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Ecosystem Services of Entoto Mountain Forest in Addis Ababa, Ethiopia

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This is to certify that the thesis prepared by Habtamu Demessie, entitled: **Ecosystem services of Entoto Mountain Forest in Addis Ababa, Ethiopia** submitted in partial fulfilment of the requirements for the degree of Master of Science in Biology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Ecosystem Services of Entoto Mountain Forest in Addis Ababa, Ethiopia

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Addis Ababa is a highland city with varied topography and landscape features. The mountains that surround the city are covered with urban forest of different types. These forests are providing various ecosystem services for the urban and peri-urban population of the city. The value of this services is however poorly documented and less recognized by the relevant scientific studies. The objective of this study was to estimate the ecosystem service of the Entoto Mountain Forest (which is a principal forest reserves of the city of Addis Ababa) in terms carbon stock and sequestration weights and oxygen production rates. This was done through the use of forest inventory data collected from 46 sample plots (each with the size of 25 x 25 m (625m^2) from Entoto Mountain Forest; and then estimating the biomass weight using on a combination of multispecies and species-specific biomass allomeric equations. The carbon sequestration and oxygen production rates were estimated through the use of mean annual tree growth rates and the corresponding biomass production rates estimates. The result shows that a total of 10,314 individual stands (which is equivalent to a density of 3,581 individual stands per hectare) were identified from the total sample plot area. The species diversity of the study area characterized by the domination of *Eucalyptus globulus* and *Juniperus procera*. The estimated amount of biomass and carbon stock weight is 1590.2 (552.3 t ha^{-1}) and 744.7 t (258 t ha^{-1}) respectively. The mean annual carbon sequestration and oxygen production rate is 23 t C y^{-1} ha^{-1} and 62 t O_2 t y^{-1} ha^{-1}. respectively. The estimated results and methodological approaches could be used as a measurement standard to determine the number of trees in an area required to maintain a healthy urban environment. The results are however a rough estimation and reaching to a more precise estimation requires continuous frost monitoring task with a focus on growth rate monitoring and biomass weigh estimation of different species.

Key Words: Biomass stock, Carbon sequestration, Forest ecosystem, Oxygen production

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List of Acronyms

AGB	Above Ground Biomass
BGB	Below-Ground Biomass
C	Carbon
DBH	Diameter at Brest Height
DW	Dead Wood
ES	Ecosystem Service
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic Information System
GPP	Gross Primary Production
GPS	Global Positioning System
LT	Litter
MEA	Millennium Ecosystem Assessment
IPCC	Intergovernmental Panel on Climate Change
NDA	Natural Database for Africa
SOC	Soil Organic Carbon
TBM	Total Biomass
USD	United States Dollar

Chapter One

1 Introduction

1.1 Background of the study

Ethiopia has a diverse range of ecosystems, from humid forests and extensive wetlands to deserts like the Afar Depression, which support a diverse range of life forms. The country's high and rugged mountains, deep gorges, and vast rolling plains demonstrate its topographic diversity. The altitudinal difference between Ras Dashen (4620 m asl) and 116 m below sea level in the Afar depression is the main reason that Ethiopia is one of the few countries rich in biodiversity.) Wide ranges of altitudes in Ethiopia have given the country a variety of ecologically distinct areas with three climatic zones (tropical, subtropical and temperate zones) that led to the diversification of endemic species. Topographic variability and temperature are identified as important predictors of avian species richness (Haregeweyn et al., 2015).

The country's natural forest mainly consists of broad-leaved trees often mixed with conifer species such as *Juniperus procera* and *Podocarpus falcatus*. The natural forests of the country particularly the around the capital city were depleted at faster rate for fuel and construction material. As a result, the development of the capital city, Addis Ababa was threatened by a fuelwood scarcity. In 1895 King Menilek II introduced fifteen *Eucalyptus* species for a trial in and around the capital city to solve fuelwood shortage. The introduction of *Eucalyptus* species was a great success. Sooner or later the planting of *Eucalyptus* species for fuel, particularly, *Eucalyptus globulus* and *Eucalyptus camaldulensis* was expanding in the vicinity of Addis and other small towns in the country (Horst, 2006).

Entoto Mountain is one of the areas where the first *Eucalyptus* species were planted; and hence it remained as a reservoir of forest in the closer areas of Addis Ababa. Currently is one of the very few remnant forests left from the century old deforestation process in the country (Esayas & Bekele, 2011; Fekadu Debushe, 2008). Due to this and its proximity to the mega city of the country; it is carrying a huge burden of serving the nearby human population through a number of ecosystem services. At the same time, the importance of the ecosystem services generated in the protected areas, the linking biological corridors, and the mountain as a whole is not sufficiently well recognized or valued to attract the attention of conservation agencies and policy makers at national and international levels (Woldegerima et al., 2017). This is largely due to the lack of a standard methodology that can be used to compare the costs of conservation with the cumulative benefits acquired from natural ecosystems and the returns per unit cost from conservation with those from other sectors of the economy. To overcome this problem, valuation ecosystem services in quantitative terms is becoming a popular method for highlighting the importance of protected areas, corridors, and mountain in the conservation discourse (Costanza et al., 1997). Hence the objective of the current study was to evaluate the air quality regulating ecosystem services of the prinicpal urban forests of Addis Ababa City. This is helpful to demonstrate how forest conservation can provide tangible and intangible economic, environmental social benefit, and avoiding environmental damage and provides information that can facilitate conservation policies (Costanza et al., 1997).

1.2 Statement of the Problem

Forest ecosystem services play an essential role for human wellbeing through delivering a variety of ecosystem services. Urban forests, particularly trees constitute one of the specific ecosystems which plays a significant role in regulating the welling of human population in the closer vicinities (Livesley et al., 2016). Insufficiency in the abundance of appropriate forest cover in and around urban areas and densely settled places is a health treat for the nearby human population (Salmond et al., 2016). This is due to that fact that the urban areas are the most polluted ecosystems and requires a purification mechanism to reduce the environmental impacts of these pollution. Increasing forest covers is one of the mitigation mechanisms to reduce the problem. These is because forests can improve in air and water quality, building energy conservation, cooler air temperatures, reductions in ultraviolet radiation, and many other environmental and social benefits (Nowak et al., 2007).

The city of Addis Ababa is one of the places where there is a poor management system of urban trees and inadequacy of forest cover to reduce the impact of urban pollution. The forest reserves of the city have been affected by anthropogenic activities, mostly by tree cutting for construction and fuel wood and settlement, resulting in a reduced species composition and diversity (Horst, 2006). This has been exacerbated by the degradation of the urban forests on the mountains of the city, possibly affecting the various ecosystem services provision potential of the forests. Therefore, it is essential to work towards conservation of urban are forests and to augment the flow of ecosystem services.

Scientific studies about the ecosystem services of most forest ecosystems in Ethiopia and specifically about the ecosystem serves value of Entoto Mountain Forest are very few in number. Some of the available studies focuses only on a few elements of the ecosystem services (mainly s carbon stock weights) without giving enough attention for the other essential elements (Fetene & Worku, 2013; Woldegerima et al., 2017). The purpose of the current study was to fill this knowledge where the ecosystem service of Entoto Mountain Forest was evaluated not only in terms of carbon stock weights but also in terms of carbon sequestration and oxygen production rates which have never been addressed by any of the previous studies.

In addition to the prevailing knowledge gap, the reason for making a closer look on the air quality regulation services with specific focus on carbon sequestration and oxygen production rates are from national and international forest conservation policy dimensions. Due to their being intangible, forest ecosystems are facing multiple ecosystem threats and less conserved by the conservation agencies (Livesley et al., 2016). Hence, a quantitative valuation of the ecosystem services is one of the possible ways to make the significance of forest ecosystem services get recognized by the concerned institutions and drive conservation attention (Woldegerima et al., 2017).

In addition to deriving conservation attention, a quantitative estimation of carbon sequestration and stock weights will be an important information to determine the tradeoff between greenhouse gas emission and sequestration levels of urban centers (Wainger & Ervin, 2013). This is to know if a city is emitting more carbons as compared to the sequestration potential of trees in its vicinity. This information is important to design climate smart cities and contribute to the global greenhouse gas reduction initiatives. This is through providing information about the optimum amount of forest cover which needs to be presented in the vicinities of towns and cities to create a positive balance between greenhouse gas emission and sequestration levels of cities (Perera et al., 2018). The importance of oxygen production of urban forests also lies in here, which will serve as another parameter to know the number of trees which needs to be planted around the vicinities of urban areas (Livesley et al., 2016). The tradeoff between the amount of oxygen production by the urban trees and the oxygen demand of residing population has been served as an important measure of evaluating the air quality status of urban areas (Nowak et al., 2007).

The other significance of the air quality regulation service valuation is to assist in ongoing carbon trading systems being implemented in the country. The study of carbon sequestration potentials could provide a ready to use information about the monitory value forest which assist decision making in the selection of forest areas for integration in to the ongoing international carbon trading projects (Sun & Liu, 2020). In this regard, the nobility of this research lies on providing tree growth rate-based carbon stock weights estimation as an alternative approach of valuing the monitory value of carbon sequestrations for global carbon marketing systems. The conventional forest area changes-based estimation approach missies the carbon sequestration values which are created due to tree growth (Petrokofsky et al., 2012). Hence, research doing on carbon stock weights as a function of tree growth would look for enhancing the benefit of the country from the global carbon market systems. The objective of this study was therefore to estimate ecosystem services from the forested areas of Entoto Mountain, with respect to structural and species composition of tree species in the forest.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of the study is to quantify the ecosystem services of Entoto Mountain in terms of carbon stock, carbon sequestration and oxygen production amounts with respect to species and structural composite of the forest.

1.3.2 Specific objectives

1. Examine the species and structural composition of Entoto Forest;
2. To quantify the biomass weigh and productivity rates of the different tree species in the forest; and
3. To estimate the ecosystem service of Entoto Mountain Forest in terms of carbon stock weights and Oxygen production rates.

1.4 Research Questions

1. What is the proportion of different tree species in Entoto Forest?
2. What is the total biomass weight of the trees in Entoto Forest?
3. How much carbon is being sequestered annually by the Entoto Mountain Forests?
4. What is the significance of Entoto Mountain Forest in terms of oxygen production to regulate the oxygen demands of the nearby areas?

1.5 Significant of the Study

The study will provide significant information for researchers, policy makers and the society about the intangible benefit that forests are providing for humans. Scientific studies about ecosystem service values in Ethiopia are very few in number; hence the study will play a significant role in bridging the existing gap about the issue. In addition; for the policy makers; it will be an important input to make them take in to consideration the importance of forests whenever making a decision about natural resource management. And also land use policy and regulations have an important role for establishing markets for ecosystem services, and market-based programs have developed in response to regulations for wetlands, water and endangered species, reduce pollution.

Chapter Two

2 Literature Review

2.1 Definition of basic terms

2.1.1 Forest

According to FAO, forest is a land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ. It may consist either a closed forest formations in which trees of different stand structure and undergrowth constitutes a high part of the ground; or an or open forest formations where three is a prominent ground vegetation cover in where tree crown cover could reach to 10 percent. In addition, smaller tree stands and all plantations established for forestry purposes which are anticipated to have a crown density of 10 percent or tree height of 5 m in a recent time are a part of forest (Brown, 1997).

Forest landscape is on the other hand a natural or built-up area at any scale, in which trees constitutes the principal part of the main ecosystems. In this regard, forests are considered as local or regional patches where ongoing biological and ecological processes are principally controlled by trees.(Pant et al., 2012). A forest landscape constitutes not only natural components that are present together with their spatial heterogeneity, but also the human ecosystems which might have an effect on the patterns and processes within the landscape. At a global scale, about 30% of the Earth's land area is estimated to be forest landscapes which is equivalent to four billion hectares, which account for closely 75% of terrestrial gross primary production and 80% of total plant biomass. Forest landscapes constitutes more carbon (in biomass and soils) than the total stored in the atmosphere. They are also harbor most of the species on Earth and provide the most valuable goods and services to humanity (Perera et al., 2018).

2.1.2 Forest ecosystems

According to Masiero et al. (2019) a forest ecosystem is characterized by: (1) Soil or some geological and organic substrate in which the trees and other plants are rooted (2). An atmosphere and a regional climate that is modified locally by slope and aspect; a microclimate that results from the shade, the reduced wind speed and the increased humidity created by the trees. (3) Organisms, including plants. Forest ecosystem structure reflects to a great extent the horizontal and vertical arrangement of the living forest plants are different life form. Life forms include mosses, liverworts and lichens; grasses and non-grass herbs, shrubs, climbers, and various types of trees like (gymnosperm) evergreen and, coniferous like that of (angiosperm) In addition to the living plants and there are standing dead trees (snags) and, decaying wood, dead and living fungi, bacteria and animals and other. A wide variety of animals and microbes is associated with these living and dead plant components of the ecosystem structure.

2.1.3 Forest Ecosystem Services

According to the Millennium Ecosystem Service Assessment (one of the most comprehensive analyses of ecosystem services to date) ecosystem services are benefits that different biome provide to people. The benefits include timber, food, and fuel (Provisioning Services), and ecosystems' abilities to purify air and water, to reduce flood risk, and to regulate pollination and carbon sequestration (Regulating Services). Soil formation, nutrient cycling, and primary production are necessary for the production of all other ecosystem services (Supporting Services). Less tangible services of ecosystems concern aesthetics and space for recreation (Cultural Services). These different ecosystem types vary in species composition, productivity, biological diversity and response to ecosystem disturbance (MEA, 2005).

2.1.4 Biomass and forest biomass

Biomass refers to the mass of living organisms, including plants, animals, and microorganisms, or, from a biochemical perspective, cellulose, lignin, sugars, fats, and proteins. Biomass includes both the above- and belowground tissues of plants, for example, leaves, twigs, branches, boles, as well as roots of trees and rhizomes of grasses (Salunkhe et al., 2018). Biomass is often reported as a mass per unit area and usually as dry weight. Forests biomass on the other hand refers to any biomass found in forests including trees, leaves, branches, roots. Specific types of biomasses targeted for use in energy systems include: tops and branches of trees left after timber harvests, poor quality trees in managed forests, trees removed during land clearing operations, wood waste from urban areas, and wood residues produced by sawmills (Rosillo-Calle & Woods, 2012)

2.1.5 Carbon sequestration and storage

Carbon sequestration is the removal of carbon from the atmosphere to relatively stable storage in the terrestrial system. It represents the long-term storage of carbon in plants, soils, geologic formations, and the ocean (Schoene, 2003). It occurs both naturally and as a result of anthropogenic activities and typically refers to the storage of carbon that has the immediate potential to become carbon dioxide. Forest carbon stock on the other hand is the amount of carbon that has been sequestered from the atmosphere and is now stored within the forest ecosystem, mainly within living biomass and soil, and to a lesser extent also in dead wood and litter (Sun & Liu, 2020).

2.2 Assessments of Forest Structure

Assessments of forest structure are of fundamental importance to forest management, providing information on the size distribution of trees on which harvesting plans can be developed. Measurements of forest stands also provide much information relevant to forest ecology and conservation, enabling the regeneration characteristics of different tree species to be identified, providing insights into the processes of forest dynamics and indicating the potential value of the stands as habitat for other organisms. If there is one thing that foresters know about, it is how to measure trees (Newton, 2007). The sections presented here on forest inventory techniques and common forest structure assessment approaches based on the forestry literature.

2.2.1 Forest inventory

Forest inventory refers to the process of collecting information about the extent and condition of forest resources within a specified area. Traditionally, forest inventories were primarily carried out to determine the quantity of available timber, but increasingly the scope of such inventories has been expanded to include ecological variables such as measures of the quality of habitat provided for different species. A forest inventory may therefore be carried out to obtain a range of different information (Hui et al., 2019).

Inventory methods used by forestry professionals have been refined over many years of use in a wide range of forest types. The design of the inventory or forest survey (sometimes referred to as a cruise or enumeration) will vary according to the specific information needs. For example, ecologists may be interested in variables such as the structure and composition of the stand, the extent and pattern of natural regeneration, and those variables that describe the quality of the forest as habitat for wildlife, such as the amount of deadwood (Standovár et al., 2016).

The procedures in forest inventory starts with setting appropriate sampling design, hence it is rarely possible to measure all of the trees in a particular forest. Therefore, a sample must be taken from the complete population of all sample units. The most important basic principle is to ensure that the sample is representative. Otherwise, the information obtained will be biased in some way, and the inferences drawn from the data are likely to be invalid (Newton, 2007). The sampling requires having a preliminary knowledge of the forest to be invented; such as basic climate condition and spatial extent. Once the sampling was done; the actual forest inventory is conducted though taking a measurement of the individual trees from the selected sample plots. The selection of parameters to be measured would vary depending on the objective of the study. The basic data that are common for all of the forest inventory types includes tree species name; DBH size and height. Age, crown cover and other related parameters may be required for detail investigation of forest characteristics (Burkhart & Tomé, 2012).

2.2.2 Forest stand structure

Stand structure refers to the distribution of species or tree sizes within the stand. Stands are commonly differentiated into those that are even-aged, where all trees are of approximately the same age, and those that are uneven-aged, where trees display a variety of different ages. The size distribution of trees within a stand can provide some insights into the history of tree recruitment and patterns of previous disturbance. The structure of a stand is generally characterized by analyzing the frequency of individual trees per different DBH and tree height distributions (Burkhart & Tomé, 2012). However, basal area and the extent of crown cover can also be used as measures of stand density. The other method is to calculate the stand density which refers to the number of trees within a given area. This can be most simply obtained by counting the number of trees present within a stand and measuring its area, then dividing the former by the latter. Stand density is of great importance to forest management, primarily because of its importance in determining the volume of timber likely to be obtained from a particular stand (Kangas & Maltamo, 2006).

2.2.3 Species richness and diversity

Species richness refers to the number of species in a particular area, whereas species diversity refers to a combination of richness and relative abundance. If information on the species abundance distribution is available, namely the relation between the number of species and the number of individuals in those species, this can also be used to estimate species richness (Kangas & Maltamo, 2006). A wide variety of different models have been used to characterize species abundance distributions. Species diversity is generally assessed by using some type of diversity index, which incorporates information on species richness and evenness. The term evenness refers to the variability in the relative abundance of species. Measures of evenness (or heterogeneity) can be divided into two groups: those that are based on the parameter of a species abundance model, and non- parametric methods that make no assumptions about the underlying species abundance distribution (Martínez-Falero et al., 2013).

2.3 Ecosystem Services from Forests

Ecosystem services are the outcomes from ecosystem functions that benefit to human beings.

Human beings derive direct benefit from a particular position of ecosystem goods as well as from the activities and products of organisms, in both wild and human-dominated ecosystems. e.g., better fishing, hunting, cleaner water, better views, wild pollinators, safer or less vulnerable areas to natural disasters, lower global warming, new discoveries for pharmaceutical use and more productive soils. The all-rounded range of ecosystem benefits to human life is grouped under the concept of ecosystem services Since this concept was first introduced it has evolved into a global phenomenon (Pant et al., 2012).

Forest ecosystems, in particular provide critical ES to humanity. Forests play a multifunctional role in which attempts are made to balance human commodity needs with the production of other goods and services, including the habitat needs of forest-dependent organisms (Grunewald & Bastian, 2015) The following are some of the key ecosystem services provided by forests.

Climate and life*:* Forests help stabilize the climate, lessening extreme events (e.g., by slowing down water runoff) and removing greenhouse gases and other pollutants from the atmosphere.

There is a long-standing belief that deforestation reduces rainfall or the forests are increase rainfall. Deforestation breaks the local water recycling process by removing evaporation transpiration from the forests. Knowing that in some cases this evaporation transpiration represents 80% of incident rainfall (Newton, 2007).

Carbon Storage*: Carbon* in forests is sequestered through photosynthesis and so is directly related to the species level of biodiversity. Carbon is stored in five distinct pools in forests: above-ground and below-ground live biomass, in deadwood including snags, litter, and soil. Carbon in forests is a function of forest productivity (Liu et al., 2018).

Cultural values: Forests have clear and important cultural values for people both leaving in or near the forests or in towns. Obviously cultural values and symbolism is higher for forest dependent cultures. For early human societies, trees have been viewed as having souls and spirits. Trees have long been believed to possess natural powers, including a wide range of natural forces such as making the rain fall and the sun shine, ensuring abundant harvests, helping flocks and herds to multiply, ensuring the fertility of women and easing childbirth (Perera et al., 2018).

Some indigenous people have referred to humans as "walking trees," whose spine is the tree's trunk, whose pelvis enfolds the roots and whose brain is contained in the branches. The belief that forests and trees are homes of the gods can be found in nearly every culture. It has led to both respect and reverence for sacred forests or trees, which were often protected from cutting or dismemberment (Wainger & Ervin, 2013).

Aesthetic beauty: together with intellectual and spiritual stimulation: Human beings have a deep appreciation of natural ecosystems, especially forests, as evidenced by enjoyment of such pursuits as nature photography, bird watching and camping. In forests humans find an unparalleled source of wonderment and inspiration, peace and beauty, fulfillment and rejuvenation (de Groot et al., 2012).

Tourism: Forests hold a wide range of recreational opportunities. They constitute crucial habitat for game animals and fish sought by hunters and anglers. A major part of non-consumptive recreational activities such as hiking, bird watching, wildlife viewing and other such pursuits occur within forest stands. Ecotourism is a booming business and constitutes a potentially valuable (Groot et al., 2012)

Services supplied by soils: Forests provide a critical role in forming soils, as well as in retaining them through reducing soil erosion. Forest soils moderate the water and carbon cycles, they retain and deliver nutrients to other organisms, and they provide a consistent and high-quality source of water within forested basins (Masiero et al., 2019).

Generation and maintenance of biodiversity: Forests support most of the terrestrial biological diversity, which benefits humanity through the direct delivery of goods (genetic and biochemical resources) used by humans or through the interaction of complex ecological systems (Pant et al., 2012).

Pollination: A principal part of human diet (about one -third of it) depends of insect-pollinated vegetables, legumes, and fruits. These pollinators, the majority of which are restricted to wooded areas, enable the effective reproduction of a wide range of economically and non-economic blooming plants. Pollination is an important aspect of maintaining a healthy forest environment. While some plants pollinate themselves or are pollinated by the wind, most trees require pollinators to produce fruit and seed. Over 100,000 invertebrate species - bees, moths, butterflies, beetles, flies, etc. pollinators depend on the existence of a wide variety of habitat types needed for their feeding, successful breeding, and completion of their life cycles (Thorsen et al., 2014).

Natural pest control services: Several species compete with humans for goods and for other provisioning services. One approach to pest control is to use biotechnology or chemical compounds. Another option is to take advantage of biological control species that occur in nature, as many species (e.g., insects such as wasps and other species such as owls and bats) help humans live in forested landscapes. The natural pest control is an estimated 99 percent of potential crop pests are controlled by natural attackers, including many birds, spiders, parasitic wasps and flies, lady bugs, fungi, bacteria, viral diseases, and large numbers of other types of organisms (Masiero et al., 2019).

Production of ecosystem goods: The range of products obtained from forests includes food (e.g., fruits, nuts, mushrooms, honey, or spices), fuel wood, fiber, pharmaceuticals, and industrial products. In addition, animals such as cattle, goats, and sheep are raised in forests pastoral systems and these animals are the source of many trade products (e.g., meat, milk, wool, and leather). Hunting is also important for sport and can be critical to the survival of low-income people in developing countries (Newton, 2007).

2.3.1 The ecological role of forest carbon stock

Forests can play a variety of roles in the carbon cycle, ranging from net emitters to net sinks of carbon, depending on their properties and local circumstances. Forests sequester carbon by absorbing CO_2 from the atmosphere and converting it to biomass via photosynthesis. (Brown, 1997). Sequestered carbon is then accumulated in the form of biomass, deadwood, litter and in forest soils. The sink of carbon sequestration in forests and wood products helps to offset sources of carbon dioxide to the atmosphere, such as deforestation, forest fires, and fossil fuel emissions (Toochi, 2018).

Hence, there has been a surge in interest in terrestrial carbon sequestration as a means of addressing climate change mitigation. As a result, carbon sinks control carbon concentration by using CO2 from the atmosphere for their daily requirements, therefore reducing climate change's effects(Helseth, 2012).

Despite their significant role in regulating the global climate change, forests and their role in the carbon cycle are affected by changing climatic conditions. Evolutions in rainfall and temperature can have either damaging or beneficial impacts on forest health and productivity, which are very complex to predict (Lal & Augustin, 2012). Climate change will either reduce or boost carbon absorption in forests, which raises questions about how much the world's forests will be able to contribute to climate change mitigation in the long run. Forest management actions have the ability to influence carbon sequestration by promoting certain processes and reducing the negative effects of other ones. (Helseth, 2012).

Sustainable forestry techniques can help forests sequester more carbon from the atmosphere while also improving other ecosystem services like soil and water quality. Long-term forest carbon increases can be achieved by planting new trees and increasing forest health through thinning and regulated burning. Carbon is now a valued environmental commodity in the global marketplace as a result of government, industry, and individual promises to decrease carbon dioxide emissions. (IPCC Panel, 2014).

2.3.2 The process of oxygen production from forests

Trees release oxygen when they use energy from sunlight to make glucose from carbon dioxide and water. Like all plants, trees also use oxygen when they split glucose back down to release energy to power their metabolisms. Averaged over a 24-hour period, they produce more oxygen than they use up; otherwise, there would be no net gain in growth. It takes six molecules of CO_2 to produce one molecule of glucose by photosynthesis, and six molecules of oxygen are released as a by-product (Toochi, 2018). A glucose molecule contains six carbon atoms, so that’s a net gain of one molecule of oxygen for every atom of carbon added to the tree (Li et al., 2020). If carbon dioxide uptake during photosynthesis exceeds carbon dioxide release by respiration during the year, the tree will accumulate carbon (carbon sequestration). Thus, a tree that has a net accumulation of carbon during a year (tree growth) also has a net production of oxygen. The amount of oxygen produced is estimated from carbon sequestration based on atomic weights (Nowak et al., 2007). As an example, a mature sycamore tree might be around 12m tall and weigh two tones, including the roots and leaves. If it grows by five per cent each year, it will produce around 100kg of wood, of which 38kg will be carbon. Allowing for the relative molecular weights of oxygen and carbon, this equates to 100kg of oxygen per tree per year (Li et al., 2020).

2.4 Forest Biomass and Carbon Stock Weight Estimation Approaches

2.4.1 Relationship between forest biomass and Carbon stock

Biomass is defined here as the total amount of live and inert organic matter above and below ground expressed in tons of dry matter per unit area. It constitutes the mass of woody part (stem, bark, branches, twigs) of trees, alive or dead, shrubs and bushes, excluding stumps and roots, foliage, flowers and seeds (FAO, 1998). The biomass of these components generally accounts for the greatest fraction of total living biomass in a forest and does not pose too many logistical problems in its estimation (Brown, 1997).

The ecological role of forests in the global Carbon cycle is commonly explained through estimates of biomass. Carbon enters a forest biomass from the atmosphere, mostly through photosynthesis, and its storage in the forest is commonly known as Gross primary production (GPP) or carbon assimilation (Helseth, 2012). A small amount is also input from the weathering of bedrock and by lateral transfer by animals and by the wind. (Chen et al., 2014). Forest carbon stock is therefore the amount of carbon that has been sequestered from the atmosphere and is now stored within the forest ecosystem, mainly within living biomass and soil, and to a lesser extent also in dead wood and litter. Hence, foresters need to know the amount of biomass in order to estimate the stored carbon (Brown, 1997).

The total biomass and carbon pools within a forest are generally divided in to two specific pools; such as above and below ground biomass. Above ground biomass refers to the total mass of biomass in live trees (such as stem, branches, leaves), brush and woody live plants above the ground (Projects, 2015). This is the biggest pool that includes/stores the majority of carbon (Matula et al., 2015). Below-ground biomass is defined as the entire biomass of all live roots, although fine roots less than 2 mm in diameter are often excluded because these cannot easily be distinguished empirically from soil organic matter. Below-ground biomass is an important carbon pool for many vegetation types and land-use systems and accounts for about 20% to 26% of the total biomass(Brown, 1997). Below-ground biomass accumulation is linked to the dynamics of above-ground biomass. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface. Revegetation of degraded land leads to continual accumulation of below-ground biomass whereas any disturbance to topsoil leads to loss of below-ground biomass (Sun & Liu, 2020).

2.4.2 Forest Carbon stock estimation methods

Biomass and carbon calculations are usually calculated together because carbon is stored in forest biomass and is tightly related with biomass. The most common way to get estimates of carbon is to multiplied biomass weights by 0.5; assuming that about 50% of biomass of a tree stand is carbon content (FAOSTAT, 2021) Hence, the typical forest carbon stock estimation method used by many scientific studies is to estimate the biomass weight of the forest and the corresponding Carbon stock proportions (Brown, 1997) .

The carbon stock in a forest ecosystem commonly constitutes five different pools, and hence the total equation for carbon pool estimation is e.g., $C=AGB +BGB +DW+ LT +SC$ where, C is total carbon, AGB is above-ground biomass, BGB is below-ground biomass, DW is deadwood, LT is litter and SC is soil organic carbon (Brown, 1997).

The total biomass and carbon stock of a forest is therefore estimated by measuring the weight of these five pools using different methods (sum of which are explained int in the coming sections). However, this study focuses on above and below ground biomass and carbon pools which are briefly described in the following section.

Above ground biomass (AGB) and carbon stock estimation methods

The approach for estimation of carbon stock varies depending on the pools; basically, among the above ground and below ground weights. There are two above ground carbon storage estimation methods; such as forest inventory method (which in turn is divided in to destructive and equation-based method) and satellite-based estimation (Salunkhe et al., 2018).

i. Satellite-based estimation:

With the application of modern technologies such as Remote Sensing, Geographic Information System (GIS) and Global Positioning System (GPS) at different scales, multi-source remote sensing data have become alternative means of quantifying forest aboveground bio- mass/carbon storage (Sun & Liu, 2020). At present, there are three main types of datasets used for estimating vegetation carbon storage: optical remote sensing data, synthetic aperture radar satellite data, and Lidar data. The data source is used to derive information about the stand characteristics, vegetation health and temporal dynamics of a forest; based on which the biomass weight and temporal dynamics were estimated with the use of forest ancillary data (Salunkhe et al., 2018).

ii. Forest inventory-based methods

Inventory-based estimation is an old sustaining method of biomass and carbon stock weight measurement system within forest ecosystems. These methods work based on collecting a forest stand structure data, such as forest types, stand age, stand density, stand volume, mean tree height and diameter at breast height (DBH). Once a forest inventory is made the biomass and carbon stock is determined through two different approaches; such as destruction methods and allometric based methods (Petrokofsky et al., 2012)

Destructive sampling

Estimation through destructive sampling and related regression analysis is the most accurate method to identify individual tree biomass. As the name implies, destructive methods require the cutting of trees and the measurement of its fractions to drive required variables for regression models (Rosillo-Calle & Woods, 2012). The measured variables are usually the biomass weight of the different tree components. The accuracy and reliability of the results depends on the representativeness of the sample trees; which also affects the applicability of the results for generating regional stand models. (Mohammadi et al., 2017). One approach to increase the accuracy is to account for differences across individual trees and species diversities as well as various fine scale environmental heterogeneity while doing the forest inventory task. The sample sizes of destructive studies range from 30 trees for localized estimates to 2,410 various species in a biome level comparison (Salunkhe et al., 2018). The final step that comes next of forest inventory and biomass weight determination is to develop equations in an expression of confidence and model limitations. Some of the necessities needed to be considered while developing the equations includes the standard error of the biomass estimates and geographic or ecological limitations in the proposed equations. This determined model applicability for other geographical regions. (Petrokofsky et al., 2012).

Allometric equations

The allometric based methods is through the use of preestablished relationships of tree biomass and tree stand structure (such as DBH and height) derived based on destructive biomass estimation methods. The equations would vary depending on the type of mathematical relationship used to estimate the biomass from the forest structure data; which includes average biomass method, volume-derived method and biomass allometric equation (Petrokofsky et al., 2012). The average biomass or average carbon density of carbon content rate is through the use of previously estimated regional biomass and carbon weigh estimation coefficients of a specific geographical region and applying them to estimate the biomass weight based on the forest inventory data (multiplying the coefficient values with the total density of trees in a forest). The Volume- derived method is through the use of stem volume data of living trees and applying it with the already established biomass volume estimates of a specific geographical region (Chen et al., 2014). These four methods have their own unique advantages and disadvantages, the detail methodological approaches vary considerately and further explanations can be consulted from relevant literature.

An extra explanation was given for allometric equation methods which is the focus of the current study.

The regression based allometric equation is through the use of a regression equation that is best adapted to the conditions in the study area. These methods provide efficient estimates for stand level biomass (Rosillo-Calle & Woods, 2012). Using appropriate allometric equations derived developed through destructive sampling method is a plausible alternative to a full empirical study. This needs a critical analysis of limitations due to variation in specific species or geographic location disparities on the generated results (Petrokofsky et al., 2012).

Estimation of forest biomass using allometric equations is a stepwise process that follows four basic consecutive steps (1) choosing a suitable functional form for the allometric equation; (2) setting appropriate values for adjustable parameters in the equation; (3) field measurements of the input variables such as diameter at breast height (DBH); and (4) using the allometric equation to give the aboveground biomass. (Salunkhe et al., 2018).

Exogenous data such as DBH and tree height (H) from common forest stand exams or inventories are used in allometric equations to model species-specific endogenous factors. Single tree biomass estimations are applied to density measurements of trees per hectare to determine stand level features, depending on the research aims and scale of study. (Sun & Liu, 2020). For dominating stands or plantations where just one species' allometry is in consideration, scaling up the method is appropriate. While there are more generalized formulas for estimating mixed species forests with high variety, their accuracy is questioned due to large allometric variance among species. When geographical, climatic, and species-specific equations are given, the accuracy of allometric equations improves. (Matula et al., 2015).

Below Ground Biomass

Plants can store up to 30% of their primary production below ground, depending on the species and environmental conditions. Due to the omission of important components such as root respiration and mycorrhizal respiration and turnover, methods to estimate BGB and C storage are labor expensive (Schoene, 2003). Destructive methods for measuring belowground biomass necessitate a significant financial expenditure in order to remove all biomass from a representative sample of trees. Because belowground biomass is difficult to quantify using aboveground parameters such as root collar, Diameter at Brest Height (DBH), and height, the procedure destroys both the soil layers and the tree, which may not be practicable for conservation studies involving endangered species or environmentally sensitive places (Petrokofsky et al., 2012).

Chapter Three

3 Materials and Methods

3.1 Study Area

The study was conducted in the western mountains of Addis Ababa; commonly known as Entoto Mountain Forest. The total area of Entoto Mountain Forest is closer to 6300 hectares. Most part of the forest is insider the boundary of Oromia regional state. The specific study sites of the current study are on a part of the forest found in the administrative boundary of Addis Ababa city which is about 1600 hectare. Geographically it lies between the northern limit of the city of Addis Ababa at around 2600 m asl. Astronomically, it is located between latitudes of 09°04′N to 09°06′N and longitudes of 38°44′E to 38°49′E (Figure 1). The natural vegetation of Entoto Mountain is an Afro-montane Forest type with woodland and open meadows. At present, most of the Entoto Mountain range is covered by introduced *Eucalyptus* plantations, which are widely used for fuel (Davison, 2009). The area has bimodal rainfall: a short rainy season from February or March to April or May and a long rainy season from July to October. The average annual temperature at the apex of Entoto is about 14°C with a rainfall of about 1400 mm (Woldegerima et al., 2017).

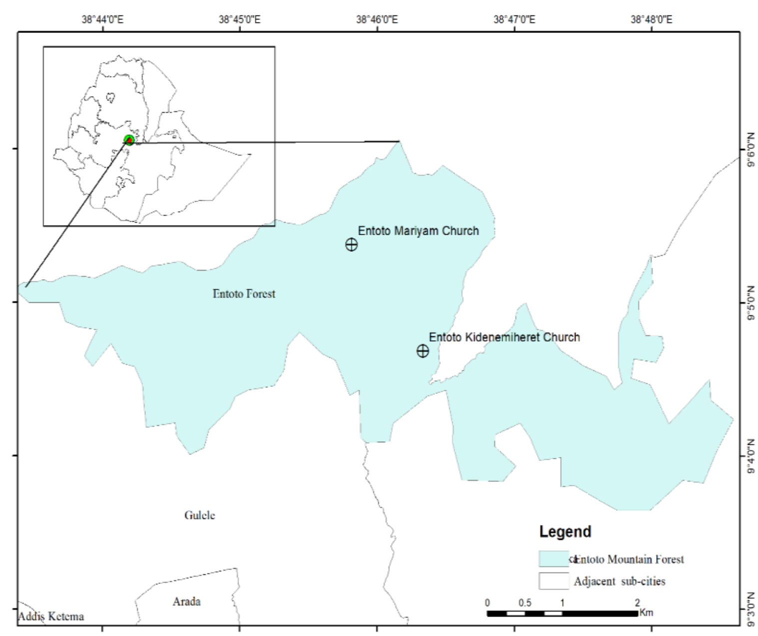

Figure 1: Location map of Entoto Mountain Forest

3.2 Data Sources and Methods of Collection

3.2.1 Sample plot selection

The forest inventory was conducted by producing a forest inventory map where possible sample plots were displayed. The forest boundary was divided in to a 500X 500 grid zones; and the approximate center of each grid zone was identified as potential sample plot. The 500X 500 grid zone allows to maintain appropriate distance among the different sample plots and also makes it possible to make a balance distribution of sample plots among the different parts of the forest boundary. The selection of specific sampling plot was made based on personal judgment and preliminary filed visit. Some of the grid centers were along road lines and in non-forest places (such as settlement and farmlands). These and other grid centers on the edge of the forest boundary were first removed from the sampling list. The remaining grid centers were used to establish the sample plots. The size of each plot was about 25 X 25 meter (625m^2). The total number of sample plots was made to be 46 which makes the entire sample plots 2.875 hectare(Figure 2). The sample plot size was to determine in consideration with optimization of the larger size of the area and the available research facilities. The selected sample plot locations were marked in a sampling map which was used to navigate to the actual sample location during the filed inventory.

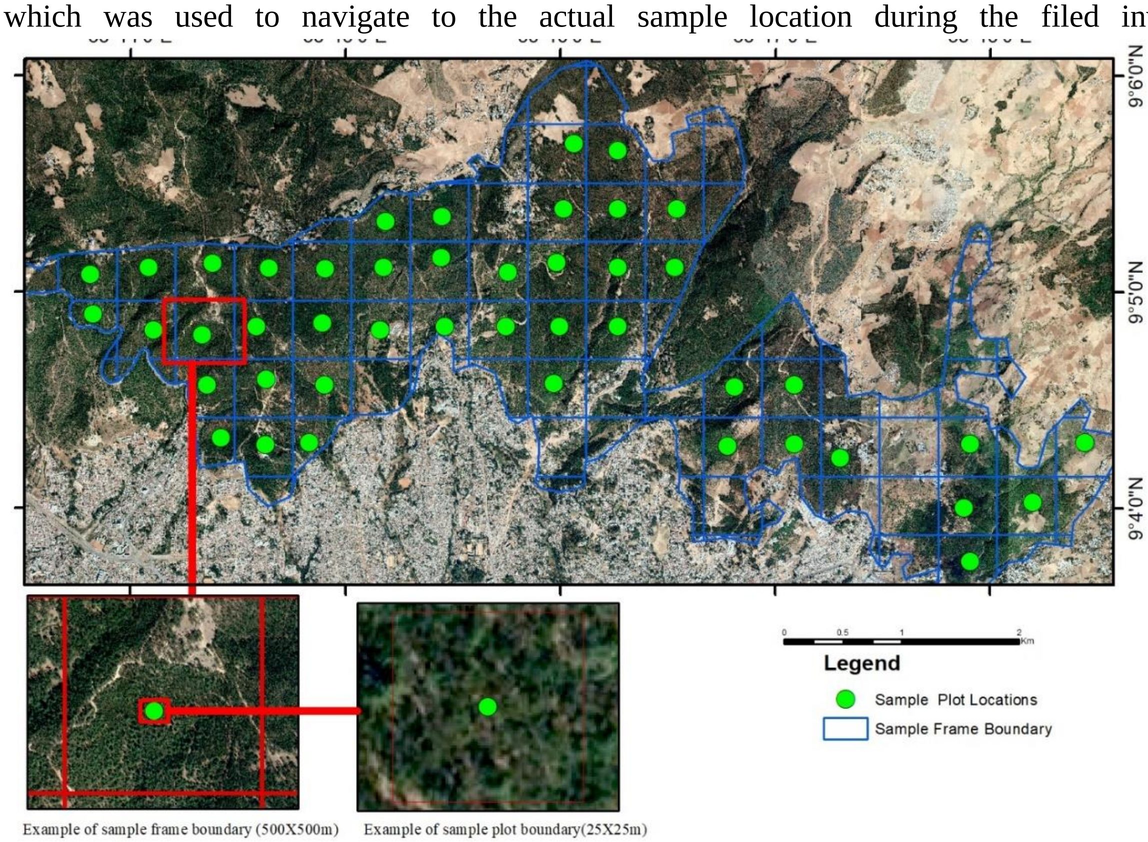

Figure 2: A sampling plot map of the study area with examples of sample frame and selected plot boundaries.

3.2.2 Forest inventory

During the forest inventory; all the trees and shrub species with a DBH of greater than 2.5 cm (a steam circumference of 7.5 cm) were enumerated. This was done through listing the local name of each species and tallying their frequency in a filed note. The local name of the species was used to make an initial registration of the vegetation list on the field list. The local name identification was done with the aid of local peoples and also consultation with those having a local experience to the study area. This was followed by referencing the scientific name and family class of the species based on botanical information of The Natural Database for Africa (NDA) and the publication of Bekele-Tesemma & Tengnäs, (2007). The species listing was done in line with the measurement of the DBH size of each individual stands and tallying its frequency in the appropriate DBH category. The DBH measurement was done using a measuring tape at the breast height (approximately 1.3m). The measured value in the field were steam circumference which were latter converted to diameter by dividing the measured values to 3.14

3.3 Methods of Data Analysis

3.3.1 Analysis of species and structural composition of the forests

The collected forest inventory data was manually encoded in to MS excel data base and then the statistical analysis were conducted accordingly. The abundance and distribution of each vegetation species in the sample plots was analyzed using descriptive statistics. The number of a species in the entire sample plots was calculated and its relative abundance was determined through calculating the percentage of its frequency to the total occurrence. Species abundance frequency was also calculated through dividing the frequency of a species to the total sample plot area (2.875 hectare). Shannon and Wiener index of species diversity was applied to quantify species diversity and richness. This method is one of the most widely used approaches in measuring the diversity of species. The Shannon-Wiener Diversity Index (H') was computed using the following formula (Newton, 2007) .

$$H = -\sum(\mathrm{Pi} \ln \mathrm{Pi}) \qquad 1$$

Where H is the Shannon and Wiener diversity index, Pi is the ratio of a species average to the total species average. The other method used to measure species diversity was Simpson's Diversity Index; which is a measure of diversity taking in to account the number of species present, as well as the relative abundance of each species. A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance (Newton, 2007). The formula is

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right) \quad 2$$

n = the total number of individuals of a particular species

N = the total number of individuals of all species

D represents Simpson's Diversity Index which ranges between 0 and 1. With this index, 1 represents infinite diversity and 0, no diversity.

The other diversity measure is Pilou evenness; which is a measure of biodiversity to quantify how equal the community is. It compares the actual diversity value (such as the Shannon-Wiener Index) to the maximum possible diversity value (when all species are equally common). It is represented by the following formula:

$$J = \left(\frac{\mathrm{H}}{H_{Max}}\right) \quad 3$$

Where H is the Shannon-Wiener Diversity Index H_{max} , is the maximum possible value of H. *J* is constrained between 0 and 1. The less evenness in communities between the species (and the presence of a dominant species), the lower *J'* is. And vice versa (HR et al., 1998)

3.3.2 Biomass and carbon stock weight estimation method

The live biomass weight of the trees identified in the sample plots was estimated using biomass allometric equations. This is through the combined use of multispecies and species specific allometric equations depending on the availability of species specific allometric equations which best fits to the context of the study area (in terms of climate and topography profile). Species specific allometric equations were applied for five of the most common species where there are available equations in the literature. This includes *Eucalyptus globulus*, *Juniperus procera, Olea europaea*, *Rosa abyssinica* and *Rhamnus staddo* (Table 1).

For the *Eucalyptus globulus* the regression coefficient developed by Zewdie et al. (2009) was used to derive the biomass weight of the sample trees. The model is selected because it is site specific as Entoto Mountain was one of the model experimental sites; which makes it the most reliable of all the available estimation models. For *Juniperus procera* the biomass estimation model developed by (Tetemke et al., 2019) was used. Despite a slighter variation in the climate condition of the experiment site (dry Afromontane forests of Northern Ethiopia); it's the most appropriate of all the other models available in literature. For *Olea europeae* the biomass estimation was done based on the regression model of (Kebede & Soromessa, 2018); which was developed based on sample trees in the Bale area of South Eastern Ethiopia which makes it the most relevant one as compared to the other estimation models. *Rosa abyssinica* equation is also developed from an area where there is an approximate similarity to the context of the current study site (Debela, 2017).

The multispecies allometric equation: it is not possible to find appropriate species specific allometric equations for many of the species. A multispecies allometric equations was used instead. The selected equation is the one recommended by FAO (Brown, 1997) which was applied in many forest inventories of Ethiopia (Woldegerima et al., 2017). This equation however works for species where the DBH is greater than 10; and it was necessitated to use additional model to address the biomass of small tree and shrubs with a DBH size of less than 10. A similar type of equation that was recommended by FAO was employed (Brown, 1997).

Table 1: Above ground biomass allometric equations employed in the study

Species	Biomass Equation	Source
Eucalyptus globulus	$AGB = 1.17 + 0.12X\ \ DBH^{\ 2.51}$	(Zewdie et al., 2009)
Juniperus procera	$AGB = 0.61\ X\ DBH^{2.199}$	(Tetemke et al., 2019)
Olea europaea	$AGB = 1.09\ X\ DBH^{1.684}$	(Kebede & Soromessa, 2018)
Rosa abyssinica	$AGB = 0.31\ X\ DBH^{2.0251}$	(Debela, 2017)
Rhamnus staddo	AGB=2.4031+1.9747(DBH)	(Belete et al., 2019)
The multi species formula (DBH>10)	$AGB = 34.703 - 8.067(DBH) + 0.6589(DBH^2)$	(Brown, 1997)
For shrubs and trees (DBH<10)	$\text{AGB} = \exp\{-2.134 + 2.530^{*}\ln(\text{D})\}$	(Brown, 1997)

Belowground biomass

All the allometric equations yields the above ground dry biomass weight of individual trees; which fails to take in to account below ground biomass weight. Hence, below ground biomass was calculated based on the relationship between root and shoo using the internationally recommended root to shoot ratio of 1:5 was. Accordingly; belowground biomass was estimated by multiplying the aboveground biomass by a factor of 0.2 (belowground biomass = aboveground biomass × 0.2) (Newton, 2007).

3.3.3 Tree age and growth rate estimation approach

The annual amount of biomass yield is a function of tree growth rate; which in turn is employed to estimate mean annual carbon sequestration and oxygen production rate of the sample forests. Hence it was necessitated to estimate the mean annual growth rate of the sample trees so as to quantify the annual biomass production rates. The growth rate estimation result is then employed to quantify the anticipated DBH size of a sample tree after a year the in comparison to the concurrent measured DBH values using the following equation

$$DBH_{Yi} = DBH_{Y} + DBH_{rate} \quad 4$$

While the DBH_{Yi} is to refer the anticipated DBH size of a tree after a year of its current measurement; DBH_{Y} is the measured DBH size of the tree and DBH_{rate} is the growth rate of a tree in terms of mean annual DBH increment size (in centimeter). To address the DBH change equation; it was necessary to establish a growth rate values for the sample trees. This was through searching relevant growth rate and tree age estimation data from the available literature. About four of the common species (two of them are most abundant) such as *Eucalyptus globulus*, *Juniperus procera*, *Olea europaea* and *Podocarpus falcatus*; it was possible to find species specific regression-based growth rate models (conducted based on experimental sites placed in Ethiopia) from the available literature; which were used to predict the anticipated yearly change in the DBH size of the sample based on the measured DBH values(Table 2).

For *Eucalyptus globulus* the mean annual yield estimation developed by (Pukkala & Pohjonen, 1990) was used. The model is developed considering tree growth rate scenarios of the central part of Ethiopia and is the most appropriate one as compared to others. For *Juniperus procera*, *Olea europaea* and *Podocarpus falcatus* the, growth rate estimations in the study of Siyum et al., (2019) were used; which were derived based on data from the Northern part of Ethiopia.

Table 2: Growth rate estimation equation of the most dominant species employed to estimate anticipated yearly change in the biomass weight of the sample trees.

Species	Age estimation models	Reference
Eucalyptus globulus	$tree\ age = 0.0228(DBH^2) + 0.6032^{DBH} + 1.1641$	(Pukkala & Pohjonen, 1990)
Juniperus procera	$tree\ age = 1.4367(DBH) + 21.88$	(Siyum et al., 2019)
Olea europaea	$tree\ age = 3.3279(DBH) + 3.9396$	(Siyum et al., 2019)
Podocarpus falcatus	$tree\ age = 1.055(DBH) + 13.688$	(Siyum et al., 2019)

It is not however possible to find a regression-based growth rate estimation models for many of the species. This makes it difficult to consider growth rate differences among trees of different DBH size. As an alternative it was tried to establish a common growth rate value for all of the sample species irrespective of their difference in DBH size. This was based on searching measured temporal growth rates and estimated forest ages of trees with different levels of DBH size from the available literature (Table 3).

It was tried to use the most relevant age estimation results to the context of the current study area and many of these estimates were determined based experimental sites of Afro-montane Forest type in Ethiopia and some other in Kenya (Bussmann, 1999; Gliniars, 2011). The result is then applied to establish a single mean annual growth rate of a species irrespective of their difference in stand structure. As of the biomass estimation models it was tried to use the most relevant literature to the study area in terms of climate and physiographic conditions. For those species where it is not possible to find any information about growth rate or tree age; the growth rate data of a spices in a similar family and taxa category was adopted.

Table 3: Mean annual growth rates of different tree species employed to estimate the anticipated yearly change in the biomass weight of the sample trees identified in the study area.

Species	Mean annual DBH growth rate (cm y^{-1})	Reference
Acacia abyssinica	0.7	Gourlay, 2016)
Millettia ferruginea	0.5	(Dlamini, 2004)
Hagenia abyssinica	1.036667	(Bussmann, 1999)
Rhamnus staddo	0.09	(Gliniars, 2011)
Pittosporum viridiflorum	0.4	(Letsela & Hankey, 2002)
Erythrina brucei	0.5	(Dlamini, 2004)
Ekebergia capensis	0.5	(Dlamini, 2004)
Syzygium guineense	0.9	(Pukkala & Pohjonen, 1990)
Ficus sur	0.141	(Gliniars, 2011)
Croton macrostachyus	0.423	(Gliniars, 2011)
Ficus vasta	0.141	(Gliniars, 2011)
Olinia rochetiana	1	(Dlamini, 2004)

Prunus africana	1.085	(Cheboiwo et al., 2015)
Bersama abyssinica	0.5	(Dlamini, 2004)
Maytenus arbutifolia	0.5	(Dlamini, 2004)
Vernonia amygdalina	0.5	(Dlamini, 2004)
Osyris quadripartita Decn.	0.5	(Dlamini, 2004)
Myrsine melanophloeos	0.5	(Dlamini, 2004)

3.3.4 Estimation of anticipated mean annual total biomass weigh of individual trees

The anticipated yearly change of DBH size is employed to estimate the corresponding total annual biomass weights of the sample trees(TBM_{yi}) using a similar procedure employed in the estimation of biomass weights of the measured DBH values. All the procedures are the same to those mentioned in section 3.3.2, with the exception of the DBH values; which were replaced by the newly established DBH sizes of the tree based on tree growth rate estimations. This was done for the tree and tree/shrub species only; many because of the probability of high mortality rate of the shrub species as well as the absence of appropriate model to estimate the yearly growth rate of the shrub species. There haven't been any previous knowledge about the survival rates of the shrub species to estimate approximate biomass changes based on survival and mortality rate proportion.

Mean annual biomass production rate ΔTBM: The Mean annual biomass production rate was estimated by subtracting the initial year biomass weights (TBM_y) from the anticipated biomass weights (TBM_{yi}).

$$\Delta \text{TBM} = TBM_{yi} - \text{TBM}_y \quad (5)$$

Estimation of carbon Storage and sequestration weights

The carbon stock weight of the sample trees is extracted from the estimated biomass weight using an established fact that approximately half of the total biomass weigh of a tree is the weight of a carbon. This is through using the following formula (Newton, 2007).

$$\text{C} = \text{TBM}\ X\ 0.47 \quad (6)$$

Estimation of carbon sequestration rates (ΔC)**:** The sequestration rates is the weight of carbon sequestrated each year as a result tree growth. This was estimated through the estimating the carbon stock weight of individual trees for two different time intervals; first for the first year based on the initial year biomass weights and second for the second year based on the anticipated mean annual biomass weights. This gives a two consecutive time period carbon stock weights; which were used to estimate the carbon sequestration rate based on subtracting the final year carbon weight (C_{yi}) from the initial year carbon weight (C_y) using the following equation.

$$\Delta C = C_{yi} - C_y \qquad 7$$

3.3.5 Estimation of net oxygen production rates by trees

The men annual oxygen production rate of the sample trees was estimated based on the methods developed by (Nowak et al., 2007); which is drawn based on the concept that Net oxygen production by trees is based on the amount of oxygen produced during photosynthesis minus the amount of oxygen consumed during plant respiration. If carbon dioxide uptake during photosynthesis exceeds carbon dioxide release by respiration during the year, the tree will accumulate carbon (carbon sequestration). Thus, a tree that has a net accumulation of carbon during a year (tree growth) also has a net production of oxygen. The amount of oxygen produced is estimated from carbon sequestration based on atomic weights (using the ration of carbon to oxygen weights 32/12) using equation 8.

$$O_2 relese = C\ sequestration\ X \frac{32}{12} \qquad 8$$

Chapter Four

4 Results and Discussion

4.1 Vegetation Composition and Species Diversity

4.1.1 Vegetation composition

A total of 49 plant species belonging to 32 families were identified from the study area. The total number of individual stands in the total sample area is 10314; which is equivalent to a density of 3,581 individual stands per hectare. In terms of growth habit; the majority of the species belongs to the shrub (27 species); constituting 54.9% of the total species; followed by tree (16 species) and tree/shrub species (6 species) with a relative share of 33.3 and 11.8% respectively (Table 4).

Among the individual species; *Eucalyptus globulus* is the most dominant species constituting 3577 individual stands (35%) with an average density of 1242 individual stands per hectare. *Juniperus procera* is the second most dominant species having a total number of 2082 individual stands (20.3%) and a tree density of 723 individual stands per hectare. These two species make up more than half of the total species in the study area. The next higher level of frequency belongs to three shrub species; such as *Erica arborea* (640), *Rosa abyssinica* (528) and *Asparagus africanus* (421) which have a density of 222.2, 183.3 and 146.6 individual stands per hectare respectively. This makes them the 3rd, 4th and 5th most common species of the entire study area respectively. *Maytenus arbutifolia* is the 6th common species of the total study area and the first among the tree/ shrub species; with a total frequency of 340 individual stands and 118.06 tree density. Hence about 73% of individual species in the study area belongs to six of these species; and the rest (27%) is covered by all the remining 43 species; which have an individual share of less than 2%. Hence; this shows that the species diversity of Entoto Mountain Forest is less diverse; dominated only by two species, such as *Eucalyptus globulus* and *Juniperus procera* forest.

Among the species families; Rosaceae, Fabaceae and Asteraceae are the richest families each of which have four species in the study area. This is followed by three families such as Myrsinaceae, Celastraceae and Lamiaceae families each contributes three species. The next greater level of contribution comes two species per family found among six families such as Rubiaceae, Oleaceae, Euphorbiaceae, Moraceae, Asparagaceae and Myrtaceae. The contribution of all the remaining 19 families is one species per family. This is not however in line with species abundance. The highest individual stands were found among those which contributes less in terms of spices richness. In this regard, the highest frequency was found among Myrtaceae (34.9%) and Cupressaceae (20.2) families through their *Eucalyptus globulus* and *Juniperus procera* species. This is followed by Rosaceae and Ericaceae families constituting 6.5 and 6.1 % of the total individual stands (Table 4).

The list of species and their frequency of abundance are approximately similar to the previous studies about the vegetation structure of Entoto Mountain Forest (Fekadu Debushe, 2008). The total number of species in the current finding is however one of the lowest; mainly due to the fact that herb species and smaller trees with a DBH size of 2.5 and less were not considered in the current study; which were well addressed in the previous studies (Atinafe et al., 2020). This has created a lower level of vegetation density per the entire sample area as well as lower species numbers in the current study as compared to the previous studies.

Table 4: List of species identified in the study area with their frequency of abundance

Growth Habit	Family Name	Botanical Name	Total frequency	Relative Frequency	Density
Tree	Myrtaceae	*Eucalyptus globulus*	3,577	34.98	1,242.0
	Cupressaceae	*Juniperus procera*	2,082	20.36	722.9
	Oleaceae	*Olea europaea*	247	2.42	85.8
	Fabaceae	*Acacia abyssinica*	189	1.85	65.6
	Fabaceae	*Millettia ferruginea*	118	1.15	41.0
	Rosaceae	*Hagenia abyssinica*	69	0.67	24.0
	Rosaceae	*Prunus africana*	67	0.66	23.3
	Podocarpaceae	*Podocarpus falcatus*	65	0.64	22.6
	Rhamnaceae	*Rhamnus staddo*	33	0.32	11.5
	Pittosporaceae	*Pittosporum viridiflorum*	31	0.30	10.8
	Fabaceae	*Erythrina brucei*	27	0.26	9.4
	Myrtaceae	*Syzygium guineense*	18	0.18	6.3
	Meliaceae	*Ekebergia capensis*	18	0.18	6.3

	Moraceae	*Ficus sur*	12	0.12	4.2
	Moraceae	*Ficus vasta*	11	0.11	3.8
	Euphorbiaceae	*Croton macrostachyus*	11	0.11	3.8
Tree/ Shrub	Celastraceae	*Maytenus arbutifolia*	340	3.33	118.1
	Oliniaceae	*Olinia rochetiana*	91	0.89	31.6
	Melianthaceae	*Bersama abyssinica*	89	0.87	30.9
	Asteraceae	*Vernonia amygdalina*	78	0.76	27.1
	Santalaceae	*Osyris quadripartita*	60	0.59	20.8
	Myrsinaceae	*Myrsine melanophloeos*	40	0.39	13.9
Shrub	Ericaceae	*Erica arborea*	640	6.26	222.2
	Rosaceae	*Rosa abyssinica*	528	5.16	183.3
	Asparagaceae	*Asparagus africanus*	421	4.12	146.2
	Myrsinaceae	*Myrsine africana*	241	2.36	83.7
	Apocynaceae	*Carissa spinarum*	241	2.36	83.7
	Flacourtiaceae	*Dovyalis abyssinica*	214	2.09	74.3
	Asteraceae	*Vernonia leopoldi*	158	1.55	54.9
	Celastraceae	*Maytenus senegalensis*	124	1.21	43.1
	Smilacaceae	*Smilax aspera*	112	1.10	38.9
	Hypericaceae	*Hypericum revolutum*	58	0.57	20.1
	Loganiaceae	*Buddleja polystachya*	35	0.34	12.2
	Lamiaceae	*Clerodendrum myricoides*	34	0.33	11.8
	Asteraceae	*Laggera tomentosa*	31	0.30	10.8
	Lamiaceae	*Satureja paradoxa*	21	0.21	7.3
	Rosaceae	*Rubus apetalus*	21	0.21	7.3
	Oleaceae	*Jasminum stans*	21	0.21	7.3
	Flacourtiaceae	*Dovyalis verrucosa*	21	0.21	7.3
	Asparagaceae	*Asparagus setaceus*	19	0.19	6.6
	Euphorbiaceae	*Clutia lanceolata*	16	0.16	5.6
	Verbenaceae	*Lippia adoensis*	14	0.14	4.9
	Araliaceae	*Schefflera abyssinica*	12	0.12	4.2
	Asteraceae	*Vernonia filigera*	11	0.11	3.8
	Lamiaceae	*Satureja imbricata*	11	0.11	3.8
	Rubiaceae	*Pentas schimperiana*	10	0.10	3.5
	Rubiaceae	*Pentas lanceolata*	10	0.10	3.5
	Celastraceae	*Maytenus gracilipes*	9	0.09	3.1
	Anacardiaceae	*Rhus vulgaris*	8	0.08	2.8
	Grand Total		**10314**	**35281.2**	**3581**

4.1.2 Species diversity

Species diversity was estimated for the entire sample plot as well as for three different forest types. This was done through dividing the species frequency results of the total sample plots in to three different categories based on the dominant species found in each sample plot. Spices dominancy was identified using a 40% threshold; in which a species which constitutes more than 40% of the total trees counted in a specific sample plot were used to cluster the plot belonging to the corresponding species category. In this regard; *Eucalyptus globulus* and *Juniperus procera* are two of the specific species which dominants most of the sample plots and used to cluster the species category in to *Eucalyptus* and *Juniperus* dominated forest classes. Those plots with the absence of dominant species (if the relative share of all the species in a plot is less than 40% of the total individual stands) were categorized as mixed forest category. Among the three forest types; the relatively greater level of species diversity was found in the Mixed Forest which constitutes 47 of total 49 spices found int the study area. This is followed by *Juniperus* forest which constitutes 40 of the total species. The least diverse forest type is *Eucalyptus* Forest where there are only 28 species. This is also in line with the measure's species diversity and evenness indexes. Specifically, the Shannon and Wiener index of species diversity measurement shows that the relatively grater level of species diversity was found in the mixed (2.2) and Juniper (1.9) forests than the *Eucalyptus* (1.3) forests as well as the diversity index of the entire study area (1.9).

The evenness estimate implies the same implication to the diversity measurement; where the evenness values for *Eucalyptus* Forest is slightly lower than the remaining forest types; implying the domination of individual species in the *Eucalyptus* Forest than the others (Table 5). Despite all the variation among the individual forest classes; the forest species composition of the entire study area is less diverse and is dominated with a very few numbers of species. This also reflected with the frequency of species appearance; as the study area is dominated by a very few numbers of species such as *Eucalyptus globulus* and *Juniperus procera*.

Table 5: Estimated statistical values of species abundance and distribution

Plot category	Species Richness	Shannon Winner Index	Simpson Index	Evens Index
Eucalyptus	28	1.3	0.617	0.185
Juniper	40	1.9	0.709	0.192
Mixed	47	2.2	0.734	0.190
Total	**49**	**1.9**	**0.707**	**0.180**

Hence, it can be concluded that Entoto Forest is very poor in terms of species diversity. The reason for this is that it is a manmade forest created in the late nineteenth century to supply the newly founded capital of Ethiopia with firewood and timber. The city was undergoing a serious shortage of both commodities at the time and the quick-growing *Eucalyptus* was crucial to Addis' survival and its status as the Ethiopian capital (Horst, 2006). The *Eucalyptus* tree, however, loves water. The clustering of so many eucalypti prevent the growth of most other plants and the effect is a poor species diversity as was the observation in the species diversity analysis (Goded et al., 2019). As a reflection; the species diversity is better in the area where the dominancy of *Eucalyptus* is lower; such as int the Juniper and mixed forest areas. In this regard; the afforestation activities of the past 20 years might have contributed a positive improvement since more diverse tree species were introduced in the peripheries of the forests where plantation activities were conducted. This can be evidenced by a more diverse species in the recent plantation areas where there are a mix of young tree species specifically *Hagenia abyssinica*, *Juniperus procera* and *Acacia abyssinica*.

In addition to the natural barrier of *Eucalyptus* in supporting a mix of species; intensive human intervention is the other factor that contributes for the poor species diversity of the area. This is specifically due to the prevalence of mixed land use activities such as settlement; farming and uncontrolled grazing uses inside the middle of the forest which might be a hinderance for successive regeneration of smaller plant species as well as a barrier for the existence of shrub and herb species which are more vulnerable for disturbance and growth interruption. The other anthropogenic disturbance is through fuelwood collection by the local residents. In this regard; the litter surface of the entire area (specifically the *Eucalyptus* dominated areas) is always in disturbance and litter and seeds shading from the bigger trees were hardly left on the ground surface for natural regeneration. Dead shrub species and dry tree branches in the human accessible height limits are the target of the fuel wood collectors; which might have a significant impact in reducing the growth of ecologically significant species which are sensitive to disturbance and intervention (Haile, 1991). This impact is more pronounced in the *Eucalyptus* dominated forest areas where there are more fuel wood products to collect. The impact is relatively slighter in the relatively inaccessible areas for frequent human

The species diversity analysis of the previous studies is approximately in line with the current finding. The basic findings lie on the poor species diversity nature of Entoto Mountain Forest and the dominancy of *Eucalyptus globulus* species than any other tree species. The detail statistical results of diversity measures are however marked with a notable difference. One of this is the higher level of Shannon Winner Index estimated (closer to 2.9) by the studies of Woldegerima et al., (2017) and Atinafe et al., 2020 (2020) which were conducted in the same geographical location to the current study. The reason for the difference might arises due to methodological biases while considering vegetation species types. The highest estimates of the previous studies were recorded while considering herbs and smaller trees in the forest inventory times; which were not in the scope of the current study. Hence the current diversity analysis represents only vegetations with a growth habit shrubs and trees having a DBH size of greater than 2.5. The Shannon Winner Index of another study for the tree layers was in approximate similar range with the current study (Fetene & Worku, 2013). This signifies the fact that species diversity results could vary significantly depending on growth type consideration during the forest inventory.

4.1.3 Stand structure

The density of tree species per DBH category shows that the study area is dominated by high density of species in the lowest category with a DBH value lower than 10. The most dominant DBH class was between 6 and 10; where the number of individual stands reaches to 2200. The distribution of individual stands was evenly distributed in the first three DBH classes (lower than 15); which declines abruptly in the next DBH class (between 16 and 20) and continues to decrease towards the remaining the highest classes (Figure 3).

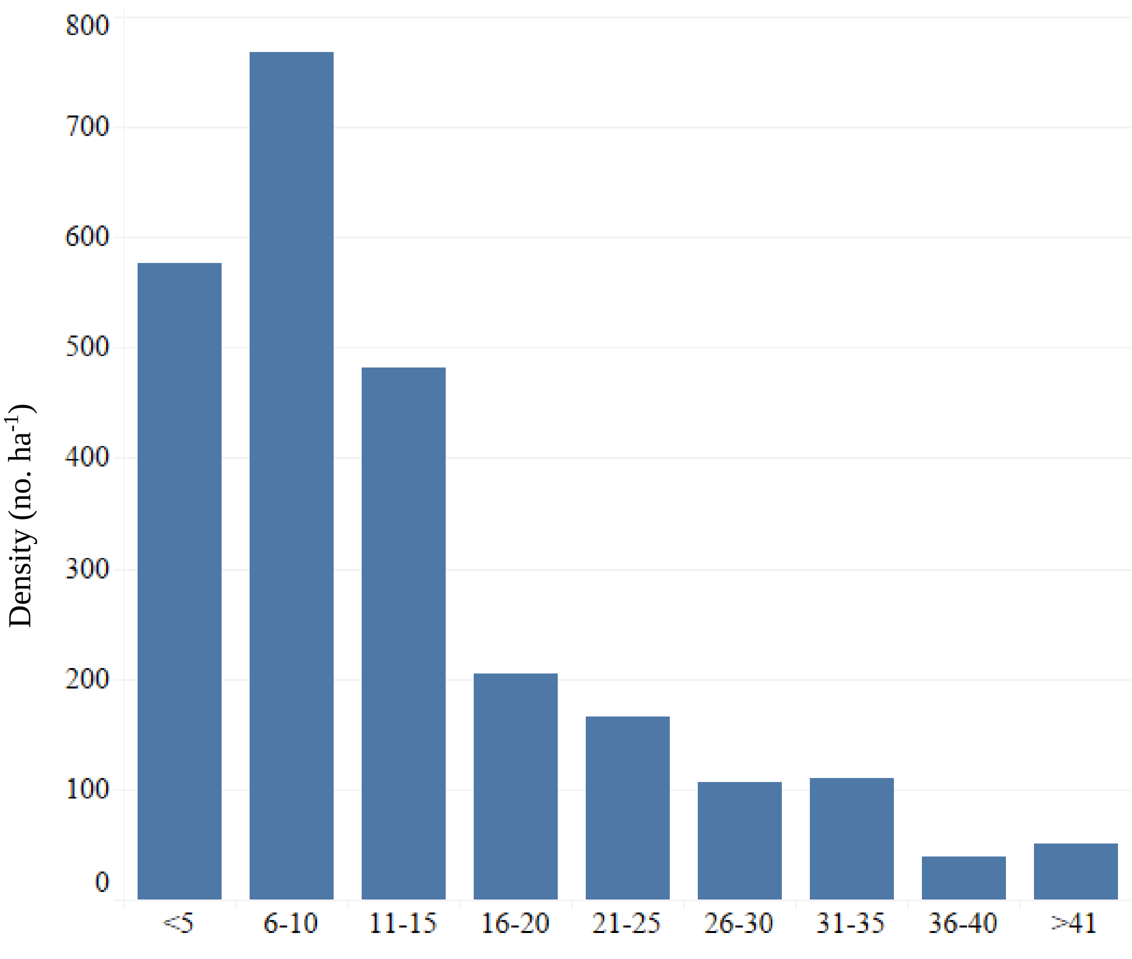

Figure 3: Tree density of the sample plots per different DBH classes

To reveal the reason for the observed stand structure; the DBH value of the most dominant tree species were investigated separately. The result shows that the DBH pattern of the total study area is most mainly a reflection of *Eucalyptus globulus* population structure which is characterized by a bell-shaped curve structure. Accordingly, the majority of the individual stands belongs to the middle DBH class; with the highest values reaching to 760 individual stands per hectare in the second class (between 6 and 10) while the frequency decreases sidewise to the opposite direction. This is in contrary to the age of the forest where would be expected to find more trees in the higher DBH class (showing at least a 50 years growth rate). The reason is that the *Eucalyptus* trees were harvested at frequent interval and the majority of them were copied stands regenerated from last harvesting time which is assumed to be in the recent decades (Figure 4). *Juniperus procera* is the other important species influencing the size-class distribution of the overall study area as it is the second most abundant tree species. The result shows that it has approximately a similar structure with the *Eucalyptus globulus* characteristics; where the highest frequency of individual stands is found at the lowest values (ranging from lower than 10). The largest concentration is found in the second which is approximately 215 individual stands per hectare; while for the remining DBH classes the frequency is merely between 50 and 100. This indicates lack of consecutive recruitment and also the lack of old trees. A few of those in the highest-class categories might represent the remnant of the original tree species which were there long before the plantation of *Eucalyptus* species was started a century ago (Figure 4). Their fewer number might be an indication of selective removal of the tree species after a certain age due to human intervention. They were indeed the most dominant sources of construction materials and timer production during the historical time. On the other hand; those which are in the medium class and leftwards towards the lower category are probably the result of plantations intervention of the past 20 years.

The size class distribution of other species than *Eucalyptus globulus* and *Juniperus procera* shows that their distribution an inverse J shape with the highest frequency of individual stands appeared in the lower DBH class. Those in the lower DBH category represent the younger trees which might have been planted by the reforestation activities of the past 20 years. This includes *Acacia abyssinica*, and *Hagenia abyssinica* species where there are plenty of them in the recent plantation areas. On the other hand; those in the medium category and beyond might represent a few of remnants of primary indigenous tree species which were there long before the introduction of *Eucalyptus globulus* plantation. This includes *Podocarpus falcatus*, *Olea europaea, Acacia abyssinica, Vernonia amygdalina* and *Croton macrostachyus.* In general; the stand structure of Entoto Mountain represents intensive anthropogenic intervention in the form of plantation and selective removal of individual stands than natural regeneration process. This is typically reflected in the *Eucalyptus globulus* and *Juniperus procera* stand structures; which were proved to be the target of selected removal and frequently planted species over the past 50 years respectively (Luis Gil et al., 2010). Specifically, for *Eucalyptus globulus* there were consecutive plantations activities between 1990s until the mid of the 1980s due to individual initiations as well as by government interventions. However once reaching to the middle level; the difference in the DBH class becomes less visible; manly due to recurrent cutting of the trees once reaching to a certain age. The older *Eucalyptus* trees which were planted a hundred years ago rarely sustains their original growth rate due to recurrent cutting. Once regenerated; their DBH becomes approximately similar to the recently planted trees which makes the number of trees in the higher DBH category very few in number than the others.

The stand structure result and distribution of species among different DBH classes is slightly unique from the previous studies conducted on approximately a similar geographical region (Fekadu Debushe, 2008; Woldegerima et al., 2017) The result of these studies shows that the vegetation structure is characterized by a perfectly inversed J shape structure; with an extreme variation in the density of individual stands between the first class and all the continuous lower classes. The study of Fekadu, (2008) was conducted to evaluate the then *Eucalyptus globulus* plantation activities and hence the sampling produce is concerned with the seedlings and smaller trees(which were not in the scope of the current study) as equal as the higher trees; which results in an imbalance towards the lower category. The time gap between the study periods (about 11 years) is also well enough to be reflected in the stand structure variation. The then seedlings would have been grown to a matured trees and there is no enough information if planation has been conducted since then. On the other hand the study of (Woldegerima et al., 2017) were conducted in Gullele Botanical Garden; which was not in the sampling area of the current study. The area is also one of the intensively managed forests where three are continued planation activities to create a DBH graph lining towards the lower category.

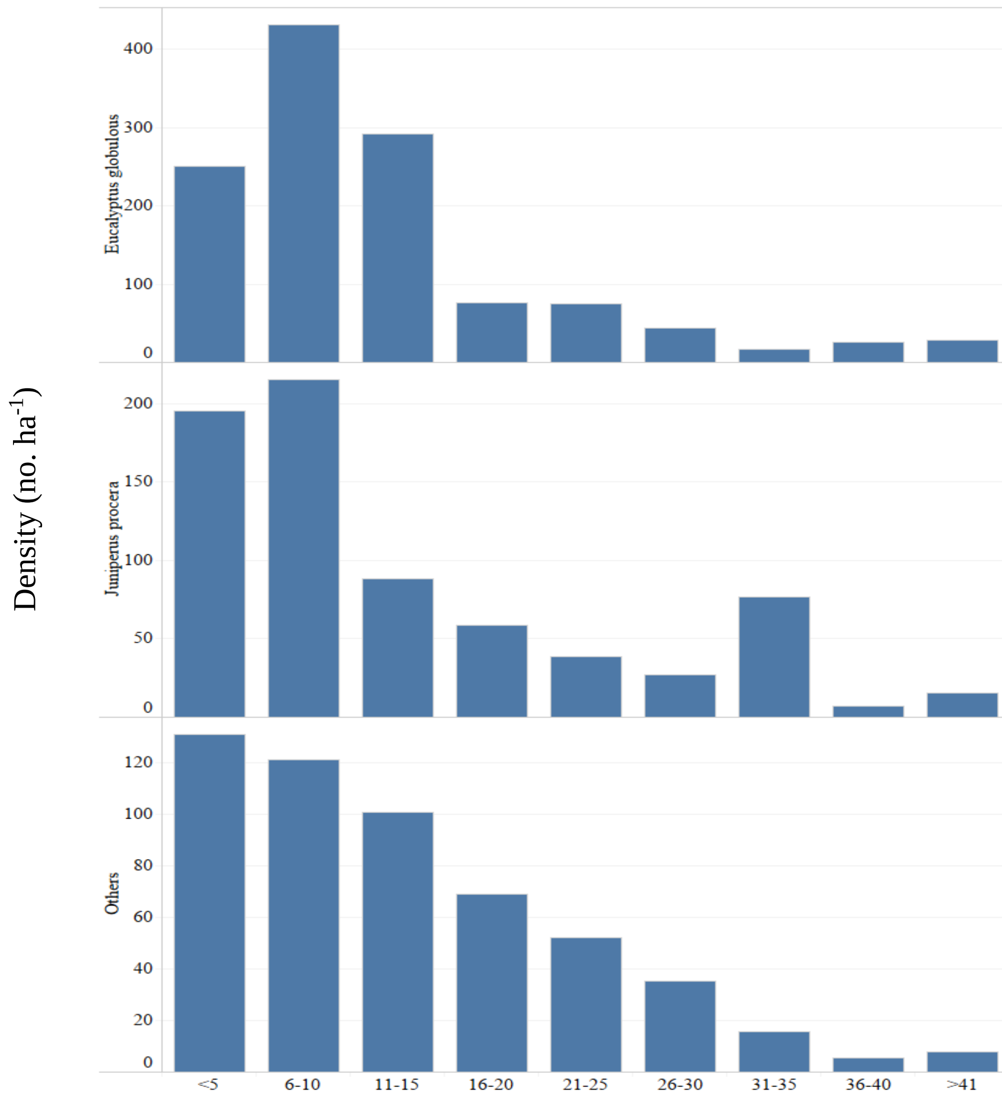

Figure 4: Density of individual stands per different DBH category of the most dominant species and the sum of all other trees identified in the sample plots.

4.2 Biomass stock and production rates of the sample trees

The biomass weight of the sample plots is computed using a combination of multispecies and species-specific biomass allometric equations for all of the 49 species; the result of which is used to compare the contribution of individual species for the total carbon storage weights. According to the result; the biomass weight of all the vegetation species is about 1590.2 t; which is equivalent to an average biomass density of 552.3 t ha^{-1}. Among the sample species; the largest share for the total biomass weight was contributed from two of the most dominant species; such as *Juniperus procera* and *Eucalyptus globulus* with a biomass density of 286 and 202. 3 t ha^{-1} respectively. This is followed by *Olea europaea* (18.24 t ha^{-1}), *Millettia ferruginea* (11.56 t ha^{-1}) and *Acacia abyssinica* (6.15 t ha^{-1}). The total biomass weight of all the remaining species is less than 10 t (the highest of which is for *Hagenia abyssinica*); the sum of which makes up 65 tons of biomass (Table 6).

Table 6: Estimated total biomass and carbon Stock weights in the sample plots

Species Name	Biomass		Carbon		Relative Share
	Weight (t)	Density (t ha^{-1})	Weight (t)	Density (t ha^{-1})	%
Juniperus procera	823.9	286.1	387.2	134.5	52.1
Eucalyptus globulus	582.7	202.3	273.9	95.1	36.8
Olea europaea	52.5	18.2	24.7	8.6	3.3
Millettia ferruginea	33.3	11.6	15.7	5.4	2.1
Acacia abyssinica	17.7	6.1	8.3	2.9	1.1
Hagenia abyssinica	11.0	3.8	5.2	1.8	0.7
Ficus vasta	8.2	2.9	3.9	1.3	0.5
Ficus sur	7.7	2.7	3.6	1.2	0.5
Erythrina brucei	7.6	2.6	3.6	1.2	0.5
Vernonia amygdalina	6.5	2.2	3.0	1.1	0.4
Podocarpus falcatus	5.4	1.9	2.5	0.9	0.3
Prunus africana	5.74	1.99	2.70	0.94	0.3
Maytenus arbutifolia	4.7	1.6	2.2	0.8	0.3
Ekebergia capensis	3.7	1.3	1.8	0.6	0.2
Bersama abyssinica	2.5	0.9	1.2	0.4	0.2
Syzygium guineense	2.2	0.8	1.1	0.4	0.1

Osyris quadripartita	1.8	0.6	0.8	0.3	0.1
Olinia rochetiana	1.6	0.6	0.8	0.3	0.1
Croton macrostachyus	1.1	0.4	0.5	0.2	0.1
Myrsine melanophloeos	1.0	0.3	0.5	0.2	0.1
Pittosporum viridiflorum	0.5	0.2	0.2	0.1	0.0
Rhamnus staddo	0.3	0.1	0.1	0.1	0.0
All Shrub Species	**6.5**	**2.3**	**3.0**	**1.0**	**0.4**
Total	**1,590.2**	**552.3**	**747.8**	**259.6**	

In addition to the existing biomass weight of the sample trees, the anticipated mean annual biomass production rate of the sample trees as function of their growth rate was estimated; which serves as an essential input to measure the air quality regulation services. According to the result; the total biomass production rate of all the sample trees is about 143 t y^{-1}; with an average density of 49.8 t y^{-1} $ha^{-1.}$ Hence, the anticipated annual increase in the biomass weight of the sample trees is estimated to be 1727 tones (Table 7). This is equivalent to 6.6% increases in the total annual biomass weight. There is however a considerable variation in the biomass production rate of different species. The largest share of biomass production among the individual species is for *Juniperus procera* and *Eucalyptus globulus* with an average production rate of 69.62 (24.17 t h^{-1} y^{-1}) and 60 t y^{-1} respectively. (20.72 t h^{-1} y^{-1}). This is followed by *Maytenus arbutifolia, Acacia abyssinica* and *Hagenia abyssinica* having an average production rate of 4, 3 and 1.4 t y^{-1} respectively. The aggregate contribution of all the remaining 17 species is closer to 4.06 metric per year. This shows that the most dominant contribution for biomass production comes from the most abundant species (Figure 5).

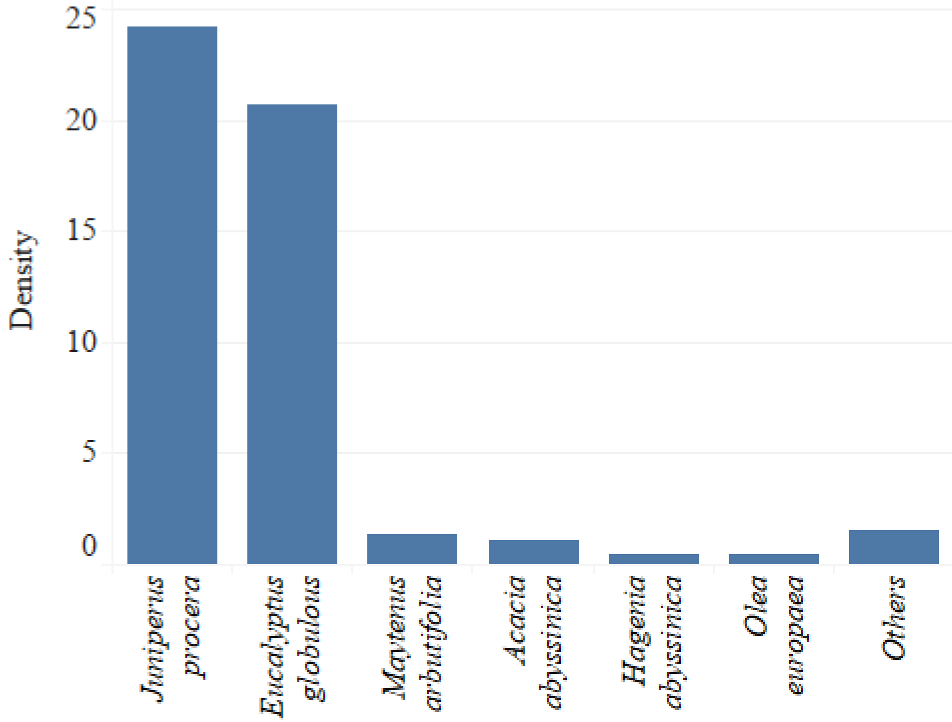

Figure 5: Mean annual Biomass Production Rate of the sample trees (density t h^{-1} y^{-1})

The estimated amount of biomass weight is approximately comparable with the findings of Woldegerima et al. (2017) who reports a biomass density of 343 t ha^{-1} for Gullele Botanical Garden forest which is adjacent to Entoto Mountain Forest. The reason for the variation with the current study is that that study of Woldegerima, (2017) was drawn based on sample trees taken from different tree density zones of the entire area. The current result is however estimated based on a similar assumption of tree density in the entire forest area. The current finding is also one of the highest compared to other studies in the other parts of the country. As an example biomass estimation in the Southern region and Western parts of the country shows that the average records of total biomass density were approximately closer to 250 t ha^{-1} (Dick OB, 2015). The mean annul biomass density of Afro-montane forest type of Ethiopia country was estimated to be 131.5 t ha^{-1} (Moges et al., 2010); which is less than the estimated amount of in the current findings. One of the reasons for the variation might be the use of different biomass allometric equations. In the current study, it was tried to use species specific allometric equations for the most dominant species; which might produce a slighter variation with the previous studies conducted based on the use of multispecies allometric equations. In this regard; the use of species-specific methods has the advantage of considering many morphological and stand structure variation of the species. As an example; in our result we, found that the biomass weight of *Eucalyptus globulus*, and *Juniperus procera* having a DBH size of 7.5 is about 20.0 and 51.2 Kg respectively. The difference arises from the variation of internal density and weight of biomass; which was wall considered in the species specific allometric equations. Hence, may similar variations will be considered in the current estimates; which produces a slightly higher level of biomass weights than many of the previous studies which relays based on the use of multi species allometric equations.

4.3 Carbon stock and Oxygen production rates of the sample trees

The total carbon storage weight of the sample trees estimated as a function of biomass weights (using a 47 % of carbon threshold system) is 744.8 tones, with average density of 258.8 t C h^{-1}. As of the observation in the biomass stock weights; there is a substantial variation in the contribution of the sample species for the total carbon storage weight. About 89% of the total carbon stock is contributed only from two species; such *Juniperus procera* and *Eucalyptus globulus;* which contributes 134.5 (387 t) and 95 t C ha^{-1} (273.8 t) of carbon storage respectively. The next higher level of relative share is found among four species such as *Olea europapaea* (8.6 t C ha^{-1}), *Millettia ferruginea* (5.4 t Ca ha^{-1}), *Acacia abyssinica* (3.7 t C ha^{-1}) and *Erica arborea* (2.3 t C ha^{-1}) which altogether have a total share of 7.5%. The individual contribution all the remining 43 species is under 2 C ha^{-1} the sum of which makes up 6.1% of the total estimated carbon weight (Table 6).

When comparing the carbon stock estimates with the other studies; the current finding parallels to the study of Woldegerima et al., (2017) which reported a total carbon storage density of 171 t C ha^{-1} in Gullele Botanical Garden. More than this study; the current finding is more closer to other studies conducted in the southern and south western parts of the country; such as 256.82 t C ha^{-1}

in Chilimo Dry Afromontane Forest (Tesfaye et al., 2020) and 323 t ha^{-1} in the western parts of Oromia region (Abetu & Bekele, 2019).

Table 7: Summary of Biomass and Carbon stock weights and Oxygen production rates of the sample plots

	Stock weight		Mean annual Change Rate		Anticipated Yearly Growth	
Parameters	Weight (t)	Density ha^{-1}	Weight t $^{-}y^{-1}$	Density t ha^{-1} y^{-1}	Weight (t)	Density t ha^{-1}
Biomass	1590.2	552.37	143.34	49.8	1727.81	599.8
Carbon	744.7	258.5	67.3	23.3	812	281.9
Oxygen			179.6	62.3		

The mean annual change in the amount of carbon stock in the sample trees that comes a result of tree growth and the resultant biomass weight change was estimated to know the contribution of Entoto Forest in sequestrating carbon emissions and its air quality regulation service. According to the result, the mean annual carbon storage weight of the sample trees was estimated to be increased by 67.3t C; which makes the anticipated yearly change of the total carbon stock of the sample trees 812 t C. The average carbon sequestration density is therefore accordingly 23.3 t C y^{-1} ha^{-1} (Table 7).

The air quality regulation services of the sample trees were also estimated in terms of oxygen production rate; which is a function of carbon sequestration levels. According to the result; the mean annual oxygen production rate of trees in the ample plot is estimated to be 179 .6t O_2 y^{-1}; with the average Oxygen production density of 62.3 t O_2 ha^1 y^{-1}.

The contribution of individual species for carbon sequestration and oxygen production levels is parallel to biomass production rate. The highest carbon sequestration and oxygen production amounts comes from those having a greater share in terms of biomass production amounts. Accordingly, the largest share comes from *Juniperus procera* and *Eucalyptus globulus* with a total sequestration rate of 11.3 and 9.7 t C ha^1 y^{-1} and oxygen production rate of 30.2 and 26 O_2 t ha-^{1}

y^{-1} respectively. The aggregate contribution of all the remaining species for carbon sequestration and oxygen production is approximately 2 t C ha^{1} y^{-1} and 5 t O_2 t ha^{1} y^{-1} respectively (Figure 6).

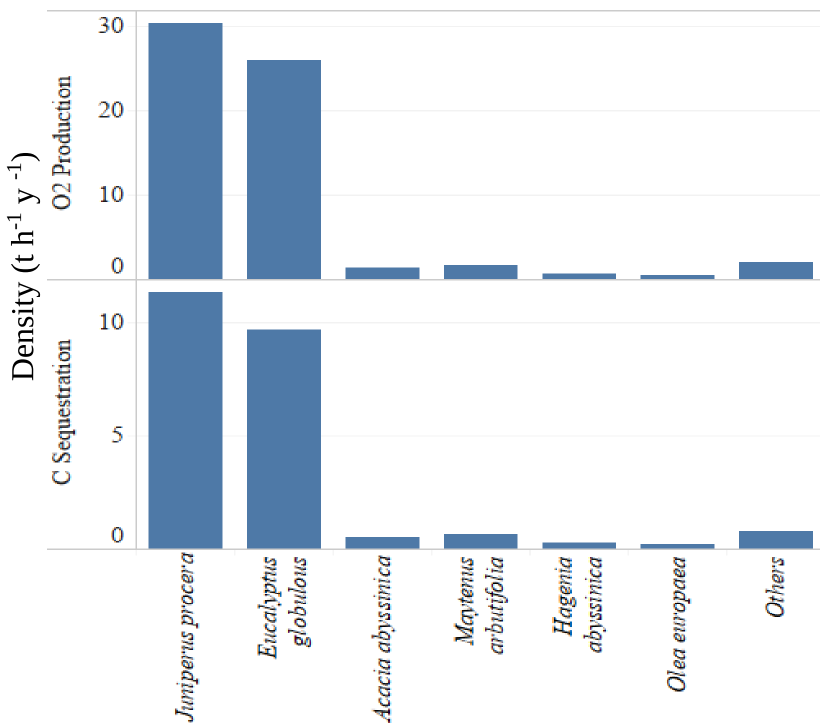

Figure 6: Mean annual Carbon sequestration and oxygen production rates of the sample trees

The main reason for the variation in the level carbon sequestration and oxygen production among the sample species is the result of species abundance, with the highest contribution comes from the most dominant species. In addition to this; the difference comes partly due to variation of annual growth rate and stand structure variation. With increasing of DBH; the rate of biomass production increases; which in turn raises carbon sequestration and oxygen production rates.

When compared to the result of previous studies; the estimated amount of carbon sequestration in the current study is found to be among highest estimates both at the country and continental levels. There are indeed fewer studies of carbon sequestration estimates which were conducted based on the same metrological procedure with the current study to make an approximate comparison. Most previous studies use a forest cover change based method to estimate carbon storage changes. This is through comparing the spatial coverage forest area between two-time intervals and estimate the corresponding biomass and carbon storage changes to estimate biomass production and carbon sequestration rates (Moges et al., 2010) . The result is however less precise as compared to the tree growth-based estimation of carbon sequestration rates (based on the assumption that a growing forest will remove carbon dioxide and produce oxygen). It is indeed well known that the forest cover change would produce alteration of carbon sequestration rates. This requires however a long-term monitoring of the forest area and the result is only an average estimate of a long period interval. It fails to take in to account the inter annual changes of carbon storage weights which happens due to forest structure changes (Aguaron & McPherson, 2012) . Although its contribution is minimal, the other reason for difference of the estimates might be due to the drawbacks of the assumptions where the current estimation where drown. One of this is the assumption of zero tree mortality rate and estimation of carbon storage weights for the same number of individual stands for a consecutive year. This might have contributed its own share for the escalated amount of carbon sequestration estimation. But the effect is still minimal to be considered as the only reason of difference. The basic reason is rather associated with the conceptual disparity between the spatial cover change and tree stand structure change based estimates.

The oxygen production estimates are comparable with the previous study where the current methodologies were adopted (Nowak et al., 2007). Int the study of Nowak et al, (2007) the mean annual oxygen production rate of a tree is estimated to be raged between 113 to 2.9 Kg O_2 y^{-1}. As of our finding; the main reason for the variation of oxygen production among different species arises mainly due to difference of stand structure. Trees with higher DBH size would tend to have a higher rate of Oxygen production than those with a lower DBH size. There is no however any relevant study conducted in Ethiopia about the oxygen production rate of trees to compare the results with the current findings.

Assuming a similar tree density in entire sample boundary (1600 hectare); it was attempted to estimate the total carbon stock and oxygen production weights of the entire Entoto Mountain Forest. This is through multiplying the estimated density vales of the sample plots to the entire study area boundary. According to the result, the total carbon stock weight is approximately 415,383.14 t, which is equivalent to 1,520,302.31 tons of Carbon dioxide(Table 8). According to the carbon finance accounting system of emission reduction for the global climate change projects in Ethiopia, the approximate economic value of a carbon stock is about 4 USD per ton (Assaye, 2015). Hence; the estimated carbon stock is worth of 6,081,209.24 US dollar. The carbon sequestration value (136,984.45 t Co_2 per year) on the other hand is equivalent to 547,937.80 US dollar per year. This is indeed a significant economic value if considered in the global carbon finance system. However, the principal emission reduction accounting systems in the country were designed based solely on area coverage change of a forest with little attention for carbon sequestration due to forest growth rate change.

On the other hand, the oxygen production rate in the entire Entoto Mountain Forest is about 99,781.57 tones (Table 8). This is undoubtedly an important ecosystem service as this gas regulates the metabolic activities of living organisms. To value how important is the estimated amount of the oxygen production rate; it was tried to make a rough estimation of its service for human wellbeing taking the population of Addis Ababa city as an example. An average adult human being consumes 0.84 kg of oxygen per day which is equivalent to 306.6Kg year used (Nowak et al., 2007). According to this value, the estimated amount of oxygen production rate in the entire Entoto Mountain Forest (99,781.57 tones) is approximately equivalent to the mean annual oxygen consumption rate of 322,346.4 individuals per year. This constitutes approximately to 8% of the total oxygen demand of the city of Addis Ababa as per the latest population estimation data of the city (4,000,000 individuals with a total oxygen consumption demand of 1,224,000 tons per year). This is however a rough estimation and the purpose is to create an imagination to make the ecosystem value of the forests recognized. It cannot be used as a measure of the sufficiency level of oxygen production rate in the city. This partially has to do with the large amount of oxygen within the atmosphere (approximately 21% of the atmosphere's weight is oxygen). The oxygen content of the atmosphere remains essentially constant with the oxygen consumed by all animals, bacteria, and respiration processes roughly balanced by the oxygen released by land and sea plants during photosynthesis. The present atmospheric oxygen content seems not to have changed since 1910. Furthermore, because air is about 20 percent oxygen, the total supply is immense. The atmosphere has such an enormous reserve of oxygen that even if all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent. Also, waters of the world are the main oxygen generators of the biosphere; their algae are estimated to replace ≈90% of all oxygen used (Nowak et al., 2007). Thus, although urban trees do produce significant amounts of oxygen, it is not a significant ecologic benefit given the global nature of oxygen and the sheer volume of oxygen in the atmosphere.

There are indeed other essential ecosystem service values of urban forests than just oxygen production. Trees in and around urban trees can improve air quality as well as reduces extreme temperature levels of urban areas. Because small changes in air pollution concentrations can have relatively considerable impacts on air quality and human health, the effects of urban forests on air pollution can be significant. Different trees species absorbs a variety of pollutant chemicals in the atmosphere. Specifically, tree effects on trace chemicals in the atmosphere (chemicals that are minor components of the total atmosphere) will have a much greater relative impact on environmental quality and human health than chemicals such as oxygen that comprise a large proportion of the atmosphere.

Table 8: The carbon stock and oxygen production weights of the entire Entoto Mountain Forest

Parameters	Existing Stock (tones)	Anticipated annual change rate (t y^{-1})	Anticipated stock after a year (t)
Biomass	883,793.92	79,632.86	963,426.79
Carbon	415,383.14	37,427.45	452,810.59
CO_2	1,520,302.31	136,984.45	1,657,286.76
Oxygen production		99,781.57	

Chapter Five

5 Conclusion and Recommendations

5.1 Conclusion

The findings of the current study indicates that Entoto Mountain Forest is an important ecosystem to regulate the ecosystem services of the city of Addis Ababa and the nearby environment. The vegetation composition is however less likely to be good biodiversity reserve. It is dominated by *Eucalyptus globulus* which is less suitable to support the growth of other species and the development of species in the lower-level forest growth habits.

The stand structure of the forest indicates that despite being a century old forest reserve; the frequency of species in the higher DBH category are very low; which indicate the presence of high mortality rate and selective removal of the available matured trees. It was also observed that the plantation intervention by the consecutive state actors (starting from the 1960s) has affected the stand structure of the forests as exhibited by the high frequency of species in the lowest DBH size category which might have been planted in recent years. This is exemplified by *Juniperus procera*, *Acacia abyssinica* and *Hagenia abyssinica*; which have high frequency of species in the lowest DBH size representing the effect of recent plantation activity. This is indeed a good starting to increase the biodiversity of the area and enhance its ecosystem service values.

The biomass weight of individual stands is used as a proxy variable to quantify the of ecosystem service value in terms of carbon sequestration and oxygen production rate. In this regard; the carbon storage and oxygen production rates were found to have a positive correlation with increasing tree size which determines the biomass weight of the trees. In addition to stand structure, the growth rate of a tree is an important determining factor of carbon sequestration and oxygen production rates.

The estimated carbon sequestration and oxygen production results could be used as an important indicator of the ecosystem service values of specifically forests in the closer vicinities of urban areas. The carbon stock estimates might be used to estimate the tradeoff between the carbon emission and sequestration rates of the city of Addis Ababa. It can also be used to value how important are the forests in terms of regulating the global climate change through reducing greenhouse gas emissions. The oxygen production estimates are also important indicators of the role of urban area forests in regulating local environments. In this regard, the significance oxygen production estimation is paramount in terms of valuing other significant air quality regulation services of urban area forests that are difficult to measure and also intangible to be conceived. The other significance is to use the oxygen production as a measurement standard of urban greenery requirement. This is to use it as one of the measurement systems to answer the question of how much trees are enough in an urban area to maintain a healthy urban life. It is also an important method to make the impacts of deforestation and fossil fuel burning perceivable by all the concerned organization and individual actors.

5.2 Recommendations

- ✓ The estimated ecosystem service values as well as the tree growth rate-based valuation methods of carbon sequestration and oxygen production by urban area forests can be used as a good indicators of urban area air quality measurement standards.
- ✓ The estimated carbon sequestration financial values yielded a higher value than many of the previous estimations which were conducted based on the conventional forest area change carbon storage accounting systems. This signifies that the use of a tree growth-based estimation of carbon sequestration weights could yield greater benefits for the country and future climate change-based cost benefit mechanisms better be designed in consideration with carbon sequestration weights from tree growth in addition to the area coverage-based accounting system.
- ✓ The ecosystem service values estimated in the current research are only very few parts of the huge ecosystem reserve of Entoto Mountain Forest. Future research activities should be oriented towards valuing other ecosystem services which were not addressed in the current study.
- ✓ The other important research direction will be establishing a tree age and growth rate estimation allometric equations; which might ease future forest monitoring activities as well as scientific knowledge about forest ecosystem values.

- ✓ It is also needed to establish a systematic and institutionalized monitoring of tree growth at a regular time interval, so that it could be possible to monitor carbon sequestration from tree growth at a regular interval.

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Appendix

Appendix 1: List of all plant species, family, and growth habit recorded from Entoto Mountain Forest

ID	Species Name	Family Name	Local Name (Amharic)	Growth Habit
1	*Eucalyptus globulus* Labill.	Myrtaceae	Bair Zaf	Tree
2	*Juniperus procera* Hochst ex Endl	Cupressaceae	Tid	Tree
3	*Erica arborea* L.	Ericaceae	Adal	Shrub
4	*Rosa abyssinica* Lindley.	Rosaceae	Kega	Shrub
5	*Asparagus africanus* Lam	Asparagaceae	Yeset Qest	Shrub
6	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	Atatt	T/S
7	*Olea europaea subsp. cuspidita* (Wall. ex G. Don) Cif.	Oleaceae	Weira	Tree
8	*Rhamnus staddo* A. Rich.	Rhamnaceae	Tsedo	Tree
9	*Carissa spinarum* L.	Apocynaceae	Agam	Shrub
10	*Myrsine africana* L.	Myrsinaceae	Qechemo	Shrub
11	*Dovyalis abyssinica* (A. Rich.) Warb	Flacourtiaceae	Koshm	Shrub
12	*Vernonia leopoldi* (Sch. Bip. ex Walp.) Vatke	Asteraceae	Chibo	Shrub
13	*Acacia abyssinica* Hochst. ex Benth	Fabaceae	Girar	Tree
14	*Maytenus senegalensis* (Lam.) Excell	Celastraceae	Atatt	Shrub
15	*Millettia ferruginea* (Hochst.) Bak.	Fabaceae	Birbira	Tree
16	*Smilax aspera* L. (Smilacaceae)	Smilacaceae	Ashkla	Shrub
17	*Olinia rochetiana* A. Juss	Oliniaceae	Asqamo	T/S
18	*Bersama abyssinica* Fresen	Melianthaceae	Afajeshgn	T/S
19	*Vernonia amygdalina* (Del.)	Asteraceae	Grawa	T/S
20	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Rosaceae	Kosso	Tree
21	*Prunus africana* (Hook.f.) Kalkm.	Rosaceae	Tiqur Inchet	Tree
22	*Osyris quadripartita* Decn.	Santalaceae	Qeret	T/S
23	*Hypericum revolutum* Vahl	Hypericaceae	Amja	Shrub
24	*Myrsine melanophloeos* (L.) R. Br	Myrsinaceae	Weyl	T/S
25	*Buddleja polystachya* Fresen	Loganiaceae	Buddleja	Shrub
26	*Pittosporum viridiflorum* Sims.	Pittosporaceae	Weyl	Tree
27	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	Blumea	Shrub
28	*Erythrina brucei* Schweinf	Fabaceae	Qwara	Tree
29	*Dovyalis verrucosa* (Hochst.)	Flacourtiaceae	Fentoflas	Shrub
30	*Jasminum stans* Pax	Oleaceae	Ano Qtel	Shrub
31	*Rubus apetalus* Poir.	Rosaceae	Enjorie	Shrub
32	*Satureja punctata* (Benth.) Briq.	Lamiaceae	Tosgn	Shrub
33	*Podocarpus falcatus* (Thunb.) Mirb.	Podocarpaceae	Zigeba	Tree

34	*Asparagus setaceus* (Kunth) Jessop	Asparagaceae	Seriti	Shrub
35	*Ekebergia capensis* Sparrm	Meliaceae	Lol	Tree
36	*Syzygium guineense* (Wild.) DC.	Myrtaceae	Doqema	Tree
37	*Ficus sur* Forssk	Moraceae	Sholla	Tree
38	*Croton macrostachyus* Hochst. Ex A. Rich	Euphorbiaceae	Bisana	Tree
39	*Ficus vasta* Forssk	Moraceae	Warka	Tree
40	*Satureja paradoxa* (Vatke) Engl. ex Seybold	Lamiaceae	Nado	Shrub
41	*Pentas lanceolata* (Forssk.) Defl.	Rubiaceae	Yejib Mirkuz	Shrub
42	*Pentas schimperiana* (A. Rich.) Vatke	Rubiaceae	Weynageft	Shrub
43	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	Qustya	Shrub
44	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	Msirich	Shrub
45	*Clutia lanceolata* Forssk	Euphorbiaceae	Fiyelefej	Shrub
46	*Lippia adoensis* Hochst. ex Walp	Verbenaceae	Koseret	Shrub
47	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	Celastraceae	Atatt	Shrub
48	*Rhus vulgaris* Meikle	Anacardiaceae	Embs	Shrub
49	*Vernonia filigera* Oliv. & Hiern	Asteraceae	Hamaka	Shrub

Appendix 2: Frequency of individual species enumerated in the sample plots in Entoto Mountain forest (the columns represent frequency of species in each plots)

ID	Species Name	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10
1	*Eucalyptus globulous*	93	84	82	79	31	95	92	94	80	89
2	*Juniperus procera*	59	82	40	23	61	45	27	46	64	18
3	*Erica arborea*	19	10	21	20	21	10	16	6	11	12
4	*Rosa abyssinica*	11	18	8	4	11	8	14	6	12	15
5	*Asparagus africanus*	7	6	8	13	9	14	6	16	9	9
6	*Maytenus arbutifolia*	8	4	8	4	5	8	10	8	8	3
7	*Olea europaea*	3	3	4	7	5	8	5	3	3	6
8	*Carissa spinarum*	6	6	8	6	7	6	8	4	5	7
9	*Myrsine Africana*	7	5	5	4	6	8	9	4	3	6
10	*Dovyalis abyssinica*	2	2	5	2	4	3	6	5	7	5
11	*Acacia abyssinica*	3	3	3	4	3	2	5	2	3	5
12	*Vernonia leopoldi*	1	5	4	3	3	4	3	3	5	5
13	*Maytenus senegalensis*	3	2	1	3	3	4	2	2	4	3
14	*Millettia ferruginea*	1	3	3	3	2	2	4	3	2	4
15	*Smilax aspera*	2	3	2	3	2	2	2	3	1	3
16	*Olinia rochetiana*	2	2	1	1	1	2	2	2	2	2
17	*Bersama abyssinica*	2	3	2	2	2	3	2	2	2	2
18	*Vernonia amygdalina*	1	2	2	1	1	2	2	2	1	2
19	*Hagenia abyssinica*	3	2	2	2	2	1	2	1	1	2
20	*Prunus africana*	1	2	1	1	1	2	1	1	1	2
21	*Podocarpus falcatus*	1	1	1	2	2	1	0	1	2	1
22	*Osyris quadripartita Decn.*	1	1	2	1	1	2	1	1	1	1
23	*Hypericum revolutum*	1	1	2	2	1	1	1	2	2	0
24	*Myrsine melanophloeos*	1	1	1	1	1	1	1	1	1	1
25	*Buddleja polystachya Fresen*	1	0	1	1	1	1	1	0	1	0
26	*Clerodendrum myricoides*	0	0	1	0	0	1	1	0	1	1
27	*Rhamnus staddo*	0	1	0	1	1	1	1	1	0	1
28	*Laggera tomentosa*	1	1	0	1	1	0	1	1	1	1
29	*Pittosporum viridiflorum*	1	0	0	1	0	1	1	0	0	1
30	*Erythrina brucei*	1	0	1	1	1	1	1	1	1	0
31	*Satureja punctata*	0	0	0	0	1	0	0	0	0	0
32	*Rubus apetalus*	0	1	1	0	0	1	0	0	1	1
33	*Dovyalis verrucosa*	0	0	0	0	0	0	2	1	1	0
34	*Jasminum stans*	0	0	0	0	0	1	0	0	0	1
35	*Asparagus setaceus*	1	1	0	1	0	0	0	0	0	0
36	*Syzygium guineense*	0	0	0	0	1	0	0	0	0	1
37	*Ekebergia capensis*	0	0	0	0	0	0	0	0	1	0
38	*Clutia lanceolata*	0	0	1	0	0	1	0	0	0	0
39	*Lippia adoensis*	0	0	0	0	0	1	2	0	0	0
40	*Ficus sur*	2	0	0	0	0	1	0	1	0	0
41	*Schefflera abyssinica*	0	1	0	0	0	0	0	1	0	0
42	*Satureja imbricata*	0	0	0	0	0	0	1	0	0	0
43	*Vernonia filigera Oliv*	0	0	0	0	0	0	0	0	1	0
44	*Croton macrostachyus*	0	0	0	0	0	1	1	0	0	0
45	*Ficus vasta*	0	0	0	0	0	1	0	0	1	0
46	*Pentas schimperiana*	0	0	0	0	0	0	2	0	1	0
47	*Pentas lanceolata*	1	0	1	0	0	0	0	0	0	0
48	*Maytenus gracilipes*	1	0	0	1	0	0	0	0	1	0
49	*Rhus vulgaris Meikle*	1	0	0	0	0	0	0	0	0	0

ID	Species Name	P 11	P 12	P 13	P 14	P 15	P1 6	P 17	P1 8	P 19	P 20
1	*Eucalyptus globulus*	52	48	98	75	94	127	88	79	101	86
2	*Juniperus procera*	45	30	53	35	45	43	62	51	20	50
3	*Erica arborea*	18	13	17	12	8	5	13	9	10	13
4	*Rosa abyssinica*	9	13	7	9	16	11	12	15	5	21
5	*Asparagus africanus*	8	10	8	1	11	8	6	12	11	14
6	*Maytenus arbutifolia*	7	4	6	7	12	4	7	7	8	7
7	*Olea europaea*	7	4	3	5	7	10	7	7	4	9
8	*Carissa spinarum*	6	6	8	4	5	8	6	1	4	5
9	*Myrsine Africana*	7	5	6	2	7	5	5	6	7	6
10	*Dovyalis abyssinica*	5	5	2	4	3	7	5	4	2	6
11	*Acacia abyssinica*	7	4	7	6	6	3	2	4	3	4
12	*Vernonia leopoldi*	4	4	4	3	4	2	4	5	3	3
13	*Maytenus senegalensis*	2	3	3	3	1	3	3	2	2	3
14	*Millettia ferruginea*	3	4	3	2	3	2	2	2	2	2
15	*Smilax aspera*	3	2	2	2	3	3	2	3	4	2
16	*Olinia rochetiana*	3	3	1	2	2	2	2	2	1	2
17	*Bersama abyssinica*	2	2	2	2	2	2	2	1	2	2
18	*Vernonia amygdalina*	2	2	1	1	2	1	2	2	2	1
19	*Hagenia abyssinica*	1	2	1	1	2	1	1	1	2	2
20	*Prunus africana*	1	2	1	1	1	3	2	1	2	1
21	*Podocarpus falcatus*	2	2	1	2	3	1	2	1	1	1
22	*Osyris quadripartita.*	2	1	1	1	2	1	2	1	2	1
23	*Hypericum revolutum*	2	2	2	2	2	1	0	1	1	1
24	*Myrsine melanophloeos*	1	1	1	1	1	1	1	1	0	1
25	*Buddleja polystachya*	1	1	0	1	1	1	1	1	1	1
26	*Clerodendrum myricoides*	1	1	1	0	1	1	1	1	1	1
27	*Rhamnus staddo*	1	1	1	0	0	1	1	1	1	1
28	*Laggera tomentosa*	1	0	1	1	1	0	0	1	1	1
29	*Pittosporum viridiflorum*	1	1	0	0	1	1	1	0	1	1
30	*Erythrina brucei*	0	0	1	0	0	1	1	1	0	1
31	*Satureja punctata*	1	0	0	0	0	0	1	1	0	1
32	*Rubus apetalus*	0	1	1	0	1	1	0	0	1	0
33	*Dovyalis verrucosa*	0	0	0	0	1	1	1	0	1	0
34	*Jasminum stans*	0	1	0	1	1	0	0	1	1	1
35	*Asparagus setaceus*	0	0	1	0	1	1	0	0	0	1
36	*Syzygium guineense*	0	0	0	0	0	1	1	0	1	0
37	*Ekebergia capensis*	0	1	2	2	0	0	0	1	1	1
38	*Clutia lanceolata*	1	0	0	1	0	1	1	0	0	1
39	*Lippia adoensis*	0	0	0	1	0	0	0	0	0	0
40	*Ficus sur*	0	0	0	0	1	0	0	0	1	1
41	*Schefflera abyssinica*	0	0	0	0	1	0	0	0	1	1
42	*Satureja imbricata*	2	0	0	0	1	0	0	1	0	0
43	*Vernonia filigera*	1	0	0	0	0	0	0	0	0	1
44	*Croton macrostachyus*	0	0	0	0	0	0	0	0	0	3
45	*Ficus vasta*	0	0	1	0	1	1	0	0	0	0
46	*Pentas schimperiana*	0	0	0	0	0	0	0	0	0	0
47	*Pentas lanceolata*	0	0	0	0	0	0	0	2	0	0
48	*Maytenus gracilipes*	0	0	0	1	0	0	0	0	0	0
49	*Rhus vulgaris*	1	1	0	0	0	0	0	2	0	0

ID	Species Name	P 21	P 22	P 23	P 24	P 25	P 26	P 27	P 28	P 29	P 30
1	*Eucalyptus globulus*	65	80	100	98	41	78	47	35	54	64
2	*Juniperus procera*	57	38	71	42	39	46	55	42	30	55
3	*Erica arborea*	19	15	9	11	15	15	8	15	25	16
4	*Rosa abyssinica*	12	9	14	20	3	10	12	8	13	13
5	*Asparagus africanus*	6	16	10	6	8	6	12	9	14	10
6	*Maytenus arbutifolia*	8	9	7	9	6	6	9	9	6	7
7	*Olea europaea*	6	4	6	7	6	6	6	5	7	6
8	*Carissa spinarum*	5	6	6	5	6	5	5	5	6	6
9	*Myrsine Africana*	5	4	5	3	4	5	5	7	6	7
10	*Dovyalis abyssinica*	7	5	6	1	4	7	4	6	8	4
11	*Acacia abyssinica*	3	3	5	3	3	6	4	5	4	2
12	*Vernonia leopoldi*	5	4	3	3	4	1	1	2	2	3
13	*Maytenus senegalensis*	3	2	3	3	1	1	3	3	5	3
14	*Millettia ferruginea*	2	3	2	3	3	3	3	4	3	3
15	*Smilax aspera*	0	2	1	2	4	2	2	3	2	3
16	*Olinia rochetiana*	2	2	2	2	2	3	2	3	3	1
17	*Bersama abyssinica*	3	2	2	2	1	2	1	3	3	2
18	*Vernonia amygdalina*	1	1	3	1	2	2	1	2	2	1
19	*Hagenia abyssinica*	2	0	2	2	2	1	1	1	1	2
20	*Prunus africana*	1	1	1	2	1	2	1	2	2	2
21	*Podocarpus falcatus*	1	1	2	2	2	1	1	0	1	1
22	*Osyris quadripartita*	1	1	1	2	1	2	1	2	1	1
23	*Hypericum revolutum*	1	1	2	1	1	1	1	1	1	1
24	*Myrsine melanophloeos*	1	1	1	1	1	1	0	1	1	1
25	*Buddleja polystachya*	0	1	0	1	0	1	1	1	1	1
26	*Clerodendrum myricoides*	1	1	1	1	1	1	1	1	1	1
27	*Rhamnus staddo*	1	1	1	1	0	1	1	1	1	1
28	*Laggera tomentosa*	0	1	1	1	1	1	0	1	1	1
29	*Pittosporum viridiflorum*	0	1	1	1	1	1	1	0	0	1
30	*Erythrina brucei*	0	1	0	0	0	1	0	0	1	0
31	*Satureja punctata*	1	0	1	1	0	0	0	1	0	2
32	*Rubus apetalus*	1	1	2	0	0	0	1	0	0	0
33	*Dovyalis verrucosa*	1	0	0	0	0	0	0	3	1	0
34	*Jasminum stans*	1	1	0	0	0	1	1	0	0	2
35	*Asparagus setaceus*	1	1	1	0	1	1	1	0	1	0
36	*Syzygium guineense*	0	0	2	1	0	0	0	2	0	0
37	*Ekebergia capensis*	1	1	0	0	1	0	0	0	0	0
38	*Clutia lanceolata*	1	0	0	0	0	0	0	0	1	0
39	*Lippia adoensis*	0	1	1	2	0	0	0	0	0	1
40	*Ficus sur*	0	2	0	0	0	0	0	0	0	0
41	*Schefflera abyssinica*	0	0	0	0	0	0	0	0	1	1
42	*Satureja imbricata*	1	0	0	0	0	0	0	1	1	0
43	*Vernonia filigera*	0	0	0	0	0	1	1	0	0	1
44	*Croton macrostachyus*	0	0	0	0	0	0	1	0	0	0
45	*Ficus vasta*	0	0	0	0	0	0	1	1	0	0
46	*Pentas schimperiana*	1	0	1	0	0	0	0	0	0	0
47	*Pentas lanceolata*	1	0	0	2	0	0	0	0	1	0
48	*Maytenus gracilipes*	0	1	0	0	0	0	1	1	0	0
49	*Rhus vulgaris*	0	0	0	1	1	0	0	0	0	0

ID	Species Name	P 31	P 32	P 33	P 34	P 35	P3 6	P 37	P38	P 39	P 40
1	*Eucalyptus globulus*	94	78	63	80	103	85	97	29	60	96
2	*Juniperus procera*	49	50	46	59	28	45	60	45	25	34
3	*Erica arborea*	13	16	15	20	15	16	10	10	20	15
4	*Rosa abyssinica*	13	10	12	16	12	10	15	15	10	9
5	*Asparagus africanus*	11	10	7	9	3	12	11	11	7	10
6	*Maytenus arbutifolia*	12	10	9	6	9	5	3	10	10	8
7	*Olea europaea*	5	3	7	5	7	5	3	5	5	5
8	*Carissa spinarum*	7	5	5	4	5	5	6	6	6	3
9	*Myrsine africana*	5	4	4	7	6	5	4	2	6	5
10	*Dovyalis abyssinica*	7	4	3	6	5	4	3	6	2	6
11	*Acacia abyssinica*	4	6	5	6	5	4	4	5	5	4
12	*Vernonia leopoldi*	3	4	6	2	5	4	3	3	5	4
13	*Maytenus senegalensis*	3	4	2	3	3	2	4	4	3	2
14	*Millettia ferruginea*	3	2	2	2	2	2	3	3	2	4
15	*Smilax aspera*	1	2	3	4	3	3	3	3	3	1
16	*Olinia rochetiana*	2	2	2	2	1	2	3	3	2	2
17	*Bersama abyssinica*	2	0	1	3	3	3	1	1	1	2
18	*Vernonia amygdalina*	1	2	2	3	1	3	2	1	2	1
19	*Hagenia abyssinica*	1	2	1	1	2	1	2	1	1	2
20	*Prunus africana*	0	2	2	2	2	2	2	2	2	2
21	*Podocarpus falcatus*	2	3	2	2	1	2	2	2	1	1
22	*Osyris quadripartita*	1	1	1	1	2	2	2	1	2	2
23	*Hypericum revolutum*	1	1	1	1	2	1	1	2	2	0
24	*Myrsine melanophloeos*	1	1	0	1	0	1	1	0	1	1
25	*Buddleja polystachya*	0	1	1	1	0	1	1	1	0	1
26	*Clerodendrum myricoides*	1	0	0	1	1	1	0	1	1	0
27	*Rhamnus staddo*	0	1	0	1	1	0	1	0	1	0
28	*Laggera tomentosa*	1	0	0	0	1	0	0	1	1	1
29	*Pittosporum viridiflorum*	0	1	1	1	1	1	1	1	1	1
30	*Erythrina brucei*	1	1	1	1	0	0	0	1	1	1
31	*Satureja punctata*	1	1	3	0	0	0	0	1	0	1
32	*Rubus apetalus*	0	0	1	0	0	0	1	1	0	1
33	*Dovyalis verrucosa*	0	1	0	0	1	1	1	0	0	2
34	*Jasminum stans*	1	0	1	0	0	0	0	0	1	1
35	*Asparagus setaceus*	1	1	1	0	0	0	1	0	0	0
36	*Syzygium guineense*	1	0	1	1	0	1	1	1	0	0
37	*Ekebergia capensis*	0	0	3	0	0	0	1	0	1	0
38	*Clutia lanceolata*	0	0	2	0	0	1	0	1	0	1
39	*Lippia adoensis*	0	0	0	0	1	0	1	1	1	0
40	*Ficus sur*	0	0	0	0	0	1	0	0	0	0
41	*Schefflera abyssinica*	1	0	1	0	0	0	0	0	0	0
42	*Satureja imbricata*	0	0	0	1	1	0	0	0	0	0
43	*Vernonia filigera*	0	1	1	0	2	1	0	0	0	0
44	*Croton macrostachyus*	1	0	0	0	0	1	0	0	1	0
45	*Ficus vasta*	0	0	1	0	0	0	1	0	0	0
46	*Pentas schimperiana*	2	0	0	0	0	0	1	0	1	0
47	*Pentas lanceolata*	0	0	1	0	0	1	0	0	0	0
48	*Maytenus gracilipes*	0	1	0	1	0	0	0	0	0	0
49	*Rhus vulgaris*	0	0	0	0	0	0	0	0	0	0

ID	Species Name	P 41	P 42	P 43	P 44	P 45	P 46
1	*Eucalyptus globulus*	102	64	83	60	80	74
2	*Juniperus procera*	35	50	50	51	32	49
3	*Erica arborea*	18	16	15	11	4	14
4	*Rosa abyssinica*	8	16	16	10	9	8
5	*Asparagus africanus*	10	8	8	7	8	6
6	*Maytenus arbutifolia*	8	5	6	6	11	11
7	*Olea europaea*	4	5	5	4	3	7
8	*Carissa spinarum*	2	5	3	2	4	2
9	*Myrsine africana*	6	4	3	7	4	5
10	*Dovyalis abyssinica*	5	6	5	3	7	6
11	*Acacia abyssinica*	4	6	2	4	4	4
12	*Vernonia leopoldi*	4	4	1	3	3	4
13	*Maytenus senegalensis*	2	2	3	3	2	3
14	*Millettia ferruginea*	1	2	3	2	2	2
15	*Smilax aspera*	4	2	3	3	2	2
16	*Olinia rochetiana*	2	2	2	1	1	3
17	*Bersama abyssinica*	1	2	2	1	1	3
18	*Vernonia amygdalina*	2	2	2	2	2	2
19	*Hagenia abyssinica*	1	2	1	2	2	1
20	*Prunus africana*	0	2	1	1	1	1
21	*Podocarpus falcatus*	1	1	1	1	1	2
22	*Osyris quadripartita*	1	1	1	1	1	1
23	*Hypericum revolutum*	2	1	1	2	1	1
24	*Myrsine melanophloeos*	1	1	0	1	1	1
25	*Buddleja polystachya*	1	0	1	1	1	1
26	*Clerodendrum myricoides*	1	0	1	0	1	1
27	*Rhamnus staddo*	1	0	1	1	0	1
28	*Laggera tomentosa*	1	0	1	0	1	0
29	*Pittosporum viridiflorum*	0	1	0	0	1	1
30	*Erythrina brucei*	1	0	1	1	1	0
31	*Satureja punctata*	1	1	0	0	0	1
32	*Rubus apetalus*	1	0	0	1	0	0
33	*Dovyalis verrucosa*	1	1	0	0	0	0
34	*Jasminum stans*	0	0	2	0	1	0
35	*Asparagus setaceus*	1	0	0	0	0	0
36	*Syzygium guineense*	0	0	0	1	0	1
37	*Ekebergia capensis*	0	1	0	0	0	0
38	*Clutia lanceolata*	0	0	2	0	0	0
39	*Lippia adoensis*	0	0	0	0	1	0
40	*Ficus sur*	0	0	1	0	0	1
41	*Schefflera abyssinica*	1	1	0	1	0	0
42	*Satureja imbricata*	0	0	0	0	0	1
43	*Vernonia filigera*	0	0	0	0	0	0
44	*Croton macrostachyus*	0	1	0	1	0	0
45	*Ficus vasta*	0	0	0	0	2	0
46	*Pentas schimperiana*	0	0	0	0	1	0
47	*Pentas lanceolata*	0	0	0	0	0	0
48	*Maytenus gracilipes*	0	0	0	0	0	0
49	*Rhus vulgaris*	0	1	0	0	0	0

Appendix 3: Astronomical location of the sample plots

	Location in degree		Location in meter (WGS 1984, UTM Zone 37N)	
Plot ID	Longitude	Latitude	Easting	Nothing
1	38.739299	9.071617	471350.8	1002780
2	38.743849	9.07162	471850.8	1002780
3	38.748398	9.071623	472350.8	1002780
4	38.780248	9.071644	475850.8	1002780
5	38.784797	9.071646	476350.8	1002780
6	38.789347	9.071649	476850.8	1002780
7	38.738091	9.076617	471218.6	1003333
8	38.743845	9.076142	471850.8	1003280
9	38.748395	9.076146	472350.8	1003280
10	38.766595	9.076158	474350.8	1003280
11	38.780245	9.076166	475850.8	1003280
12	38.784795	9.076169	476350.8	1003280
13	38.730192	9.080655	470350.8	1003780
14	38.734742	9.080658	470850.8	1003780
15	38.739292	9.080662	471350.8	1003780
16	38.74406	9.079588	471874.7	1003661
17	38.748392	9.080668	472350.8	1003780
18	38.752942	9.080671	472850.8	1003780
19	38.757492	9.080674	473350.8	1003780
20	38.762042	9.080677	473850.8	1003780
21	38.766592	9.08068	474350.8	1003780
22	38.771142	9.080683	474850.8	1003780
23	38.730189	9.085178	470350.8	1004280
24	38.734739	9.085181	470850.8	1004280
25	38.739289	9.085184	471350.8	1004280
26	38.743839	9.085187	471850.8	1004280
27	38.748389	9.085191	472350.8	1004280
28	38.752939	9.085194	472850.8	1004280
29	38.757489	9.085197	473350.8	1004280
30	38.762039	9.0852	473850.8	1004280
31	38.766589	9.085203	474350.8	1004280
32	38.771139	9.085206	474850.8	1004280
33	38.775689	9.085208	475350.8	1004280
34	38.752936	9.089716	472850.8	1004780
35	38.757486	9.089719	473350.8	1004780
36	38.766586	9.089725	474350.8	1004780

37	38.771136	9.089728	474850.8	1004780
38	38.775686	9.089731	475350.8	1004780
39	38.766583	9.094248	474350.8	1005280
40	38.771133	9.094251	474850.8	1005280
41	38.798395	9.062463	477844.5	1001764
42	38.797881	9.066689	477788.3	1002231
43	38.79828	9.0716	477832.5	1002774
44	38.802906	9.06686	478340.6	1002250
45	38.807418	9.071657	478836.6	1002780
46	38.725639	9.085174	469850.8	1004280