.7

Vangueria volkensii	Tree	19	13	0.29	38.2	2.1	14.0	0.8	0.1	1.3	1.4	4.3
Vepris dainelli	Tree	62	29	0.35	85.3	4.7	45.6	2.6	0.1	6.0	2.1	9.4
		2342	620	16.13	1823.5	100.0	1722.1	100.0	4.6	264.9	100.0	300.0

Appendix 4: Relative Frequency, Relative Density, Relative Dominance and Importance Value Index (IVI) of tree species coffee based Zege natural forest

Botanical name	plant form	Aban dance	Occur rence	DBH (m)	Fre	RR (%)	D (ha^{-1})	RD (%)	BA (ha)	RBA (ha)	RDO (%)	IVI
Acokanthera schimper	Tree	15	7	0.44	25.0	1.7	15.6	1.1	0.2	2.9	2.3	5.7

Albizia grandibracteata	Tree	47	13	0.34	46.4	3.1	49.0	3.5	0.1	1.7	4.3	8.3
Albizia lophantha(Willd)	Tree	148	21	0.37	75.0	5.1	154.2	10.9	0.1	2.0	15.9	18.0
Albizia malacophylla	Tree	18	9	0.32	32.1	2.2	18.8	1.3	0.1	1.5	1.4	5.0
Albizia schimperiana	Tree	58	17	0.51	60.7	4.1	60.4	4.3	0.2	3.9	11.8	12.2
Allophylus abyssinicus	Tree	10	7	0.31	25.0	1.7	10.4	0.7	0.1	1.4	0.8	3.9
Apodytus dimidiata	Tree	8	3	0.57	10.7	0.7	8.3	0.6	0.3	4.8	2.0	6.1
Bersama abyssinica	Tree	23	14	0.32	50.0	3.4	24.0	1.7	0.1	1.5	1.8	6.6
Carica papaya	Tree	3	7	0.16	25.0	1.7	3.1	0.2	0.0	0.4	0.1	2.3
Celtis africana	Tree	72	20	0.46	71.4	4.8	75.0	5.3	0.2	3.1	12.0	13.3
Citrus aurantifolia	Tree	8	6	0.13	21.4	1.4	8.3	0.6	0.0	0.3	0.1	2.3
Citrus aurantium	Tree	10	5	0.12	17.9	1.2	10.4	0.7	0.0	0.2	0.1	2.2
Combretum molle	Tree	5	3	0.42	10.7	0.7	5.2	0.4	0.1	2.6	0.7	3.7
Cordia africana	Tree	40	16	0.54	57.1	3.9	41.7	3.0	0.2	4.3	9.2	11.1
Croton macrostachyus	Tree	67	23	0.48	82.1	5.6	69.8	4.9	0.2	3.4	12.1	13.9
Ehretia cymosa	Tree	101	23	0.41	82.1	5.6	105.2	7.5	0.1	2.5	13.3	15.5
Ekebergia capensis	Tree	3	2	0.27	7.1	0.5	3.1	0.2	0.1	1.1	0.2	1.8
Entada abyssinica	Tree	2	2	0.4	7.1	0.5	2.1	0.1	0.1	2.4	0.3	3.0

Euphorbia tirucalli	Tree	3	2	0.42	7.1	0.5	3.1	0.2	0.1	2.6	0.4	3.3
Ficus ovata	Tree	4	3	0.34	10.7	0.7	4.2	0.3	0.1	1.7	0.4	2.7
Ficus sur	Tree	6	4	0.44	14.3	1.0	6.3	0.4	0.2	2.9	0.9	4.3
Ficus thonningii	Tree	12	7	0.45	25.0	1.7	12.5	0.9	0.2	3.0	1.9	5.6
Ficus vasta	Tree	5	4	0.5	14.3	1.0	5.2	0.4	0.2	3.7	1.0	5.0
Flacourtia indica	Tree	9	3	0.24	10.7	0.7	9.4	0.7	0.0	0.9	0.4	2.2
Gardenia ternifolia	Tree	23	10	0.26	35.7	2.4	24.0	1.7	0.1	1.0	1.2	5.1
Grewia bicolor	Tree	5	4	0.15	14.3	1.0	5.2	0.4	0.0	0.3	0.1	1.7
Grewia ferruginea	Tree	11	6	0.12	21.4	1.4	11.5	0.8	0.0	0.2	0.1	2.5
Jacaranda mimosifolia	Tree	10	5	0.35	17.9	1.2	10.4	0.7	0.1	1.8	1.0	3.8
Mangifera indica	Tree	3	2	0.12	7.1	0.5	3.1	0.2	0.0	0.2	0.0	0.9
Millettia ferruginea	Tree	105	20	0.5	71.4	4.8	109.4	7.8	0.2	3.7	20.6	16.3
Mimusops kummel	Tree	28	15	0.35	53.6	3.6	29.2	2.1	0.1	1.8	2.7	7.5
Olea capensis	Tree	3	3	0.5	10.7	0.7	3.1	0.2	0.2	3.7	0.6	4.7
Olea europaea	Tree	2	2	0.46	7.1	0.5	2.1	0.1	0.2	3.1	0.3	3.8
Piliostgma thonngi	Tree	1	1	0.31	3.6	0.2	1.0	0.1	0.1	1.4	0.1	1.7
Pittosporium viridiflorum	Tree	3	2	0.42	7.1	0.5	3.1	0.2	0.1	2.6	0.4	3.3

Podocarpus falcatus	Tree	6	4	0.59	14.3	1.0	6.3	0.4	0.3	5.2	1.6	6.6
Prunus africana	Tree	7	4	0.34	14.3	1.0	7.3	0.5	0.1	1.7	0.6	3.2
Rhamnus prinoides	Tree	21	11	0.37	39.3	2.7	21.9	1.6	0.1	2.0	2.3	6.2
Rhus glutinosa	Tree	18	7	0.24	25.0	1.7	18.8	1.3	0.0	0.9	0.8	3.9
Rhus vulgaris	Tree	21	13	0.19	46.4	3.1	21.9	1.6	0.0	0.5	0.6	5.2
Ritchiea albersii	Tree	161	27	0.37	96.4	6.5	167.7	11.9	0.1	2.0	17.3	20.4
Rothmannia urcelliformis	Tree	190	27	0.49	96.4	6.5	197.9	14.0	0.2	3.6	35.8	24.1
Siygium guineense	Tree	12	6	0.31	21.4	1.4	12.5	0.9	0.1	1.4	0.9	3.8
Steganotaenia araliacea	Tree	10	6	0.31	21.4	1.4	10.4	0.7	0.1	1.4	0.8	3.6
Stereospermum kunthian	Tree	27	13	0.46	46.4	3.1	28.1	2.0	0.2	3.1	4.5	8.3
Trema orientalis	Tree	1	1	0.35	3.6	0.2	1.0	0.1	0.1	1.8	0.1	2.1
Vangueria volkensii	Tree	9	4	0.32	14.3	1.0	9.4	0.7	0.1	1.5	0.7	3.1
		1354	414	0.38	1478.6	100.0	1410.4	100.0	5.3	100.0	186.5	300.0

Appendix 5: Total ecosystem carbon stocks of different pools in plots

	Transect line	Plot #	AGB (t/ha)	AGC (t/ha)	BGB (t/ha)	BGC(t/ha)	LB (t/ha)	LC (t/ha)	SOC(t/ha)		TCS (t/ha)	TCSCO$_2$ t/ha)
									0-20	20-40		
Wood forest	1	1	163.85	81.93	42.60	21.30	0.59	0.28	81.40	68.00	252.90	928.15
		2	167.92	83.96	43.66	21.83	0.62	0.29	87.90	63.10	257.08	943.48
		3	118.22	59.11	30.74	15.37	0.48	0.23	94.60	62.30	231.61	849.99
		4	257.22	128.61	66.88	33.44	0.70	0.33	84.70	61.90	308.98	1133.95
		5	230.79	115.39	60.00	30.00	0.53	0.25	90.80	72.60	309.04	1134.19
		6	232.80	116.40	60.53	30.26	0.63	0.29	86.60	79.10	312.66	1147.45
		7	185.94	92.97	48.34	24.17	0.55	0.26	86.40	69.20	273.00	1001.91
		8	179.66	89.83	46.71	23.36	0.55	0.26	89.60	60.10	263.14	965.72
	2	9	71.28	35.64	18.53	9.27	0.62	0.29	94.10	76.20	215.50	790.88
		10	129.72	64.86	33.73	16.86	0.50	0.23	81.30	78.10	241.35	885.77
		11	165.44	82.72	43.01	21.51	0.66	0.31	93.70	81.70	279.93	1027.36
		12	310.95	155.48	80.85	40.42	0.69	0.32	104.30	70.10	370.62	1360.18
		13	118.31	59.16	30.76	15.38	0.78	0.37	87.00	63.80	225.71	828.34
		14	172.19	86.10	44.77	22.38	0.81	0.38	76.40	59.20	244.46	897.17
		15	109.24	54.62	28.40	14.20	0.84	0.40	87.70	74.00	230.92	847.47

		16	187.47	93.74	48.74	24.37	0.67	0.32	82.70	60.90	262.02	961.63
	3	17	194.73	97.37	50.63	25.32	0.72	0.34	88.20	74.30	285.52	1047.86
		18	205.15	102.58	53.34	26.67	0.87	0.41	86.30	76.20	292.16	1072.21
		19	141.41	70.71	36.77	18.38	0.49	0.23	99.00	82.20	270.52	992.81
		20	141.41	70.71	36.77	18.38	0.57	0.27	86.40	64.90	240.66	883.21
		21	173.85	86.92	45.20	22.60	0.60	0.28	75.20	62.00	247.01	906.52
		22	226.11	113.06	58.79	29.39	0.60	0.28	104.60	77.70	325.03	1192.86
		23	168.99	84.50	43.94	21.97	0.83	0.39	77.80	69.30	253.96	932.03
		24	104.92	52.46	27.28	13.64	0.80	0.38	88.80	71.60	226.88	832.64
		25	128.33	64.17	33.37	16.68	0.88	0.41	88.80	60.40	230.46	845.80
	4	26	112.75	56.38	29.32	14.66	0.53	0.25	79.20	65.10	215.59	791.20
		27	124.48	62.24	32.37	16.18	0.50	0.24	95.90	61.70	236.26	867.07
		28	236.17	118.08	61.40	30.70	0.76	0.36	86.70	59.00	294.84	1082.07
		29	151.48	75.74	39.39	19.69	0.85	0.40	91.30	53.80	240.94	884.24
		30	214.97	107.48	55.89	27.95	0.63	0.30	76.60	56.30	268.63	985.86
		31	204.84	102.42	53.26	26.63	0.85	0.40	82.90	66.80	279.15	1024.47
		32	187.18	93.59	48.67	24.33	0.59	0.28	82.40	70.30	270.90	994.22

		33	95.73	47.86	24.89	12.44	0.52	0.24	98.90	62.80	222.25	815.66
		34	122.40	61.20	31.82	15.91	0.64	0.30	82.90	76.40	236.71	868.74
Coffee based forest	5	35	100.59	50.30	26.15	13.08	0.51	0.24	77.40	63.80	204.81	751.66
		36	69.38	34.69	18.04	9.02	0.57	0.27	66.90	66.80	177.68	652.07
		37	106.34	53.17	27.65	13.82	0.60	0.28	67.30	53.30	187.88	689.51
		38	115.41	57.70	30.01	15.00	0.49	0.23	77.20	60.50	210.64	773.04
		39	143.11	71.56	37.21	18.60	0.43	0.20	75.30	62.70	228.36	838.09
		40	120.38	60.19	31.30	15.65	0.48	0.22	80.70	64.10	220.86	810.57
		41	140.78	70.39	36.60	18.30	0.51	0.24	70.10	67.10	226.13	829.91
		42	151.32	75.66	39.34	19.67	0.40	0.19	74.20	63.30	233.02	855.17
		43	139.36	69.68	36.23	18.12	0.44	0.20	80.70	44.80	213.50	783.56
	6	44	124.34	62.17	32.33	16.16	0.50	0.23	76.80	60.20	215.57	791.14
		45	118.68	59.34	30.86	15.43	0.45	0.21	70.90	55.70	201.58	739.79
		46	139.99	70.00	36.40	18.20	0.50	0.23	54.50	46.00	188.93	693.37
		47	148.32	74.16	38.56	19.28	0.55	0.26	67.60	54.30	215.60	791.26
		48	94.80	47.40	24.65	12.32	0.53	0.25	76.90	62.10	198.98	730.24
		49	104.97	52.48	27.29	13.65	0.49	0.23	71.20	57.50	195.06	715.86

		50	96.05	48.03	24.97	12.49	0.53	0.25	66.80	44.70	172.26	632.20
		51	198.57	99.29	51.63	25.81	0.57	0.27	61.20	52.20	238.77	876.28
		52	108.76	54.38	28.28	14.14	0.58	0.27	86.60	64.90	220.29	808.48
	7	53	100.10	50.05	26.03	13.01	0.57	0.27	76.40	59.10	198.83	729.71
		54	113.92	56.96	29.62	14.81	0.57	0.27	82.00	53.10	207.14	760.21
		55	127.95	63.97	33.27	16.63	0.50	0.23	70.40	57.50	208.74	766.08
		56	122.73	61.37	31.91	15.96	0.38	0.18	77.90	59.00	214.40	786.85
		57	116.15	58.08	30.20	15.10	0.36	0.17	80.00	67.90	221.24	811.96
		58	128.04	64.02	33.29	16.64	0.50	0.24	87.70	64.70	233.30	856.21
		59	71.64	35.82	18.63	9.31	0.39	0.18	71.50	69.40	186.22	683.41
		60	157.30	78.65	40.90	20.45	0.23	0.11	73.10	62.30	234.61	861.00
	8	61	138.73	69.36	36.07	18.03	0.52	0.25	84.10	61.20	232.95	854.91
		62	160.96	80.48	41.85	20.93	0.38	0.18	68.40	46.00	215.99	792.67
Mean			148.30	74.15	38.56	19.28	0.58	0.27	81.53	63.80	239.03	877.23