ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE
DEPARTMENT OF ZOOLOGICAL SCIENCE

The Role of *Eucalyptus globulus* Plantation in Promoting Natural Regeneration of Native Florstic Species: A Case Study at Entoto hillside in Addis Ababa, Ethiopia

A THESIS SUBMITTED TO CENTER FOR ZOOLOGICAL SCIENCE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS IN BIOLOGY

BY

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BY

Gudeta Endalew

Advisor: Debessa Lemessa (PhD)

Augest, 2024
Addis Ababa, Ethiopia

DECLARATION

I, **Gudeta Endalew**, declare that the thesis entitled "*the role of Eucalyptus globulus plantation in promoting natural regeneration of native florstic species: a case study at Entoto Park in Addis Ababa, Ethiopia,"*is my original work. I have carried out the present study independently with the guidance and support of the research advisor, **Debessa Lemessa (PhD)**. Any other contributors or sources used for the study have been duly acknowledged.

Gudeta Endalew _______________ _______________

Signature Date

Conformation by advisor _______________ _______________

Debissa Lemessa (PhD) Signature Date

STATEMENT OF CERTIFICATION

*This is to certify that Gudeta Endalew's research work on the topic entitled "**The role of eucalyptus globulus plantation in promoting natural regeneration of native florstic species: a case study at entoto park in Addis Ababa, Ethiopia**" is his original work and suitable for submission for the award of Master's Degree in* zoological science. *This project paper has been submitted for examination with my approval as a university advisor.*

____

Debissa Lemessa (PhD)

(Advisor)

Augast, 2024

Approved by:

Approved by name and signature of examining board members that verify all programs and legislation requirements are fulfilled

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LIST OF ACRONYMS

CEC: Cation Exchange Capacity

DBH: Diameter at breast height

EHT: Ethiopian Heritage Trust

EMSE: Ethiopian Meteorological Institute

EPA: Environmental Protection Authority

FAO: Food and Agriculture Organization of the United Nations

GPS: Global Position System

IUFRO: International Union for Forestry Research Organization

LSD: Least Significant Difference

NGO: Non Governmental Organization

SPSS: Statistical Package for Social Science

WCMC: World Conservation Monitoring Centre

WWDSE: Water Works Design and Supervision Enterprise

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Abstract

The purpose of this study was to determine whether the eucalyptus forest plantation at Entoto Mountain, which is located roughly 10 km north of Addis Ababa's downtown, permits natural regeneration: a case study at Entoto Park in Addis Ababa, Ethiopia. Sixty plots (each size: 20 × 20 m) size were established along a transect lines at every 300 m distance between them. A total of 68 woody species belonging to 55 genera and 32 families were identified. Asteraceae (8 species) was the most dominant family. Forty-one of the 68 plant species identified in the Entoto Eucalyptus plantation were naturally regenerated woody species. They represented 33 genera and 25 families. For the analysis of vegetation diversity, woody species density and soil environmental factors, the individual Eucalyptus plantation stands were used to classify the plots into three categories. These are C1 (plots with less than 64 Eucalyptus stands), C2 (plots consists of 64 to 82 Eucalyptus stands) and C3 (plots with greater than 82 Eucalyptus stands). Twenty plots were identified for each category. There was significance difference ($P < 0.05$) in the species diversity (H') between C1 and C2, as well as C1 and C3 while there was no significant difference between C2 and C3. The species richness was also significantly different ($P < 0.05$) among the three categories of Eucalyptus plantations. The species diversity and species richness increased with the decrease in Eucalyptus plantation and vice versa. Sorenson similarity index showed highest similarity between C1 and C2 while C2 and C3 showed relatively weak similarity. The density of naturally regenerated woody species showed a decreasing trend with the increase in the density of Eucalyptus plantation and vice versa. However, the study on vegetation and population structure showed that the density of tree species was high at the lower DBH class and there was good regeneration status. Density of naturally regenerated woody species greater than 2.5 cm DBH (cal.932.1 ha^{-1}), height, frequency, basal area and the respective IVI values for naturally regenerated woody species were also calculated. Therefore, in the research region, responsible stakeholders should prioritize the conservation of huge trees that are significant for both ecology and economy through the use of appropriate conservation techniques. Since the regeneration status under eucalyptus depend on the number of individual eucalyptus stands, there should be a certain distance between individual eucalyptus plantations to promote regeneration.

Keywords: Conservation, Diversity, Regeneration, Restoration, Species diversisity.

1. INTRODUCTION

1.1. Background of the Study

Eucalyptus is one of the most planted woody species in the world next to Pinus and Cunning hamia. Eucalyptus is a member of the Myrtaceae family, which also includes the genera Corymbia, Angophora, and Eucalyptus (FAO, 2006; Onalaska, 2010).

There are about 900 species, subspecies and hybrids of Eucalyptus globally. Australia is home to over 700 species of eucalyptus (Boland, 2006; Oballa Phanuel O, *et al*., 2010).

Outside its natural eco-region, Eucalyptus is expanding from 0.7 million ha in 1955 to more than 20 million ha in 2009, distributed to over 100 countries. It can grow in tropics, sub tropics and some temperate regions and covers 0.5% of the global surface forest area. In Australia, Brazil, China, India, and South Africa, eucalyptus is growing quickly.

The expansion of Eucalyptus from Australia to Europe began before 200 years in Portugal (Ashagre *et al*., 2005).

The United States was first exposed to eucalyptus around the middle of the 1800s.

It further distributed to other parts of the world in the late 19th century and the beginning of 20th century when the demand for fuel and energy escalated in Europe, South America, Asia and Africa (Daniel Jaleta, 2016).

Eucalyptus serves millions of homes in both urban and rural locations for a variety of social and economic reasons. It has successfully replaced a few of the natural forest's functions, mostly in the supply of wood; as a result, it has helped to ease pressure and slow down deforestation. However, eucalyptus was blamed for ecosystem nutrient and water drains as well as the allelopathic effect that inhibits the growth of native vegetation.

Especially in sub-Saharan countries the degradation of natural resources typically forest resources depleted rapidly and leads to a complete eradication of natural resource services (Water, forest, fertile soils, biomass or fuel), different natural hazards (flood, drought) and lack of modern technology for accessing food production (Smalling *et al*., 1996; Mulugeta Lemenih, 2004).

Planting fast-growing trees in the remaining natural forest would help to mitigate environmental concerns (deforestation is a major cause of environmental problems) and meet the growing demand for forest products (Ashagre *et al*., 2005).

Eucalyptus was introduced to Africa, and Ethiopia, about completely of the 19th century, in 1890s. Since then it has persisted to extend to cover roomier terrestrial areas inside Ethiopia: small highland and lowland. An acute shortage of timber and fuel existed in the early days of the city, but this was solved, at the turn of the century by Emperor Menelik II allowed the establishment of a trial plot of eucalyptus, and 15 species of eucalyptus were imported for trial in and around the capital city (Pohjonen and Pakulla 1990).The word eucalyptus comes from the Greek eu "well", kalyptos "covered" and refers to the buds of the flowers of this tree (Getachew Tesfaye and Abiyot Berhanu, 2006)..

Ethiopia is an important regional center of biological diversity, and the flora and fauna have a rich endemic element (Getachew Tesfaye and Abiyot Berhanu, 2006). The country has the fifth best flora in equatorial Africa.Vegetation types in Ethiopia are highly diverse, varying from Afro alpine to desert vegetation. However, the plants possessions of the country have been shortened on account of various determinants. The most important ones are clear-cutting, growth of farm land, overgrazing, unsustainable exercise, encroachment of exotic variety, and overexploitation for differing purposes in the way that firewood, charcoal, explanation material, and trees, all spurred by fast human population growth(Getachew Tesfaye and Abiyot Berhanu, 2006).

The study exhausted Ethiopian highlands by Pohjonen and Pukkala (1990) signifies fast increasing exotic variety were cultivated extensively to save disgraced land, unfertile land extent and abandoned land apart from its gift to resolve the shortage of woodland crop demand for various purposes, in the way that, explanation materials, trees and strength consumption.These exotic species have been planted on unproductive forest areas which have low quality. In the year 1992 more than 200,000 ha of land in Ethiopia were covered with exotic fast growing species, out of this a minimum of 60% were covered with eucalyptus (Ashagre *et al.*, 2005; EFAP, 1994). Eucalyptus is considered currently as the main woody species to fulfill the shortage of forest products and a means to give economic benefits especially for small scale framers in developing countries.

Plantation establishments using exotic species have both advantages and disadvantages (Lugo A.E, 1992). Despite the resistance of the people to the introduction and establishment of exotic species however, little research work has been undertaken to elucidate the harmful and beneficial impacts of exotic plantations. In the absence of empirical evidences, any claim against the establishment of exotic species cannot be warranted, in countries such as

Ethiopia where there is a desperate and urgent need of expanding the forest resource base to meet the ever-increasing demand for wood (Demel Teketay, 2001).

Recently many studies have indicated that forest plantations can foster the regeneration of native woody species under their canopy and catalyze the subsequent succession processes (*Bone et al*., 1997; Yitebitu Moges, 1998; Feyera Senbeta and Demel Teketay, 2001; Feyera *et al*.2002; Getachew Tesfaye and Abiyot Berhanu, 2006).

While the catalytic part of orchards in embellishing native woody regenerations in addition to reconstructing disgraced lands have existed widely noticed in many nations, understanding of the mechanisms and processes complicated is completely restricted.For instance, knowledge on the relationships among the catalyzing effect of tree plantations on succession of forests, the role of dispersal mode, origin of seeds (seed bank or seed rain), and the effect of management and types of species, is scanty (Yitebitu Moges, 1998; Feyera Senbeta and Demel Teketay, 2001).

Mostly, Eucalyptus is feared for ecological hazardous and ecosystem destructor, but Eucalyptus is an important tree in fostering ecosystem serving as conservation tree at beginning of restoration process of degraded sites.

Eucalyptus plantations in southern Ethiopia were used as a buffer for degrading natural forest and have reduced impact on the forest (Feyera Senbata, 2002). It is substituting the fuel wood and construction materials harvested from natural forest which previously lead to deforestation due to the huge gap of demand and supply without the presence of this species (Zegeye Hailu., *et al*.,2013).

The Eucalyptus plantation has reduced natural forest deforestation in one way and reduced human impact in other hand that provide time for natural forest regeneration and allow improvement of biodiversity richness. Some study has marked that Eucalyptus ranches aids that the process of wood sequence by providing a nurse influence for the settling native variety and attracted seed dispersal agents. Additionally, Eucalyptus plantations can be used to foster natural forest re-colonization and succession process (Adimassu Z, 2004). Similarly, it can again speed the regeneration of native woodlike class in the estate through reducing soil deterioration and furthering appealing environments for seed grminarion.In addition, Eucalyptus plantation can also foster the regeneration of other native woody species in degraded area by providing protection (Demel Teketay, 2000, Zegeye Hailu, 2003, Feyera Senbeta, 2001).

Eucalyptus is widely deliberate to have few allelopathic effect that decreased the biodiversity under the Eucalyptus plantation.The studies related to Eucalyptus's allelophatic effect were done mostly in the laboratory, which does not perfectly represent the actual ecosystem. According to Chu (Mortimer *et al*, 2014) the root length of the native species was significantly inhibited in Eucalyptus plantations compared to other plantations, but the study concluded that allelopathy in the Eucalyptus plantations is selective. Eucalyptus has potential in encouraging the recruitment, establishment and successions of native species, which promote biodiversity improvement (Mulugeta Lemenih, 2004 cited on Daniel Jaleta, 2015). Regeneration of Juniperusprocera on previously Eucalyptus plantation was also possible at Entoto, Ethiopia, which has shown wrong believes that planting other trees after harvesting Eucalyptus is not possible.

Eucalyptus is blamed for heavy use of soil moisture, leaf litter and soil humus, consumption of soil nutrients, less soil conservative, non-fodder and habitat (Gessesse Dessie, *et al.*, 2011). Studies by (Kidanu S.2004, (Bargali *et al.*, 1992) argued that Eucalyptus decreases soil nutrients within 20 m distance from the trees. The comparison study of Eucalyptus with mixed plantation has revealed that Eucalyptus has three times more fine root biomass in surface soil which indicated that planting crops in association and adjacent to Eucalyptus should be avoided (Gindaba J.2003).However, Eucalyptus species exceptionally can extend the nutrient cycling deep to ground soil where other trees and crop could not access that much depth (Zegeye Hailu, *et al*., 2003). In addition to the above, the soil under Eucalyptus becomes water repellent and the perceptions of the local farmers agreed with the experimental findings by reducing the crop productivity of the land. On contrary to the above, (Tadele D, et al,2014) has found that the maize dry matter production and grain yield planted on cleared felled Eucalyptus stand are significantly higher than adjacent field. According to (Zegeye Hailu, *et al*., 2003) Eucalyptus does not over exploit the soil than the traditional fuel usage such as litter and cow dung collection. Similarly, the study has indicated that due to non-browsed characteristics of Eucalyptus than other fodder tree, it is well fitted for soil protection purposes if it is incorporated with avoidance of liter and bark collection in overgrazing practiced places.

Plantations in general and Eucalyptus plantation in particular can have a catalytic effect on the regeneration of native species and can be used as a management tool for restoration of degraded forest lands. Because of the large damage of the peak woods, concern has stood about the unaffected regeneration of indegenous species. Regeneration is thus defined as the reassembly of floristic and structural diversity back to self-perpetuating climax states. In Ethiopia, the uncontrolled removal of trees and land disturbance, such as collection of fire wood, cultivation of lands, and grazing, severely reduce the density of the species and affect regeneration (Getachew Tesfaye and Abiyot Berhanu, 2006).

In the Ethiopian highland, which contract an illness harsh deforestation and biomass fuel crisis, Eucalyptus is the conspicuous tree in administration and society estate homesteads by way of its ready procreation through coppicing, resistance to browsing by livestock, and rapid growth rate. Currently, about 55 Eucalyptus species are available in Ethiopia. However, the most common and widespread Eucalyptus species include Eucalyptus Labill.

The natural regeneration of plants is an important subject in both conservation biology and management. Cost-effective plant regeneration, especially natural regeneration (i.e., regeneration of native plant species), is the keystone of sustainable forestry. Natural regeneration depends on the seed bank.

In this study, our objective will be to identify the vegetation resources and the current regeneration status of woody species of the Entoto mountain range that lies on the Northwestern Entoto, Central Yeka, Ankorcha affix, and Northeastern Yeka Abado at the edge of the city of Addis Ababa, Ethiopia where the integrated tourist destination development programs would take place.

1.2. Statement of the Problem

Entoto Mountain and at many other places around Addis Ababa, Eucalyptus is the most dominant vegetation types. This is an Australian tree brought to Ethiopia by Emperer Menelik II some 100 years ago. At that time most of the area around the town had been deforested due to the need for wood for construction and fuel. The introduction of the new species was very successful, as its speed of growing surpassed the indigenous trees. Some of the eucalyptus on Entoto has their origin in that first phase of reforestation, but plantations have been added now and then through this century. At present, the largeness of the Entoto park region is covered by eucalyptus plantation. The new species is an integral part of the Ethiopian history, but at the same time, it is a tree that does not belong to the Ethiopian flora (Getachew and Abiyot, 2006).

The combined effects of biomass shortages, soil and land degradation, overgrazing and increasing populations are hindering the success of sustainable agricultural systems in the western part of Ethiopian. Ethiopia currently has very limited tree cover and the establishment of trees or other types of leafy ground cover that provide biomass fuel, environmental services including climate change statues, soil nutrient and water retention.

The need to expand cultivated land and shortages of fuel biomass has led to the removal of well- adapted, nutrient additive indigenous trees. Cropping extents have expanded into borderline lands, to a degree steep slopes and mountainous regions, and inactive periods have been diminished or deserted. Despite this expansion, food insecurity remains because land productivity has existed dangerously eroded by resource depletion. Two major constraints of Ethiopian conifers are Low natural regeneration and Deforestation. Eucalptus can be used as conservation tree as wind break, biodiversity conservation and maintenance of ecosystem processes by promoting the regeneration of native species even on bare land. Some species of Eucalyptus can be preferred for medicinal use (traditional) and in pharmaceutical industries. Eucalyptus can be used as a source of pollen and nectar production for apiary industries.

Understanding of the processes that may allow us to develope plantation management for provision of urgently reuired goods and services, coupled with enhancement and maintenance of biodiversity, are very essential. Therefore, the objective of this study is to assess the role of Eucalyptus forest plantation in promoting Natural Regeneration: a case study at Entoto Park Addis Ababa city, Ethiopia

1.3. Significance of the Study

The study will provide information about explore the controversial issue of eucalyptus tree planting in Entoto Park area from ecological aspects and the assessment will be made on species diversity. Scientific studies about ecosystem service values in Ethiopia are very few in numbers; 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 that importance of forests whenever making a decision about natural resource management. This study provides a framework for discussion and policy recommendations concerning whether or not planting eucalyptus on farmland and on other land types is a viable natural resource management technology to help achieve sustainable livelihoods in the Entoto Park area.

1.4. Objectives of the Study

1.4.1. General Objective

To understand the role of *Eucalyptus* plantations in promoting the regeneration of native floristic species at Entoto hillsides of Addis Ababa city, Ethiopia.

1.4.2. Specific Objectives

The specific objectives of the study are:

- To assess the regeneration status of native floristic species under Eucalyptus plantations forests;
- To examine the population structures of naturally regenerated dominant native woody species under Eucalyptus plantation forests;
- To examine the species composition of native florstics under Eucalyptus plantation forests

1.5.Research questions

In general, the study answered the following research questions:

- What is the regeneration status of native woody species under Eucalyptus plantation forests?
- What will be the current condition of population structures of naturally regenerated dominant native woody species under Eucalyptus plantation forests?
- What is the status of the native woody species composition under Eucalyptus plantation forests?

1.6. Organization of the thesis

This thesis comprises five chapters. The first chapter includes introduction which contains backgrouncd of the study, statement of the problem, objectives, significance of the study, and organization of paper.The second chapter discusses about the review of related literature.

The third chapter contains research design and methodology of the study. The fourth chapter deals with analysis, discussion and interpretation of the data. The fifth chapter deals with the summary of findings, conclusions and recommendations of the study. Finally, references, a set of appendices, questionnaires are presented at end of this paper.

2. LITERATURE REVIEW

2.1. Eucalyptus plantation forest

Forest plantations in Ethiopia are mainly monocultures of exotic species, such as *Eucalyptus camaldulensis*, *Cupressus lusitanica*, *Casuarina cunninghamiana*, *Pinus patula* and *Pinus radiata*. Nevertheless, forest plantations in Ethiopia are predominantly monocultures of Eucalyptus, which are estimated to cover about 93% of the total plantation area in the country (FAO, 1981). In 2000, the estimated forest plantation area was 216,000 hectares, and about 2,000 hectares of new plantations are established each year (FAO, 2001). Nowadays many people in Ethiopia are absolutely dependent on Eucalyptus for fuel wood, construction wood and income generation (Davidson, 1995). The sale of Eucalyptus poles and products has substantial potential to raise farm incomes, reduce poverty, increase food security and diversify smallholder farming systems in less-favored areas (Jagger and Pender, 2000).The other greatest positive contribution of Eucalyptus is perhaps in replacing indigenous species for firewood, thereby, preventing further denudation of natural forests (Evans, 1992).

In Ethiopia, demand for woody biomass as an alternative to burning dung and crop residues is critical and requires a short-term solution if soil degradation is to be slowed. Approximately 95% of total demand for wood and woody biomass in rural Ethiopia is for fuel wood (EFAP, 1993). With Ethiopia's remaining forest and woodland cover estimated to be diminishing at a rate of 50 000 to 200 000 hectares per year, the need to increase biomass by significant volumes in the near future is critical. In northern Ethiopia, dung and crop residues account for as much as 81% of total household energy consumption, leaving little organic matter for the fertilization of crops and causing soil degradation and accelerated erosion (Bekele-Tesemma, 1997). Although grasses and shrub type plants contribute to net biomass, trees are generally acknowledged to most efficiently convert deep soil nutrients and water into biomass.

In severely stressed biomass deficit regions, fast growing tree species such as *Eucalyptus globules, camaldulensis* and *E. Saligna* may be planted to produce high volumes of biomass within a short time frame.

Eucalyptus is one of the most divers' genuses in the world. Globally, Eucalyptus comprises more than 900 species and unknown number of hybrids and varieties. Most Eucalyptus species (Eucalypts) occur naturally in Australia. A few species are naturally found in Philippines, Papua New Guinea, Indonesia and Timor. Eucalypts grow in diverse ecological conditions with some hardy species growing in semi- arid areas, while others are able to grow on marshy and swampy sites. Eucalypts also grow under a variety of soils including fertile loamy soils, infertile sands and heavy clays (Boland *et al*., 2006). It is exotic tree species which has been associated in Ethiopian environment. The population pressure in Ethiopian highlands has led to a change in land use or land cover and establishment of wood lots, so plantation of exotic tree species such as Eucalyptus has long been advocated as strategy for relieving pressure on indigenous forests and wood lands in the Ethiopian high lands (Zegeye H, 2010). It has provided forester and farmers with valuable resource of fast growing species able to grow under a wide range of conditions depending on the particular species being used. The major factors driving farmers to plant Eucalyptus are; increasing demand for wood products in the market, the un availability of wood on farm, high rate of biomass production, easy to cultivate, and wider adaptability, no palatability to live stock (Demel Teketay, 2000). The species of eucalyptus provides multiple environmental and socio economic benefits such as utilized for fuel wood production (for fire), pole production¸ house building, medicine (e.g. blue gum used to treat flue, common cold), timber production (Breitenbach, 1961). On other hand, Eucalyptus is often considered to have undesirable ecological qualities such as depletion of soil water and nutrients, aggressive competition for resources with native flora, unsuitability for erosion control, production of allelopathic chemical that suppress the growth of other plants and provision of inadequate food and habitat for wildlife (Zegeye Hailu, 2010).

2.2. The Expansion of Eucalyptus

The major planting of the Eucalypts, outside its native environment of Australia, the Malaysian region and the Philippines, started in 1904 in Brazil. Today Eucalyptus plantations cover at least 12 million ha throughout the tropical zone, 90% of which have been established since 1955 (Iglesias, 2008). The genus was introduced to East Africa in the late 19th and early 20th century and by the early 1970s the area of eucalypts in Ethiopia, Rwanda, Uganda, Kenya and Sudan had reached 95,684 ha (Oballa Phanuel O, *et al*., 2010). The largest plantations at that time were in Ethiopia and Rwanda, at 42,300 ha and 23000 ha, respectively. Concerns began to be raised around this time about possible negative impacts of these plantations on the environment, which resulted in banning their planting on farmlands, stream banks and catchment areas (Konuche, 1989).

Eucalyptus began to be used in plantations outside its natural distributions area over 200 years ago in Europe. It is native species in Australia and it is reached South Africa and Brazil in the late nineteenth century and in the early twentieth century. This species was the first to be introduced to Ethiopia and used in reforestation or afforestation program (Konuche, 1989). Among the different species of Eucalyptus, *E.globulus* and *E.camaldulenesis* are the two dominantly spreading species (Getache Admassu, 2016). In Ethiopia due to wood product scarcity, the genus was introduced during the region of Emperor Minilik II (1868-1907) in 1894 to full fill the construction and firewood requirements of people in Addis Ababa at the back of deforested native trees around the town (Getachew Admassu, 2016). Since then the plant was expanded to all corners of the country and the concerns began to be felt around this time about the possible negative impacts of plantation environment. He was introduced the tree for its fast growing feature. Its cultivation has gradually expanded throughout all Ethiopia and encouraged by academic research and development institution including Alemaya Collage of Agriculture Development (Konuche, 1989).

Eucalyptus has increasing in importance globally, because many species of eucalyptus have the ability to improve conditions in treeless areas. In many places, eucalyptus has helped to raise people‟s living standard by providing several end uses and the many farmers continue to plant and use in many ways such as for building materials, and fuel wood and charcoal making, locally they are also found in shelterbelt, shady groves in and around the village, churches and other dwelling, they also constitute a major source of honey and their leaves as traditional medicine to fight flue and fever (Konuche, 1989).

In Ethiopia several Eucalyptus plantation projects were established in the 1980s with support from UNSO, DANIDA, FINNIDA, World Bank, and the African Development Bank. These plantations were established to supply fuel wood for the towns of Debreberhan, Dessie, Gondor, Baherdar, Nazret and Addis Ababa. In Debreberhan alone UNSO invested over 3 million USD to plant 2600 ha of eucalyptus (Pohjonen, and Pukkala, T, 1990). Beyond these, the other most important eucalyptus growers in Ethiopia are smallholder farmers of the Southern Nations Nationalities and Peoples Regional State, Oromia Regional State and Amhara Regional State. In addition, the growing of Eucalyptus was financially more profitable with a considerable positive net present value compared to the alternative agricultural crops (Tesfaye Teshome, 2009).

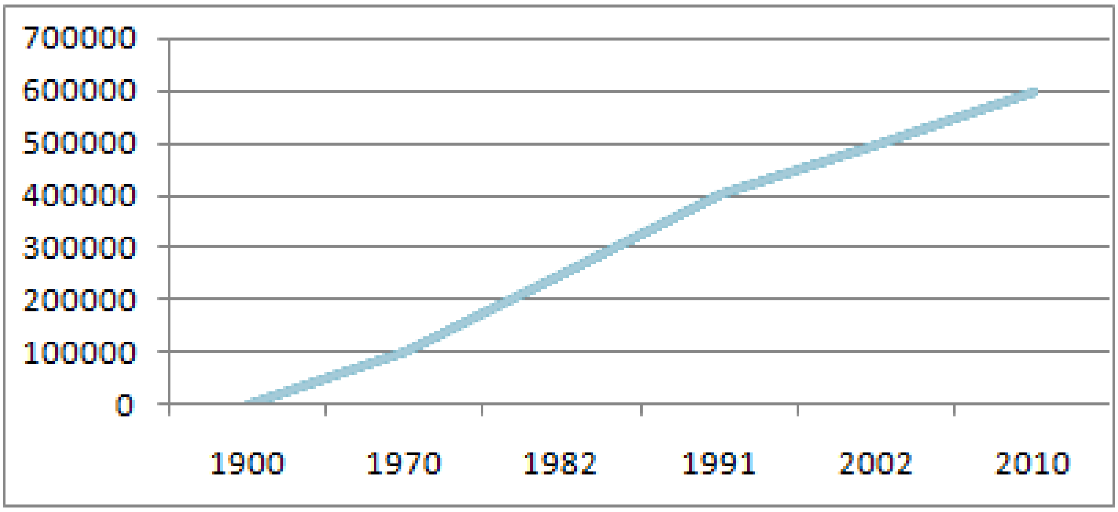


Figure 1: History of Eucalyptus expansion in hectare per year in Ethiopia, Source: (Amare Getahun 2002)

2.3. Adaptive Features of Eucalyptus

Rapid growth rates in eucalypts can be attributed to indefinites shoots (i.e. a growing tip that produces pairs of leaves at irregular intervals), and the fact that they do not develop resting buds. Given these characteristics eucalypts can grow both in height and length indefinitely under favorable conditions. Further, when a branch or shoot is damaged the „naked bud" or the growing tip, which can immediately produce a branch of next order, quickly becomes a main bud. As the upper crown increase in height the lower parts of the trunk are built up very rapidly producing large volumes of wood per hectares (FAO, 2020)

Eucalyptus growing in Ethiopia is mostly confined to the high lands where thereare suitable moisture and temperature. Ethiopia is amongst the leading top five countries (Brazil, India, South Africa, and China) that grow Eucalyptus trees. Eucalyptus growing in Ethiopia is largely confined to the high lands (1500-3200 m.a.s.l) where moisture and temperature are suitable for tree growing. The two eucalyptus species are normally altitude based with red Eucalyptus (*E.camaldulenesis*) being for lower (warmer) altitudes, that is the upper Kolla and Woina Dega Zones,and the white eucalyptus *(E.globulus*) for the cooler (higher), Dega and Wurch Zones (Amare Getahun, 2002).

Eucalyptusis one of the most successful trees, it adapts to a variety of habitats and it has an evolutionary adaptive features such as tolerance of sever periodic moisture stress through xeromorphic leaves, stomata close when water potential deficits, in the leaf is high wax coting, hairy juvenile leaves (some of the species), volatile leaf oils, deciduous in dry season (few species), tolerance of low soil fertility through adaptive capacity to soil with low nitrogen and phosphorus content. The species have specialized nutrient up take system of eco-and endo-mycorrhizae that increase phosphorus up take mainly but also zinc, copper, ammonium, tolerance of fire damage through lignotubers (underground organs) thick barks, dormant bud system, indeterminate crown ,and tolerance of insect damage by oils and phenolic compounds (Evans, E Edward, 2001). Rotations of the Eucalyptus are usually between 5-25 years. Since the Ethiopian highlands are suffering from severe deforestation and biomass fuel crises, *E.globulus* is the prominent tree in government and community estate plantations because of its fast growing ability through coppicing, resistance to browsing by livestock, and through simple sawing and potted seedling propagation (Tesfaye Teshome, 2009). Tending of Eucalyptus coppices is done to bring up second and subsequent generations of Eucalyptus. Coppices form from dormant buds on the cambium of cut trees. Coppice shoots, which are dominant and have the best form and good attachment to the stump, should be selected for retention (Amare Getahun, 2002).

The selected shoots should also be as low down the stump as possible and as wide apart as practicable. Shoots on the windward side should be preferred. The root crowns of some Eucalyptus species are lingo tuberous, which enhances coppice production. Lignotubers are swellings at the stem base that consist of a mass of tissue which assist the tree to sprout in case the main stem dies. However, there are two valuable timber species, *E.delegatensis* and *E. regnans* that hardly regenerate from coppices (Konuche, 1989).

Despite its greater importance and the potential for Eucalyptus to improve rural livelihoods and national development initiatives, *E.globulus* are undermined by several scientists and communities related to the belief that “there are significant negative environmental externalities associated with Eucalyptus trees”. Most criticisms are based on a range of technical, ecological and socio-economic arguments. For example in Ethiopia, *E.globulus* has usually been harvested at 5- 7 years for pole and construction wood while maximum wood production is commonly attained at 18 years (V Pohjonen,T Pukkala, 1990).

2.4. Socio Economic Value of Eucalyptus

In the country where 85% of the population is depending on subsistence agriculture which is mainly backward farming, poverty reduction and food security is major concern and target for policy makers and government in general. Eucalyptus significantly contributes to the household income improvement that leads to poverty reduction. In Eucalyptus planted areas, it is the largest nonagricultural source of household income. The income from

Eucalyptus contributes up to 72% of total household annual cash income for poor household in central highland of Ethiopia. In Ethiopia Eucalypts trees have many peculiar characteristics than other indigenous trees which are preferred by small land holders (Jaleta *et al*., 2016).

Farmers grow eucalyptus trees to fulfill shortage of fuel wood and construction materials. The socio economic importance of the tee can be vividly seen all the way from the capital city Addis Ababa throughout country side. the varies construction sites in big cities of the country ,the house hold energy demand of the most Ethiopians income generation ,source of the building materials for small homes to large one. Eucalyptus plantation have acted as a buffer against financial crisis for many poor farmers on land un suited to sustainable agriculture and in many developing countries the area of private planting was much greater than that planted by government departments or industries· Furthermore the plantations have increased job opportunities both in the plantations and processing industries (Jaleta *et al.*, 2016).

2.5. Factors impacting the importance of plantations as restoration tool

Several factors are known to impact the rate and trajectory of the restoration process, these include local habitat quality variables (Mathews *et al*., 2009) and a factor related to colonization and availability of propagates (Wang *et al*., 2010).

2.5.1. Local factors

Local habitat conditions that could be enhanced by plantations include changes in micro-climate that may become more favourable for forest plants, and changes in soil qualities (Feyera Senbeta and Demel Teketay, 2001; Harley, 2002; Carnus *et al*., 2006). The most effective influence of tree plantations on soils are the production of organic matter through litter fall, increased nutrient recycling, increasing rainfall infiltration, decrease of soil bulk density and an increase of soil biological activity (Lugo, 1997).

Another factor which might have a great influence on regeneration success in plantations is grazing by livestock, which in fact could either facilitative or hamper regeneration. It has been suggested that a light level of grazing can increase tree regeneration by removing competitive vegetation and fertilizing the soil by animal droppings (Carolina and Javier, 2001; McEvoy *et al*., 2006). On the other hand, a continuous and intensive grazing could prevent forest regeneration by soil compaction, trampling of tree seedlings and browsing of saplings (Opperman and Merenlender, 2000). Overgrazing on aboveground vegetation could mainly bring reduction of herb species richness and biomass in general (Roberts and Gilliam, 2003; Roberts, 2004; Chadioftu *et al*., 2009; Bergmeier *et al*., 2010).

2.5.2. Landscape factors

Landscape may not be always defined as an area having a large extent (1,000-10,000 of hectares). From an ecological point of view it could be considered as spatially heterogeneous composed of an interacting mosaic of ecosystems and encompassing populations of many species regardless of its size (Villard and Metzger, 2014).

The major focus of ecological restorations has been on understanding local factors. However, landscape factors such as dispersal limitation of individuals or propagules across the surrounding matrix can also constrain the restoration (Matthews *et al*., 2009). Dispersal limitation, the absence of a species from a community due to lack of propagules entering a communitycan be a major constrain for the possibility of native biodiversity to establish in plantations (Stein *et al*., 2008). Seed dispersal through animals is predominant in tropical tree species (Howe and Smallwood, 1982). Hence, a successful colonization depends on, if and to what extent, different dispersal vectors will travel across the matrix between the seed sources and the focal restoration sites. Some studies indicate that seeds drop at short distances from native forests (Holl *et al*., 2000; Cramer *et al*., 2002). On the other hand there are also studies reporting that trees have established in plantations at several kilometres from the seed sources (Zanne andChapman, 2001; de Mendonça-Lima *et al*., 2014). Compared to open habitats, plantations of trees could be more attractive to seed dispersing birds flying across landscapes, since they could find perches and perhaps resources there (Luck and Daily, 2003). The impact of the behaviour of the dispersal agents could be illustrated by an example from de Mendonça-Lima *et al*., (2014), who found a higher frequency of animal-dispersed plants in plantations compared to in native forests.

A large proportion of plant species in tropics are adapted to dispersal by birds and/or mammals (Howe and Smallwood, 1982). Particularly, most Afromontane herb species have seeds that stick tightly to animals and are dispersed for long distances (Demel Teketay, 2005). Furthermore, some seeds are also dispersed by wind (Demel Teketay, 2005). The range of dispersal distance may vary based on the type of dispersal agents (Nathan, 2006). For example, dispersal by ants may travel a distance of less than 1m, whereas dispersal by wind covers a distance of greater than about 10 km (Corlett, 2008). Generally, it is reported that wind and vertebrate dispersed species have longer dispersal distance (Gomez, 2007; Vitoz and Eagler, 2007).

2.5.3. Historical factors

The age of plantations could influence the regeneration of native flora (Ito *et al*., 2004; Soo *et al*., 2009). Older plantation stands provide better habitat for forest species than young stands because of increased spatial and vertical heterogeneity (Lugo,1997; Lamb *et al*., 1998), well-developed soil organic layers (Firn *et al*., 2007), increased dead wood on the forest floor which in turn improve litter layer (Bremer and Farley, 2010). For example, the indigenous species richness was significantly higher in older compared to younger stands of pine plantations in Switzerland (Brockerhoff *et al.*, 2003).

2.6. Eucalyptus plantations in Ethiopia

Eucalyptus, which belongs to the Myrtaceae family (Friis, 1995) is not indigenous to Ethiopia, but has been planted over 100 years. In 1895, Emperer Menelik II introduced *Eucalyptus* as a potential solution to the fuel and timber shortage. As it has been reported by Breitenbach (1961), it was a French railway engineer called Mondo-Vidaillet who established trial plantation of 15 *Eucalyptus* species for the first time in Ethiopia. After 1971, additional 23 *Eucalyptus* species were introduced (Davidson, 1995). Currently among the 600 identified *Eucalyptus* species (ACIAR, 1992), about 55 of them have been reported from cultivation in Ethiopia. *Eucalyptus*, known locally as 'Nech- Baharzaf' or 'White Eucalypt', proved best by its distinguished vigour, fast and beautiful growth habit as well as high production of wood suitable both for fuel and construction. It conquered the surroundings of villages, towns and capitals on the cold highlands, and was replaced by *Eucalyptus camaldulensis*, known locally as 'Key-Baharzaf' or 'Red Eucalypt' in the lowlands (Demel Teketay, 2000).

Forest plantations in Ethiopia are mainly monocultures of exotic species, such as *Eucalyptus*, *Eucalyptus camaldulensis*, *Cupressus lusitanica*, *Casuarina cunninghamiana*, *Pinus patula* and *Pinus radiata*. Nevertheless, forest plantations in Ethiopia are predominantly monocultures of *Eucalyptus,* which are estimated to cover about 93% of the total plantation area in the country (FAO, 1981). In 2000, the estimated forest plantation area was 216,000 hectares, and about 2,000 hectares of new plantations are established each year (FAO, 2001). Nowadays many people in Ethiopia are absolutely dependent on *Eucalyptus* for fuel wood, construction wood and income generation (Davidson, 1995). The sale of *Eucalyptus* poles and products has substantial potential to raise farm incomes, reduce poverty, increase food security and diversify smallholder farming systems in less-favored areas (Jagger and Pender, 2000). The other greatest positive contribution of *Eucalyptus* is perhaps in replacing indigenous species for firewood, thereby, preventing further denudation of natural forests (Evans, 1992).

Generally, *Eucalyptus* in Ethiopia is highly favored for planting and it is common to see them in most of the agro-ecological zones of the country. Whilst *Eucalyptus* have such and many other benefits, including fast growth and the ability to coppice, of all widely used plantation species they have attracted by far the most criticism (Evans, 1992). In the past insufficient attention was given to the native tree species of Ethiopia, especially to planting and regeneration of these native tree species. At present, in the Ethiopian millennium the trend in the country is to shift from exotic monocultures to more diverse plantation forests that also include promising native tree species.

2.7. Eucalyptus plantation and naturally regenerated forest

The presence or absence of understory vegetation in a plantation is a factor of density of the stand, the rainfall regime and management than their origin (Powers *et al*., 1997; Mulugeta Lemenih *et al*., 2004). *Eucalyptus* plantation forests can host richer species and higher seedling/sapling densities than their adjacent disturbed natural forests (Michelsen *et al.*, 1996; Eshetu Yirdaw, 2001 and 2002). Even in the native forests of Australia, it is common to find 20 to 30 species of shrubs under *Eucalyptus* plantations, and rather more in the early regeneration stages (Pryor, 1992).

Eucalyptus has also the potential in enhancing the recruitment, establishment, and successions of native woody species (Loumeto and Huttlee, 1997; Yitebtu Moges, 1998; Feyera Senbeta, 1998; Eshetu Yirdaw, 2001; Feyera Senbeta *et al.,* 2002; Mulugeta Lemenih and Demel Teketay, 2004). Therefore, *Eucalyptus* can act as succession catalysts, facilitating the recolonization of native flora through their influence on understory microclimate and soil fertility, suppression of dominant grasses, and provision of habitats for seed dispersing animals (Lugo, 1992; Parrotta *et al.*, 1997; Feyera Senbeta and Demel Teketay, 2001: Feyera Senbeta *et al.*, 2002; Eshetu Yirdaw, 2001; Mulugeta Lemenih *et al.*, 2004).

Studies on the undergrowth of indigenous species, and their diversity in *Eucalyptus* plantations in comparison with the adjecent natural forests were carried out in Ethiopia

(Michelsen *et al.*, 1993; Michelsen *et al.*, 1996; Yitebtu Moges, 1998; Kidane Woldu, 1998; Feyera Senbeta and Demel Teketay, 2001; Eshetu Yirdaw, 2001; Feyera Senbeta *et al.*, 2002; Mulugeta Lemenih *et al.*, 2004). Michelsen *et al.* (1996) studied herbaceous plant richness in plantations of *Eucalyptus* and *Pinus patula* in comparison with the adjacent natural forests and the result indicated that the species richness under plantations was as high as those of natural forests.

In the regeneration study of woody species under the canopies of tree plantations (*Eucalyptus , Pinus patula, P. radiata* and *Juniperus procera*) made by Feyera Senbeta and Demel Teketay (2001), a total of 37 naturally regenerated indigenous woody species were recorded beneath all plantation stands, with densities ranging between 1,630 and 18,270 individuals per hectare.

In the study of native woody species regeneration in exotic tree plantations (*Eucalyptus , E. saligna, Pinus patula* and *Cupruses lustanica*) at Munessa-Shahsemene forest carried out by Feyera Senbeta *et al.* (2002), a total of 55 naturally regenerated woody species were recorded beneath all plantation stands with densities ranging between 2,300 and 18,650 individuals/ hectare in different stands. The study also revealed that seedling populations were the most abundant components of the regeneration in most of the plantation stands, forming 68% of the total regeneration count in all stands.

Eshetu Yirdaw (2001) found greater abundance of naturally regenerated woody species under the exotic *C. lusitanica* than the native *Juniperus procera* stand in Ethiopia. The study also indicated that the density of naturally regenerated woody plants in plantations was over three times the usual planting density in Ethiopia, indicating a high potential of forest plantations for restoring the natural forest ecosystems on degraded lands at a comparatively low cost.

Michelsen *et al.* (1996) study on the composition of ground vegetation in plantations of *Eucalyptus , E. grandis*, *E. saligna, Pinus patula* and the adjacent natural forest result indicated that there were no differences in the species composition of the ground vegetation of natural forests and plantations. Even the species richness, cover and biomass of their herbaceous flora did not differ.

Noble and Randall (1998), in northern Australia noted a link between the positive growth responses of the pasture species *Paspalum notatum* under the tree canopy of *E. grandis*. The grass under the trees had a greater proportion of green leaf, concentrations of nitrogen and potassium, and moisture content than the grass in the full sun.

In India, Dabral *et al.* (1987) found an undergrowth vegetation of *Lantana* species, *Murraya koenigii*, *Carissa karonda*, *Jasminum officinale*, *Mallotus philippensis* and *Syzygium cumini* under *Eucalyptus* hybrid plantation, at spacing of 2 m x 2 m. Bhuiyan (1986) have observed undergrowth under *Eucalyptus* plantings at 1.8 m x 1.8 m spacing, but the diversity was less than that of native forest types. Loumeto and Huttel (1997) in Congo have carried out study on understory vegetation on *Eucalyptus* plant and found 100 different species. Finally, Poore and Fries (1985) generalized and concluded that in an arid region *Eucalyptus* may suppress ground vegetation by competing for water, but this is unlikely to occur in areas with high rainfall.

Eucalyptus has an allopathic effect there is no concrete evidence and agreement that prove its detrimental effect on the undergrowth species. On the contrary some studies show that regeneration of undergrowth species is better under eucalyptus than other exotic tree species and natural forest (C.lustinica, and P. patula).

On the other hand Alem and woldemariam (2009) study the undergrowth of different species of eucalyptus plantation and natural forest found that the condition for under growth is more conducive in natural forest for shade tolerant plant species (52 species) compared to eucalyptus (46 species); the density of understory growth in eucalyptus was 3282 stem per ha and that of natural forest 4122 stem/ha. This difference is too small compared with the livelihood benefit eucalyptus gives to smallholders and to justify a ban of eucalyptus. Debushe *et al*., (2010) also shared the above concept from their findings; about 68 plant species with 55 genera and 32 families was investigated in eucalyptus plantation in Entoto (Ethiopia) of which 41 are naturally regenerated woody species.

Figure 2: The regeneration of native plant species under eucalyptus plantation in the study area

Management regimes are important to consider as management by itself has an effect on the regeneration of understory species particularly stand-density (Debusheet al., 2010) and management of the canopy. The species growing under eucalyptus plantation at its younger stages are mainly grasses (Holgen and Svensson, 1990) but when older (more than 10 years) the under growth include different woody species, shrubs and herbs.

In relation to water consumption Poore and Fries (1985) reported that eucalyptus are not a good biological conservation methods both for soil and water since the ground cover of under story plant speciesis suppressed by the roots of eucalyptus. On the contrary Tesfaye (2009) argue that if eucalyptus is planted in a wider space it favor the under growth (Table 5), allowing the entrance of light to the surface that almost all plant species needs to grow, therefore it helps to protect soil erosion (runoff) if planted at the right spacing.

Eucalyptus has also the potential in enhancing the recruitment, establishment, and successions of native woody species (Loumeto and Huttlee, 1997; Yitebtu Moges, 1998; Feyera Senbeta, 1998; Eshetu Yirdaw, 2001; Feyera Senbeta *et al*., 2002; Mulugeta Lemenih and Demel Teketay, 2004). Therefore, Eucalyptus can act as succession catalysts, facilitating the recolonization of native flora through their influence on understory microclimate and soil fertility, suppression of dominant grasses, and provision of habitats for seed dispersing animals (Lugo, 1992; Parrotta *et al*., 1997; Feyera Senbeta and Demel Teketay, 2001: Feyera Senbeta *et al*., 2002; EshetuYirdaw, 2001; Mulugeta Lemenih *et al*., 2004).

Studies on the undergrowth of indigenous species, and their diversity in Eucalyptus plantations in comparison with the adjecent natural forests were carried out in Ethiopia (Michelsen *et al*., 1993; Michelsen *et al*., 1996; YitebtuMoges, 1998; Kidane Woldu, 1998; Feyera Senbeta and Demel Teketay, 2001; EshetuYirdaw, 2001; Feyera Senbeta *et al*., 2002; MulugetaLemenih et al., 2004). Michelsen *et al*., (1996) studied herbaceous plant richness in plantations of Eucalyptus and Pinus patula in comparison with the adjacent natural forests and the result indicated that the species richness under plantations was as high as those of natural forests. In the regeneration study of woody species under the canopies of tree plantations (*Eucalyptus*, *Pinus patula*, *P. radiate* and *Juniperus procera*) made by Feyera Senbeta and Demel Teketay (2001), a total of 37 naturally regenerated indigenous woody species were recorded beneath all plantation stands, with densities ranging between 1,630 and 18,270 individuals per hectare. In the study of native woody species regeneration in exotic tree plantations (Eucalyptus , *E. saligna*, *Pinus patula* and *Cupruses lustanica*) at Munessa-Shahsemene forest carried out by Feyera Senbeta *et al*., (2002), a total of 55 naturally regenerated woody species were recorded beneath all plantation stands with densities ranging between 2,300 and 18,650 individuals/ hectare in different stands. The study also revealed that seedling populations were the most abundant components of the regeneration in most of the plantation stands, forming 68% of the total regeneration count in all stands.

EshetuYirdaw (2001) found greater abundance of naturally regenerated woody species under the exotic C. lusitanica than the native Juniperusprocera stand in Ethiopia. The study also indicated that the density of naturally regenerated woody plants in plantations was over three times the usual planting density in Ethiopia, indicating a high potential of forest plantations for restoring the natural forest ecosystems on degraded lands at a comparatively low cost. Michelsen *et al*. (1996) study on the composition of ground vegetation in plantations of Eucalyptus , E. grandis, E. saligna, Pinuspatula and the adjacent natural forest result indicated that there were no differences in the species composition of the ground vegetation of natural forests and plantations. Even the species richness, cover and biomass of their herbaceous flora did not differ.

2.8 Ecological Impact of Eucalyptus

2.8.1 Eucalyptus and soil nutrients

One of the criticisms of *Eucalyptus* discussed by different writers is its nutrient intensive character, which creates deficit for other plant species. Normally plants obtain their nutrients from the soil either in dissolved form or as in the case of nitrogen, some species can absorb in gaseous form. Nutrients circulate in the soil through soil organisms.

In undisturbed natural conditions, dead branches of trees break off and fall to the ground; and in cases when the whole tree falls and decompose, the nutrients return back to the soil. Through this continuous process plants help to maintain the nutrient status of the soil. Compared to nitrogen fixing tree species plantations, *Eucalyptus* had a lower litter fall (Parrotta, 1999). Annual litter fall is generally low during the early stages of crop establishment (Young, 1989).

However, an increasing trend in the soil organic matter level may be realized at later periods since litter fall is higher in older plantations and two thirds of the gross annual nutrient uptake is returned to the soil through the litter (Turner and Lambert, 1983). *Eucalyptus* litter is also slow to decompose, it tends to accumulate, and there is a relatively lower incorporation of organic matter in the soil (Balagopalan and Jose, 1991). Moreover, addition of nutrients to the soil through decomposition of *Eucalyptus* litter is much less than other species (Judd *et al.*, 1996).

There is evidence to suggest that after planting *Eucalyptus* on previously treeless sites, soil fertility increases through development of mull humus (FAO, 1985). Demel Teketay (2000) stated that very few comparative studies have been made in Ethiopia on soil nutrients among plantations of different species, including *Eucalyptus*, and the adjacent natural forests (Michelsen *et al*., 1993; Lisanework Nigatu & Michelsen, 1994; Michelsen *et al.*, 1996; Betre Alemu, 1998).

In the first study, soil fertility, growth, nutrient utilization and mycorrhizal colonization were compared among plantations of *Eucalyptus* (40 years old stand coppiced 2-6 years before the study), *Cupressus lusitanica* (28 years old), *Juniperus procera* (40 years old) and the adjacent natural forest at Menagesha state forest, about 50 km west of Addis Ababa (Michelsen *et al*., 1993). The result revealed that soil of both *C. lusitanica* and *Eucalyptus plantations* had lower nutrient contents than soils of both *J. procera* plantation and the natural forest. The pool size of all nutrient elements in herbaceous plants was also much lower in the *C. lusitanica* site than other three sites. Soil of *C. lusitanica* and *Eucalyptus sites* tended to have lower density of vesicular-arbuscular mycorrhizal fungi.

In the second study, nutrient cycling in the above-mentioned plantations and in natural forest was compared at the same forest (Lisanework Nigatu and Michelsen, 1994). The results indicated that the total annual litter fall was about twice as high in the natural forest as in the plantations, with the lowest litter fall in the *C. lusitanica* plantation, and slightly higher figures in the *Eucalyptus and J. procera* plantations. The four sites differed with respect to the rate of nutrient release from decomposing litter. The *Eucalyptus plantation* had comparable nutrient release with the natural forest after one year.

The third study focused on large-scale comparative studies of understory vegetation and soil fertility in plantations and adjacent natural forests (Michelsen *et al*., 1996) in 11 areas with a total of 83 plantations in central and southern Ethiopia. The result showed that the natural forest soil had a higher content of total nitrogen, available phosphorus and exchangeable calcium. This has been attributed to a combination of loss of organic matter during conversion of natural forest to plantations, increased leaching in young plantations and low nutrient demand by natural forest trees compared with fast-growing exotics. Similarly, in the fourth study, where soil nutrient status was studied after conversion of natural forest to plantation and secondary forest at Munessa forest (Betre Alemu, 1998), the plantation stands (*Eucalyptus , E. grandis, E. salinga, Pinus patula* and *C. lusitanica*) had significantly lower pH, total nitrogen, organic matter, exchangeable calcium and magnesium than the adjacent natural forest in the topsoil.

2.8.2 Eucalyptus and hydrological impacts

It has been argued that *Eucalyptus* species take up a great amount of water from the soil, and when grown in plantations they lower the ground-water level more than other tree crops. *Eucalyptus* has the potential to develop long deep taproot in dry areas, and mostly develops fibrous roots in moist areas (Zimmer and Grose, 1958). Overall, the species have vigorous tap root systems which are able to reach depths of > 20 m (Dye, 1996). This helps the species to exploit water reserves from 6 to 15 m deep in the soil horizons than the associated crop (Lawson and Kang, 1990). As a result many *Eucalyptus* species are well adapted to grow in dry and flooding conditions (FAO, 1988; Evans, 1992; Cannell, 1999).

An experiment was done in India with trees up to one year old, and compared with agricultural crops. The result showed that, most *Eucalyptus* species need on average 785 liters of water/kg of biomass produced as opposed to cotton/coffee/banana (3,200), sunflower (2,400), field pea (2,000), cow pea (1,667), soyabean (1,430), potato (1,000), sorghum (1,000) and maize (1,000) liters/kg biomass produced (Davidson, 1989). The above figures show that *Eucalyptus* species had greater water efficiency than other crops, i.e. it consumed less water per unit of biomass produced.

Davidson (1989) additionally reported that on a “leakproof hectare” at Nekemte (Western Ethiopia) with annual rainfall of 2158 mm, *E. saligna* and *E. grandis* could produce 46.6 3m /ha/yr without drawing on water reserves (rainfall only) compared to 16.4, 16, 12.4 3 m /ha/yr biomass production for the coniferous, acacia, and broadleaf species, respectively. These figures reveal that for the same amount of water consumed *Eucalyptus* produces higher amount of biomass, which is economically profitable and acceptable.

Eucalyptus is more efficient in water use than other ‘useful’ native trees in biomass production per liter of water consumed (Chaturvedi *et al.*, 1988; Prabhakar, 1998). However, this genus has also been criticized for the high rate of transpiration, and possible contribution to water shortages in arid areas. Prabhakar (1998) notes that transpiration of *Eucalyptus* is high under conditions of high soil moisture, termed ‘luxury consumption’, and under conditions of water stress, stomatal closure occurs, which restricts water loss from the plant. Yet, there does appear to be an extreme threshold before the onset of stomatal closure.

Consequently, it is difficult to get a clear answer for this controversial issue. Therefore it is important to assess and deal with the problem by considering different sites and conditions.

A study comparing the water use of various widely planted forest plantation species showed that *Eucalyptus* had the highest water uptake of all of the tree species tested (Srivastava and Misra, 1987). FAO (1985) suggests that a plantation of *Eucalyptus* in any deforested catchment will substantially reduce water yield, but that the effect of decreasing water yield is probably less than that of pine and greater than other broad- leaved species. In native stands of *Eucalyptus* in Australia, water yield increases were correlated to the percent of a catchment logged and these yields declined as *Eucalyptus* reestablished it (Cornish, 1993). A detailed study of the effects of blue gum *Eucalyptus* plantations demonstrated that it significantly reduced both high and low flow water yields and that the reduction in these flows increased as the *Eucalyptus* stand increased with age (Sikka *et. al*., 2003). This is in part due to the fact that *Eucalyptus* have a specialized root system consisting of a deep tap root with lateral shoot roots at different levels so that the trees can take advantage of any available soil water. A study in Israel showed that mature *Eucalyptus* will use moisture from the water table even when surface sources are available (Cohen *et. al*., 1997). Generally in areas where rainfall is usually 1,100 to 1,150 mm per year that establishment of forest plantation with that of *Eucalyptus* will not adversely affect the soil water regime (Lima *et al*., 1990).

2.8.3 Eucalyptus and allelopathic effect

Allelopathy is the provision of chemicals from leaves or litter that inhibits the germination or growth of other plant species (FAO, 1985). Several authors explained about allelopathy and its impact on the regeneration of plants. Babu and Kandasamy (1997) explained that it is a direct or indirect harm of one plant by another due to its release of chemicals into the environment. *Eucalyptus* has been suspected of interference through allelopathy, the direct or indirect effect of one plant on another through the production and liberation of chemical compounds into the environment (Rice, 1984). The presence of inhibitory compounds, allelochemicals, such as phenolics, terpenoids and flavinoids have been identified from leaves, roots exudates or residual parts of *Eucalyptus* (Singh, 1991; Lisanework Nigatu and Michelsen, 1993). Furthermore, Del Moral and Muller (1969) and Espinosa-Garcia (1996) pointed out that a reduction in community diversity in the presence of some *Eucalyptus* species such as *Eucalyptus has* been attributed to the tree's allelopathic effects and impact on nutrient cycling. The debate around allelopathic properties of *Eucalyptus* is overwhelming in Ethiopia too. Demel Teketay (2000) stated that in Ethiopia two different results have been reported concerning the interaction or association of *Eucalyptus* with other plants. These are positive interactions (Mebrate Mihretu, 1992; Michelsen *et al*., 1993; Michelsen *et al*., 1996; Yitebetu Moges, 1998; Feyera Senbeta, 1998; Kidane Woldu, 1998) and negative interactions (Lisanework Nigatu & Michelsen, 1993).

To begin with the negative interaction, the potential allelopathic effect of *E. camaldulensis, Cupressus lusitanica, Eucalyptus,* and *E. saligna* on seed germination, radicle and seedling growth was investigated with four crops: chickpea, maize, pea and teff (*Eragrostis teff* Zucc.) (Lisanework Nigatu and Michelsen, 1993). The results revealed that aqueous leaf extracts of all the tree species significantly reduced both germination and radicle growth of the majority of the crops. It has been shown that the shoot and root dry weight increase of the crops was significantly reduced after 10 weeks treatment with leaf extracts. Among the four crops, chickpea and teff were most susceptible with respect to germination. From the overall data, the leaf extracts of the four tree species had been arranged according to increasing allelopathic potential: *Cupressus lusitanica, Eucalyptus, E. saligna* and *E. camaldulensis*. Based on these results, the authors suggested that planting of *E. camaldulensis* and *E. saligna* should be minimized in integrated land use systems, whereas the use of *C. lusitanica* and *Eucalyptus was* considered less damaging environmentally. Although there is sufficient evidence to indicate negative effects on crops due to allelopathy, the magnitude of these effects may be influenced by rainfall. It is likely that allelochemicals do accumulate in soil. However, these chemicals are highly soluble and rainfall is likely to leach them out of the soil surface (May and Ash, 1990). Thus the effects of allelopathy are likely negatively correlated with rainfall. Malik and Sharma (1990) noted that allelopathic effects are more severe in low rainfall regions prone to soil erosion. The relevant reports regarding positive interaction available on *Eucalyptus* plantations is like other plantation species, *Eucalyptus* plantations have been shown to foster or catalyze regeneration of native forests when they are planted close to seed sources and protected from human and animal disturbances, thereby contributing to rehabilitation of degraded lands and increasing biodiversity (Parrotta *et al*., 1997).

A study made by both Feyera Senbeta (1998) and Yitebetu Moges (1998) clearly demonstrated, provided that there is a seed source in the vicinity, establishment of forest plantations can help not only to provide wood for various purposes, to rehabilitate degraded lands and to conserve soil and water but also to foster or catalyze natural regeneration of native woody species thereby enhancing biodiversity. Inconsistent to the above results explained by Lisanework Nigatu & Michelsen (1993), a study conducted by Feyera Senbeta (1998) showed that the number of naturally regenerated native woody species in *E. saligna* (11 to 27-year-old) ranged between 18 and 25 while in *Eucalyptus stands* (13 to 22-year-old) ranged between 13 and 17 with densities ranging between 3,575 and 18,650 and 2,300 and 13,400 individuals/ha respectively.

2.8.4 Water Consumption of Eucalyptus

Different measurements about the hydrological impact of fast growing plant species particularly on eucalyptus analyzed by different researchers considering the physiology of the plant, the rainfall of the area, the moisture content of the soil and the amount of water absorbed by specific plant or tree conclude that eucalyptus does not have a unique negative impact (Davidson, 1990; Calder *et al.*, 1993; Anne, 1997). Calder *et al* (1993). They summarized from different articles that young eucalyptus plantation does not show any difference for uptake of water in a dry area up to 3 meter depth compared to indigenous plant species. In dry areas the water requirement of eucalyptus and native species are proportional to the amount of rainfall the area receive. A numbers of investigation shows that water uses of forest (both indigenous and older eucalyptus) are greater than that of crops in dry zones of India (Calder *et al*., 1993). This is true for some crop species (Maize and Sorghum) in the Ethiopian case as interpreted by Amare Getahun (2010).

However, Teshome (2009) stated these crops take more water than eucalyptus; both Maize and Sorghum needs around 1000 liter of water to produce one kg of biomass. According to Calder *et al* (1993) there is no evidence that proves eucalyptus take more water than any other indigenous dry deciduous and exotic forest in India.

The negative impact of eucalyptus on the hydrology and nutrient content of the soil does not outweigh its livelihood contributions (Ghoshet al., 1978; Zewude, 2008) from small scale farmers' point of view. Jha and Pande (1984) reported that the soil under eucalyptus maintain higher moisture levels and helps to increase the pH of the area compared to the soil under natural forest. However, Walter (1984) concludes based on a review of different studies that eucalyptus creates water deficits in semi-arid areas with a minimum rainfall.

When stand age of eucalyptus increases the uptake of water also increases and as a consequence the moisture content of the soil under mature stands is less compared to that under younger stands, up to 250 m down in the soil.Akhter *et al* (2005) wrote that the water use efficiency (WUE) of eucalyptus in dry areas is less than that of acacia species.

According to Akhter (2005) although eucalyptus produces more biomass it has less water use efficiency. But Poore and Fries, 1985; Michelsen *et al*., 1996; Jagger and pender, 2000; Kidanu *et al*, 2004 stated that the WUE of eucalyptus is higher than most tree species. Anne (1997) argues that eucalyptus causes streams and rivers to dry and disturb the water balance by lowering the water table.

Teshome (2009) also concludes that eucalyptus does not consume more water than any tree species and crops in Ethiopia; rather it is efficient in using moisture around roots and converts to biomass. In a study in Ethiopia eucalyptus produced more biomass than coniferous and broad leave tree species growing within the same amount of rainfall regime, for example, in Nekemt area (Ethiopia) *E.saligna* and *E.camaldulensis* could produce 46.6 m3/ha/yr without affecting the water reserve in an area with 2158 mm of rainfall, while conifers, broad leaves and acacia produce lesser amount of biomass 16.4, 16.0 and 12.4 m3/ha/yr respectively (Davidson, 1989; Teshome, 2009). These figures indicate the water use efficiency of eucalyptus species is comparatively good with the biomass produced.

When the water consumption of eucalyptus is compared to different agricultural crops and tree species the result found from different literature approve that eucalyptus consumes less water (Calder 1992; Davidson, 1995; Tesfaye, 2009; Patil, 1995; Getahun, 2010). However others (notably Zahid and Nawa, 2007; and Getahun, 2010) conclude that eucalyptus consumes more water than other crops such as maize and woody species. Also, D.sissoo show a better water use efficiency compared to eucalyptus. From the small scale farmers' perspective the potential of eucalyptus to produce higher biomass from as little water as possible is a concerning issue. Farmers' live in different agro ecological zones, for those living in high rainfall areas the main concern may be maximum yield of trees whereas in low rainfall areas their main focus may also be maximum biomass production but with minimum disturbance on the water consumption without costing other important production. Basically water is necessary for all production, but eucalyptus exploits the available water more efficiently to produce higher yield during short period.

The main problem comes when eucalyptus planted in large areas because of reducing the water supply for other crops. On the other hand planting eucalyptus in small plots helps to minimize the risk of competition for water.

2.8.5 Level of Nutrient Uptake of Eucalyptus

Another controversy of eucalyptus is its efficient nutrient uptake that gradually exhausts the soil nutrient. Eucalyptus is a non-nitrogen fixing tree and does not have capacity to replace the nitrogen it consumes like leguminous tree species. Compared to the natural forest, Eucalyptus can potentially decrease the fertility of the soil (Demel Teketay, 2003); since nutrients are recycled in natural forest, while eucalypt is harvested and nutrients removed. On the other hand an investigation carried out in Kenya to compare the nutrient content of tea plantation and eucalyptus showed that eucalyptus has high micro nutrient content compared to that of tea plantation (Oballa and Langat, 2002; oballaet al, 2010). Modeling the nutrient cycling for any forest type is not easy, since different environmental factors, like weathering of parent materials, affects the replenishment of nutrients (Getachew Tesfaye, 2009).

The high and efficient nutrient uptake of eucalyptus is a debated environmental agenda all over the world. Some researchers argued that eucalyptus does not consume more nutrients relative to other tree species and crops (Tesfaye, 2009) but others (Wang *et al*, 1991; Kidanu *et al*, 2006). Getahun (2010) stated that eucalyptus is not aggressive for the uptake of nutrient and water compared to other plant species and crops. It is logical that fast growing species in general, consume more nutrients and water to provide for the higher amount of biomass they produce. For poor smallholders to grow eucalyptus may be a question of subsistence and survival particularly for those that do not have an alternative.

In this case the question is about the tradeoffs between eucalyptus outputs and environmental sustainability (Anne, 1997; Kidanu *et al*, 2006; Tesfaye, 2009; Zegeye, 2010). Jagger and Pender (2000) found that for degraded land and waste land eucalyptus helps to conserve the top soil of hill sides and improve the fertility (nutrient content) of the soil through litter fall. Hence, planting of eucalyptus in degraded and non-fertile area (barren land) getting trees to survive add both value and improve sustainability of the land. The negative impact of eucalyptus might be clearly visible if planted near the annual crops (competition for nutrients); but the details of how much nutrients is depleted and how much organic matter contributed is not clearly identified (Jagger and Pender, 2000).

From their study in Ethiopian highland on Nitosol, Kidanuet al, (2004) found that the yield of crops like wheat (*Triticum aestivum*) show a significant reduction within a distance of the first 8 m during the first rotation and within a distance of 16 m during the second rotation of eucalyptus due to insufficient nutrient, light and water.

Similarly in India Saxena (1991) found a reduction in crop yield due to eucalyptus plantation around crop fields and in those fields used for cultivation adjacent to eucalyptus woodlots. Most farmers had destroyed their eucalyptus plantation after the first rotation and turned the land into crop production since the benefits of eucalyptus was less compared to annual crops. In India (Muzaffarnagar and Nainital, North west part) the loss of crop yield due to the effect of eucalyptus start from the first two year after planting; 0% in crop yield during the first and second year, 8.2% in the third year, 13.6% in the sixth year, 26.4% in the seventh and eighth year and 48.8 % in the ninth and tenth year. The loss in crop yield was attributed the completion of eucalyptus for nutrient, water and light (Ahimed, 1989; Saxena, 1991). Saxena (1991) noted that the losses of crop depend on the spacing between rows (stem density), application of water and other management regimes.

Some nutrient like potassium, phosphorus, calcium and magnesium will be returned to the soil during the logging and post logging burns (Nobel, 1992; Davidson, 1995). These findings highlight the importance of nutrient management during the cutting cycle of eucalyptus an important aspect to be considered by the smallholders as they normally lack access to fertilizer.

Table 1: Ecological effects of eucalyptus tree

Effects	**Positive effects**	**Negative effects**
Biomass production	Planting fast growing eucalyptus may be one of the best short term options for the provision of critically required biomass.	Land scarcity may be a constraint to wide scale planting.
Effects on soil, nutrient depletion andtop soil Retention	On degraded hillsides and wastelands the net soil nutrient contribution of Eucalyptus through leaf litter is likely to be positive.	Eucalyptus trees deplete soil nutrients needed by agricultural crops, however the spatial magnitude of depletion is not known.
	Good potential for topsoil retention on degraded hillside.	The ability of Eucalyptus to provide organic matter is questionable.
Allelopathic effects	Rainfall may decrease or negate the allelopathiceffects of trees on crop.	Allelo chemicals negatively influence agricultural production and are a more significant factor in dry regions.
Hydrological impact	In regions with erratic and severe rainfall the ability to take up large quantities of water may reduce runoff, flooding and water logging.	Eucalyptus may complete water away from agricultural crops decreasing agricultural output as far as 10 meters away from where trees are planted.
	On previously barren slopes, tree cover may reduce erosion and gully formation caused by rain fall.	Wide scale hydrological impacts are uncertain.

Source: **Jigger and Pender, 2000**

3. MATERIALS AND METHODS

3.1. Description of the Study Area

At the northerly edge of Addis Ababa, a mountain hill rises to an elevation of more than 3 100 meters above sea level. On the mountain Entoto, state-owned forest campany planted large areas of eucalyptus, which are nowdays being cut down by the forest company itself and by fuel-forest collectors. The region faces big problems concerning erosion, over flooding and uncontrolled exploitation.

The study area belongs to dry evergreen Afromontane forest and grassland complex (DAF) in the central highlands of Ethiopia (Friis and Sebsebe Demissew, 2001). Mount Entoto is considered to be the highest peak overlooking the city of Addis Ababa. It's altitude reaches 3,200 meters above sea level and is part of the Entoto mountain chain. This study area is located in two sub cities of Addis Ababa, namely, Gullele and Yeka sub-cities. The study will be conducted in Entoto Mountain and its surrounding area that surrounds the city Addis Ababa between latitudes 9°08′N–10°06′N and longitudes 37°47′E–37°48′E, Which includes both deep green and pale green area of the underneath map.

The elevation of the study area is between 2551 m and 3031 m a.s.l. This study will be undertaken in the Entoto mountain range that lies on the southeastern slopes of Mt Entoto, between the northern limit of the city of Addis Ababa, and the track along the mountain ridge. As can be seen from the underneath map, the elevation of the area ranges from 2,440 m to3, 196 ma.s.l.

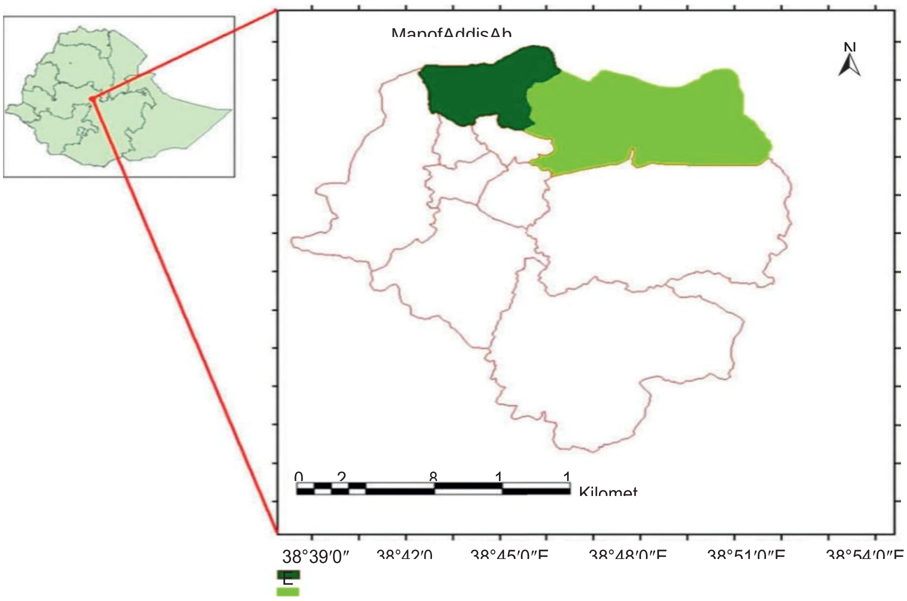


Figure 3: Location map of EntotoPark

3.2. Climate

According to Ethiopian Meteorology Institute (2021) from the10-year (2016 to 2021) the mean annual rainfall of the area is about 1226 ml. As far as the monthly rain fall record of the area is concerned, the area mostly receives its maximum rainfall between June and September. This is usually considered as the rainy/moist season (kiremt) in the area. Low amount of rainfall is recorded between Ontober and April. The average annual temperature of the area is 14°C. The maximum and minimum average annual temperatures of the area for the last ten years are 17.89 and 8.85°C, respectively.

3.3. Vegetation

Previously, indigenous trees such as *Juniperus procera*, *Olea europea* subsp. cuspidata, and Podocarpus falcautus were dominantly covering the mountain area. Similar to other parts of Ethiopia, the natural Juniperus- Podocarpus-Olea forest which was once abundant on the Entoto Mountain rapidly vanished due to an over exploitation of the indigenous trees (Pohjonen, 1989). The remnants of *Juniperus procera* and *Olea europaea* subsp. cuspidata trees in the area reflect elements of this vegetation. On steep slope areas woodland was composed of *Ekebergia capensis*, *Myrsine africana*, *Acacia abyssinica* and some others. Currently, the ultimate controlling species in the area is Eucalyptus.

Figure 4: Remnants of few indigenous tree species in *Eucalyptus* plantation forests

3.4. Sampling Design

In this study a systematic sampling design was used to collect data on vegetation and environmental variables. A total of 60 plots of size 20 m x 20 m were systematically laid in north–south directions using Compass and the distance between consicutive plots along the transect line was 300 m. Thirteen transects were laid at 500 m distance from each other.

These subplots were also used for seedling count.

3.5. Data collection

In each sampling plot all plant species were collected. The cover abundance of plant species in each plot was estimated. Diameter was measured for every individual tree and shrub species having DBH (diameter at breast height) greater than 2.5 cm using a measuring diameter tape. If a tree branched at breast height or below, the diameter was measured separately for the branches and averaged.

In case where tree/shrub boles buttressed, diameter measurements were taken from the point just above the buttresses. Height was measured for every individual tree and shrub with DBH greater than 2.5 cm using a Suunto Clinometer. Where slope, topography and/or crown structure made it difficult to use the Clinometer, height of trees and shrubs were visually estimated.

To determine the regeneration status of woody species, seedling individuals with DBH less than 2.5 cm and height less than 1.5 m and saplings (individual with height greater than 1.5 m and DBH less than 2.5 cm) were counted.

Plant specimens were collected, pressed, dried, checked and identified at the National Herbarium (ETH), Biology and Biodiversity Management of the Addis Ababa University. Identification of plant specimens was made using authenticated specimens, consulting experts and referring the published volumes of Flora of Ethiopia and Eritrea.

3.6. Data Analysis

3.6.1 Plant diversity

For the analysis of diversity and woody species density the individual *Eucalyptus* plantation stands were used to classify the plots in to three categories. These are C1 (plots with less than 64 *Eucalyptus stands or individuals*), C2 (plots consists of 64 to 82 *Eucalyptus stands* *or individuals*) and C3 (plots with greater than 82 *Eucalyptus stands or individuals*). This cut off value is determined randomly based on the number of eucalyptus individual stands in each plots (See Appendix: 3a, 3b and 3c, respectively).Twenty plots were identified for each category.

Shannon and Wiener (1949) index of species diversity was applied to quantify species diversity and richness. This method is one of the most usual approaches in measuring the diversity of species. The Shannon-Wiener Diversity Index (H') was computed using the following formula:

H = -∑ (Pi ln Pi)…………………………(1)

Where "H" is the Shannon and Wiener diversity index, "Pi" is the ratio of a species average to the total species average (pi is percentage in decimal form (prortional)) and "ln" is the natural logarism to base e (log). Species evenness is computed using the formula:

eJ = H/Hmax…………………………(2)

Where "J" is the species evenness, "H" Shannon and Wiener diversity index and "Hmax" is lnS, where S is the number of species.

One-way ANOVA was applied to test the difference in woody species diversity among the three plot categories. After checking the significant differences, I run the multiple comparsion of means using the Honest Signficance Differences (HSD) Tukey's test.

3.6.2 Population Structure

The woody species recorded in all the 60 relevés were used in the analysis of the vegetation structure. The tree/shrub density, diameter at breast height (DBH), height, frequency, basal area and importance value index were used for description of vegetation structure.

Diameter at Breast Height (DBH): DBH measurement was taken at about 1.3 m from the ground using a measuring diameter tape. This technique is easy, quick, inexpensive and relatively accurate. There is direct relationship between basal area and DBH.

Basal area = $(DBH/2)^2$ X 3.14…………………………(3)

Basal area is also calculated with the formula dbH^2 X 0.005454, where dbH is the diameter in inches at breast height (4.5 feet from the ground). 0.005454 is the forester's constant, which converts from inches to squared feet.

Density: is the number of stems of a certain species per unit area. It is closely related to abundance but more useful in estimating the importance of a species.

Frequency: The number of quadrates in which a given species was recorded. It is calculated with this formula:

$$\text{Frequency} = \frac{\textit{Number of plots in which a species occur}}{\textit{Total number of plots}} \times 100$$

The frequencies of the tree/shrub species in all the 60 relevés were computed. The higher the frequency, the more valuable the plant is in the community. A better idea of the importance of a species with the frequency can be obtained by comparing the frequency of occurrences of all of the tree/shrub species present. The result is called the relative frequency and is given by the formula:

$$\text{Relative frequency} = \frac{\textit{Frequency of species}}{\textit{Total frequency of species}} \times 100$$

$$\text{Relative density} = \frac{\textit{Density of species}}{\textit{Total density of species}} \times 100$$

$$\textit{Relative dominance} = \frac{\textit{Dominance of species}}{\textit{Total dominance of all species}} \times 100$$

Although a high frequency value means that the plant is widely distributed through the study area, the same is not necessarily true for a high abundance value. This abundance is not always an indicator of the importance of a plant in a community.

Importance Value Index (IVI): Importance value index combines data for three parameters (relative frequency, relative density and relative dominance). That is why ecologists consider it as the most realistic aspect in vegetation study (Curtis and McIntosh, 1951). It is beneficial to compare the ecological importance of species (Lamprecht, 1989). From the data, the tree and shrub population structure of the naturally regenerated woody species under Eucalyptus plantations were computed. The population structures of selected tree/shrub species were illustrated graphically. The seedlings and saplings data were used for the analysis of regeneration status of woody species in Eucalyptus plantation.

The similarity among the three category is computed using Sorenson's similarity index as indicated by the following formula.

$$SI = \frac{2C}{A+B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

SI= Sorenson's similarity index

A= Total number of species recorded in the first community,

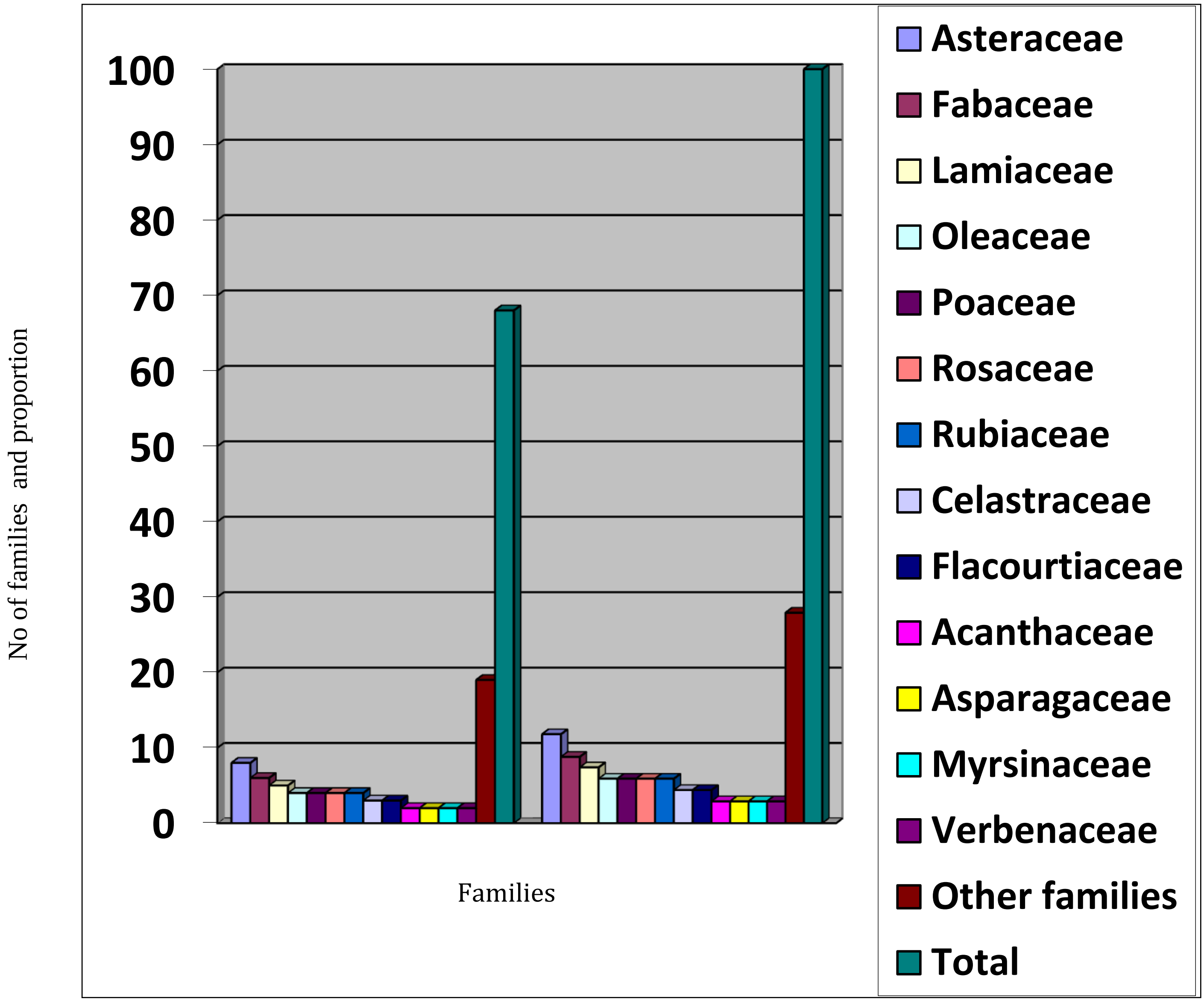
B=Total number of species recorded in the second community,

C= Total number of species common to both community.

4. RESULTS AND DISCUSSION

4.1. Floristic Composition

A total of 68 plant species were recorded which belong to 55 genera and 32 families (see Appendix 1). The study focus on the woody species which are 41 in number (see Appendix 4).Out of 68 identified species, 36.8% were herbs, 1.5% climbers, 4.4% liana, 36.8% shrubs, 8.8% trees/shrubs and 11.8% were trees.



Collected by Gudeta Endalew and Identifide by Melaku Wendaferash AAU

Figure 5: List of family, number of species and proportion (%) in Entoto *Eucalyptus* plantation

Out of 55 identified genera and 32 families, 11.8 % were Asteraceae, 8.8% Fabaceae, 7.4 %

Lamiaceae, 5.9% Oleaceae, Poaceae, Rosaceae and Rubiaceae, 4.4% Celastraceae and Flacourtiaceae, 2.9% Acanthaceae, Asparagaceae Myrsinaceae and Verbenaceae, and the remaining families consist of 1.5% each (Figure 1).

Asteraceae (8 Species) was the most dominant family. The most diverse genera were *Trifolium* which was represented by four species, followed by *Jasminum*, *Maytenus* and *Satureja*; they were represented by three species each; *Asparagus, Conyza*, *Dovyalis* and *Pentas*, (two species) and the rest contained a single species each.

4.2. Diversity and Similarity of regeneration under Eucalyptus plantations

Shannon-Wiener diversity index, species richness and species evenness, under the three categories of *Eucalyptus* plantation stands in Entoto showed considerable variation (Table 2). Magurran (1988) stated that the term diversity actually consists of species richness and relative abundance (evenness or unevenness). Therefore, the lowest *Eucalyptus* stands (<64 individual stands of *Eucalyptus* /plot or C1) exhibited the highest mean values of Shannon species diversity (3.129), species richness (61) and evenness (0.761), C2 (between 64 and 82 individual stands of *Eucalyptus* /plot) also exhibited 2.872 species diversity, species richness (58) and evenness (0.701) while the highest *Eucalyptus* stands (>82 individual stands of *Eucalyptus* /plot or C3) exhibited the lowest mean values of Shannon species diversity (2.653), species richness (45) and evenness (0.697). These results indicate that C1 harbors larger number of species than the others. The Tukey's HSD (honestly significant difference) test revealed that there was a significant difference in the species diversity (H') between each plot of C1 and C2, C1 and C3 while there was no significance difference between C2 and C3 ($P < 0.05$). The species richness was also significantly different ($p < 0.05$) among the three categories of *Eucalyptus plantations*.

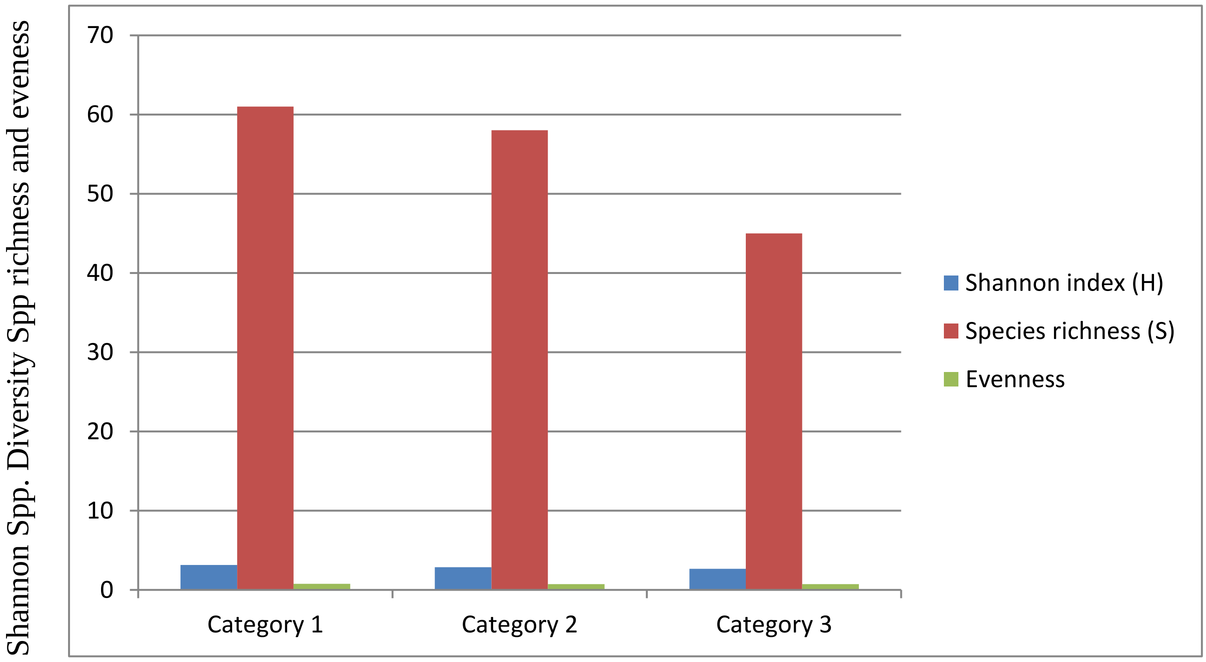
According to Kent and Coker (1992), the Shannon Weiner index was the most frequently used for the combination of species richness and relative abundance. A value of the index of Shannon-Weiner usually lies between 1.5 and 3.5 although in exceptional case, the value can exceed 4.5 (Pielou, 1969). Thus, the value of Shannon - Wiener Diversity Index of this study area falls between 2.653 and 3.129.

The mean species richness was lowest at C3 (45) while the species richness at C1 (61) was highest of all the three categories. Mean evenness values (20 quadrats per category) ranged from 0.697 in C3 to 0.761 in C1. At C1, species evenness was the highest (0.761) while the evenness index at C3 was lowest of all the three categories. Plantation stands that had high

Shannon-Wiener's diversity indices contained high mean species richness. Therefore, the less dense stands of *Eucalyptus* harbors more regenerated plant species than the high dense stands of *Eucalyptus*. In agreement with this notion, Mulugeta Lemenih (2004) demonstrated the effect of canopy cover and undersory environment of tree plantations on undergrowth species richness, and concluded that stands of plantation species with open canopies could enhance more native woody recolonization than stands with dense canopies in central Ethiopian highlands.

In fact, different site determinants such as photosynthetically active radiation (PAR) that reach forest floor might have a crutial impact on ground flora regeneration and recolonization in forest plantations.

Graph 2: Shannon-Wiener diversity index (H'), species richness and species evenness, under the three categories of *Eucalyptus* plantation in Entoto.Where: C1 < 64 individual stands of *Eucalyptus* /plot, C2 between 64 – 82 individual stands of *Eucalyptus* /plot and C3 > 82 individual stands of *Eucalyptus /plot*).



Highest similarity index was observed between the *Eucalyptus* plantation of C1 and C2. On the other hand, C2 and C3 categories of *Eucalyptus* plantation showed relatively weak similarity.

Table 4: Sorensen similarity index among the *Eucalyptus* plantations in Entoto

Category codes	C1	C2	C3
C1	1.00		
C2	0.47	1.00	
C3	0.46	0.44	1.00

4.3 Density of regenerated native woody species

Out of a total of 68 plant species, 42 of them were woody plant species including *Eucalyptus.* The woody species identified represented 34 genera and 26 families (Appendix 2). However, a total of 41 naturally regenerated woody species were recorded in Entoto *Eucalyptus* plantation. The naturally regenerated woody species identified in *Eucalyptus* plantation represented 33 genera and 25 families. Out of all identified naturally regenerated woody species in *Eucalyptus* plantation, 7% lianas, 61% shrubs, 15% trees/shrubs and 17% were trees.

The most diverse genera were *Jasminium* and *Maytenus*, they were represented by three species, followed by *Asparagus, Dovyalis, Pentas* and *Satureja*, (two species each) and the rest contained a single species each. The most diverse family was Oleaceae (9.8%), represented by four species followed by Celastraceae, Flacourtiaceae, Lamiaceae and Rosaceae (7.3%), each with three species.

A total density of 8122.9 individual stands/ha of all woody species (including seedlings, saplings and matured trees and shrubs) were recorded from 60 sample plots (2.4 ha). The relative density of *Eucalyptus* were (55.5%) (See appendix 2). *Eucalyptus* was the most dominant and common tree species in all sample plots of the study area. However, the number of naturally regenerated woody species recorded under. *Eucalyptus plantation* in this study was relatively higher than the number of species recorded under some of the exotic plantation species in Ethiopia. For example, Feyera Senbeta and Demel Teketay (2001) studied 37 species under *Eucalyptus*, *E. saligna*, *Pinus patula* and *Cupressus lusitanica* around the central highlands of Ethiopia. The number of woodlike variety written in the Eucalyptus plantations at Chancho and Menagesha were 20 and 22, respectively (Eshetu Yirdaw, 2001). The total number of regenerated woodlike class at the study scene (41 species) is approximately to prior reports from Jirren wood, South-Western Ethiopia (40 class) (Getachew Tesfaye and Abyot Berhanu, 2006), but lower than the one recorded in

Munessa-Shashemene (55 species) (Feyera Senbeta *et al*., 2002).

The individual *Eucalyptus* plantation stands were used to classify the plots into three categories. They are C1 (plots with less than 64 individual stands of *Eucalyptus)*, C2 (plots consists of 64 to 82 individual stands of *Eucalyptus)* and C3 (plots with greater than 82 individual stands of *Eucalyptus)*. Twenty plots were identified for each category (See appendix 3).

Based on this the total density of *Eucalyptus* in C1, C2 and C3 were 965.4 individuals ha^{-1}, 1411.3 individuals ha^{-1} and 2130.8, individuals ha^{-1} respectively while the total density of naturally regenerated woody species in C1, C2 and C3 were 1290.8 individuals ha^{-1}, 1258.8 individuals ha^{-1} and 1065.8 individuals ha^{-1} respectively (Figure 5). This trend showed the decrease in the density of naturally regenerated woody species with an increase in the density of *Eucalyptus*. Pearson's correlation was computed to show the strength of the relationships between the density of *Eucalyptus* plantation and density of naturally regenerated woody species, which has a strong negative correlation ($r = -0.967$ at $P < 0.05$).

4.4 Population structure

4.4.1. Density and Diameter at Breast-Height (DBH)

Density of a given species is expressed as number of stems per hectare. The total density of woody species with DBH >2.5 cm in Entoto plantation including *Eucalyptus* was 3217.1 stems ha^{-1}. In the Entoto plantation, the highest density of species was recorded for *Eucalyptus* Labill., which was 2285 individuals' ha^{-1}.

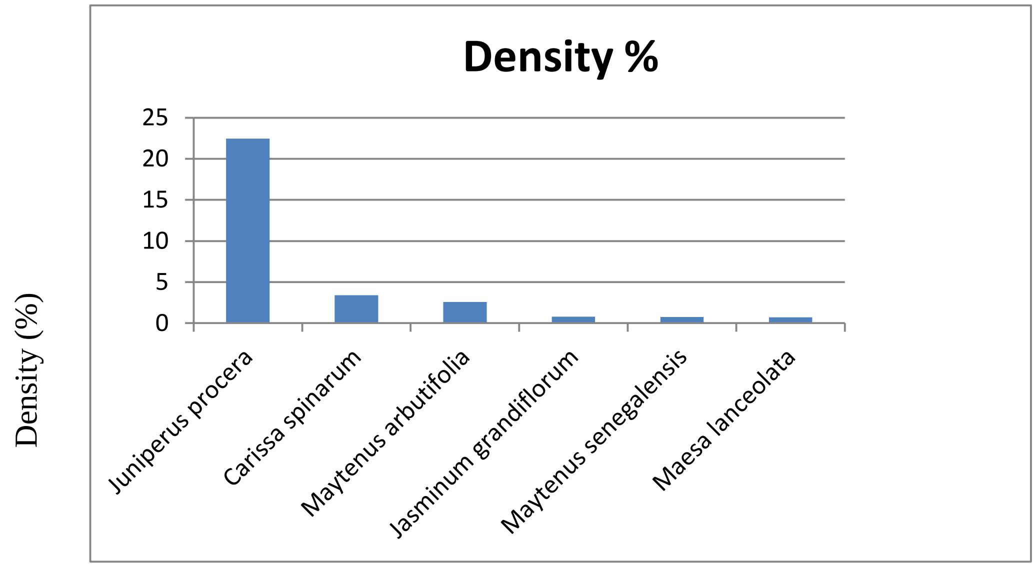


Figure 7: List of some dominant woody species

The population structure is decreasing with increasing in diameter class given below in (Table 5), indicating inverse J-shape.

The first highest density of naturally regenerated woody species was contributed by *Juniperus procera* Endl. (867.1 individuals ha^{-1}) which was followed by *Carissa spinarum* L. that makes up 17.9 individuals ha^{-1}.

The least dense species in the *Eucalyptus* plantation were *Dovyalis abyssinica* (A. Rich.) Warb, *Podocarpus falcatus* (Thunb) Mirb and *Maytenus gracilipes* (Welw.ex Oliv.) Exell. Each contributing only 0.4 individual's ha^{1}. Generally, the total density of naturally regenerated woody species was 932.1 individuals ha^{-1}.

The relationship between tree and shrub diameter and density varied among species in *Eucalyptus* plantation. In the *Eucalyptus* plantation, lower diameter class (DBH = 2.6-7.5 cm) was the dominant. The study showed that the relative density of trees and shrubs of ≤ 7.5 cm diameter constituted 72.2%.

The DBH structure of species can reveal the population dynamics. With increase in diameter class, the number of trees and shrubs decreased in the *Eucalyptus* plantation.

Based on diameter class distribution and density, the effects of plantation on the recruitment of different species can be inferred.

High density of tree and shrub species in different diameter classes means the *Eucalyptus* plantation has less impact on the undergrowth of the species, and vise versa. In the lower diameter class (2.6-7.5 cm) 14 species were recorded in *Eucalyptus* plantation. As the diameter classes increase, the number of species decreases considerably.

Trees in the higher diameter class were few (*Juniperus procera and Acacia abyssinica*) in the *Eucalyptus* plantations. However, these few large-sized trees could be remnants from the previous natural forest vegetation in the area. They were also recorded in the upper diameter class (> 42.5 cm).

Table 5: Relative density and number of species in each diameter class in the *Eucalyptus* Plantation.

Diameter Class	Relative Density, %	Number of species
1	72.2	14
2	20.8	6
3	4.4	2
4	1.3	1
5	0.5	1
6	0.2	1
7	0.2	1
8	0.2	1
9	0.2	2

Where: (1) = 2.6-7.5, (2) = 7.6-12.5, (3) = 12.6-17.5, (4) = 17.6-22.5, (5) = 22.6-27.5, (6) = 27.6-32.5, (7) = 32.6-37.5, (8) = 37.6-42.5 and (9) = >42.5 cm.

The ratio of density of individuals with DBH >10 cm to density <20 cm DBH showed the distribution of size classes (Grubb *et al.*, 1963). The densities of naturally regenerated woody species in *Eucalyptus* plantation with DBH >10 cm and DBH <20 cm were 103.3 (11.1%) and 17.9(1.9%) individuals ha^{-1}, respectively, and the ratio of the former to the latter was 5.77 (Table 5). This ratio when compared to natural forests is much greater than the ratio obtained for Jibat, Menagesha-Suba, Wof-Washa and Chilimo Afromontane forests of Ethiopia (Tamirat Bekele, 1993).

The ratio is also greater than the ratio obtained for Masha-Anderacha Afromontane forest (Kumelachew Yeshitela and Taye Bekele, 2003) and Dindin Afromontane forests of Ethiopia (Simon Shibru and Girma Balcha, 2004). More than 90% individuals of naturally regenerated woody species had height up to 10 m. About 87% of the individuals had DBH of first DBH class (2.6- 7.5 cm).

Density ratio of individuals >10 cm DBH to that of individuals >20 cm DBH showed preponderance of small-sized individuals for some species whereas comparable distribution for others in the plantation. The predominance of small-sized individuals in the Entoto *Eucalyptus* plantation was largely due to the high density of *Juniperus procera.* Generally, the very high a/b ratio in the Entoto plantation indicates the predominance of small-sized individuals; this is the result of the recent regeneration.

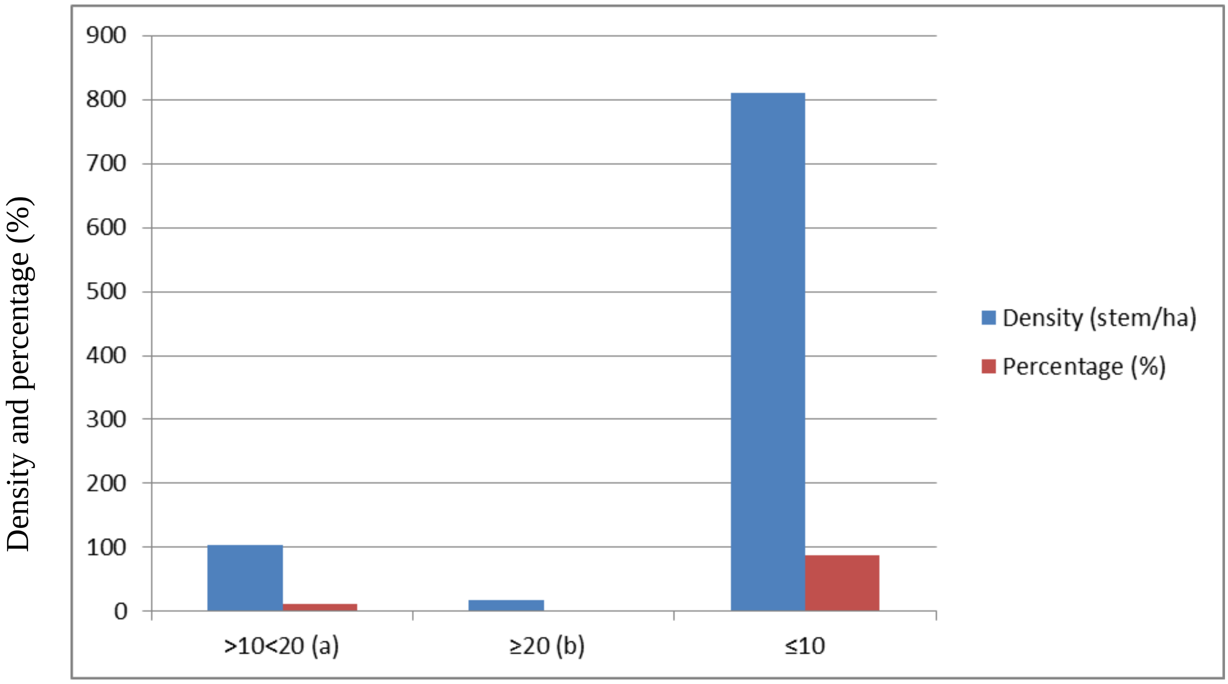


Figure 8 : Density of naturally regenerated woody species

4.4.2. Height distribution of trees and shrubs

Three canopy layers or storeys are described based on the criteria of International Union for Forestry Research Organization (IUFRO) classification scheme, which uses top tree- height to determine the vertical structure of the vegetation (Lamprecht, 1989). Accordingly, the lower storey includes all trees that are one third of the height of the uppermost tree. The upper canopy includes all trees that are more than two-thirds the height of highest tree, and the middle storey describes tree heights between one-third and two thirds of the highest tree.

In this study, the highest naturally regenerated tree species in *Eucalyptus* plantation was *Juniperus procera*, which was 22 m. This species was used to determine the different storeys. Therefore, the lower storey includes all individuals of species that are less than 7 m high, the middle storey includes all individuals that fall between 7 and 15 m, and the upper storey includes all individuals taller than 15m.

A total of 7721 individuals of all woody species have DBH >2.5 cm. Out of these 5484 individuals were *Eucalyptus* while the naturally regenerated woody species under these *Eucalyptus* plantations were 2237 individuals. The majority of naturally regenerated woody species individuals are confined to the lower canopy (89.2%), about 10.6% individuals contribute to the middle canopy while very few individuals contribute to the highest canopy (0.2%).

The ratio of stems per species is very high in the lower storey (63.9) showing the predominance of shorter high individuals of naturally regenerated woody species in the *Eucalyptus* plantations. In general, the densities of commonly regenerated woodlike class in lower, middle and upper story was establish expected 831 individual's ha-1, 99 individual's ha-1 and 2.1 individual's ha-1 respectively.

Table 4: Stem number ha^{-1}, species number and ratio of stem/ha to species number by storey.

Storey	Stem/ha	%	Specie No.	%	Ratio
Upper	2.1	0.2	1	5.3	2.1
Middle	99	10.6	5	26.3	19.8
Lower	831	89.2	13	68.4	63.9
Total	932.1	100			

4.4.3. Frequency

The frequency gives an approximate clue of the uniformity and variety of a stand. Lamprecht (1989) pointed out that high value in higher frequency and low value in lower frequency classes indicate constant or similar species composition whereas high value in lower frequency classes and low values in higher frequency classes indicate high degree of floristic heterogeneity. According to their total frequency expressed as percentage, species were grouped into the following five frequency classes: A = 81 – 100, B = 61 – 80, C = 41 – 60, D = 21 – 40, E = 0 – 20 %. Only *Juniperus procera* belongs to the frequency class A.

No other species belong to frequency class B, C and D. On the other hand, the lower frequency classes comprised all the remaining species. *Acacia abyssinica, Ekebergia capensis, Prunus africana, Premna schimperi, Dovyalis abyssinica, Podocarpus falcatus, Carissa spinarum, Maesa lanceolata, Maytenus arbutifolia, Olinia rochetiana, Maytenus gracilipes, Rosa abyssinica and Bersama abyssinica* belong to frequency class E. The most frequent naturally regenerated woody species in *Eucalyptus* plantation was *Juniperus procera* (98.3%).

In the present study high values (high number of species) were obtained in lower frequency classes whereas low values (low number of species) were obtained in higher frequency classes (Figure 6). Therefore according to the above interpretation it is possible to conclude that there exists floristic heterogeneity in the Entoto *Eucalyptus* plantation.

The species that appear in the lower frequency classes have irregular occurrence whereas those appearing in higher classes have regular horizontal distribution. A similar result was reported by Simon Shibru and Girma Balcha (2004) from Dindin natural forest.

4.4.4. Basal area

The basal area of all naturally regenerated woody species in Entoto *EucalyptusC* plantation as calculated from DBH data is found to be 4.9 m /ha. Block diagrams depicting frequency distribution of trees and shrubs among DBH classes are presented in Figure 7. Most of the naturally regenerated woody species are small sized as shown by the peak in basal area in the lowest DBH classes. Individuals that belong to higher DBH classes are few in number, but their contribution to the total basal area is significant.

The normal basal area value for virgin tropical forests in Africa is 23 – 37 m /ha (Dawkins, 1959; cited in Lamprecht, 1989). Thus the total basal area value of naturally regenerated woody species in Entoto *Eucalyptus* plantation is very low. This comparison may indicate that Entoto *Eucalyptus* plantation is composed of relatively very smaller sized naturally regenerated woody species. The basal area and density distribution of five species, selected based on the basis of a high Importance Value Index (IVI) is shown in Table 8. Among the naturally regenerated woody species most area of the sample plots were occupied by *Juniperus procera*.

Juniperus procera took the biggest share in the percentage contribution of basal area (95.16%) in this *Eucalyptus* plantation. Other large trees in this forest such as *Acacia abyssinica* (2.63%) together with *Juniperus procera* contributed 97.79% of the total basal area. *Juniperus procera* had an overriding dominance in terms of basal area and IVI. This result may indicate that *Juniperus procera* is eco-friendly and competent with *Eucalyptus.*

Few species with low density, low IVI and low frequency ranked within the top in case of basal area. An example is *Acacia abyssinica*, which could be attributed to the few but very large trees. Species with the highest basal area do not necessarily have the highest density, showing size variety among species. *Acacia abyssinica* depicted by few individuals but with high contribution to the overall basal area of the forest. *Carissa spinarum*, *Maesa lanceolata* and *Maytenus arbutifolia* were more dense than *Acacia abyssinica* but with low contribution to basal area.

Table 5: Basal area, density, IVI and frequency values for five most dominant species other than *Eucalyptus*

Species	BA/ha	Relative BA	Density	IVI	Frequency
J. procera	4.634	95.16	867.1	245.2	98.33
A. abyssinica	0.128	2.63	2.5	7	6.67
C. spinarum	0.019	0.39	17.9	8.1	10.00
M. lanceolata	0.019	0.39	4.6	4.8	6.67
M. arbutifolia	0.018	0.38	13.8	9.6	13.33

As the basal area provides a better measure of the relative importance of the species than simple stem count (Cain and Castro, 1959; cited in Tamrat Bekele, 1994), species with the largest contribution in basal area can be considered as the most important woody species in the forest. Accordingly, the most important species in Entoto *Eucalyptus* plantations were *J. procera*, *A. abyssinica*, *C. spinarum, M. lanceolata* and *M. arbutifolia*.

High density and high frequency coupled with high basal area indicate the overall dominant species of the forest (Lamprecht, 1989). Accordingly, *J. procera* was the primary dominant species in Entoto *Eucalyptus* plantation. On the other hand, high density and high frequency indicate regular horizontal distribution. *J. procera* was one of the species with such type of distribution. High density, low frequency and low dominance are typical for understory species that occur in clusters. These species include *C. spinarum*, *M. arbutifolia* and *Olinia rochetiana*. Some species with low density, low frequency and low dominance were *Dovyalis abyssinica, Podocarpus falcatus* and *Maytenus gracilipes*. Generally, these result indicated that there is a good natural regeneration of *Juniperus procera* within the *Eucalyptus* plantation.

Importance Value Index (IVI)

Importance value index combines data for three parameters (relative density, relative frequency and relative dominance). That is reason ecologists believe it as the most sensible facet in plants study (Curtis and McIntosh, 1951).They established that species with the greatest importance value are the superior dominants of the forest. It is still valuable to compare the environmental importance of species (Lamprecht, 1989).

The importance value index for naturally regenerated woody species in Entoto *Eucalyptus* plantation is shown in Table 8. *Juniperus procera* (245.2), *Maytenus arbutifolia* (9.6), *Carissa spinarum* (8.1) and *Olinia rochetiana* (7.4), all got IVI value above 7.0. They all summed up to give 270.3 IVI value (92.4%). The reason why *Juniperus procera* produced the highest IVI value is that it has the highest relative density, relative frequency and relative dominance. These results may suggest that *Eucalyptus plantation* may not have a negative effect on *Juniperus procera*. High IVI advantage signifies that the species sociological form in the society is extreme.

Table 6: The importance value index of tree and shrub species in Entoto *Eucalyptus* plantation

NO	Species	Relative Density	Relative Dominanc	Relative Frequency	IVI
		%	e %	%	
1	*Juniperus procera* Endl.	93.02	94.9	57.3	245.2
2	*Maytenus arbutifolia* (A.	1.48	0.3	7.8	9.6
3	Rich.) Wilczek *Carissa spinarum* L.	1.92	0.4	5.8	8.1
4	*Olinia rochetiana* A. Juss.	1.12	0.5	5.8	7.4
5	*Acacia abyssinica* Hochst. Ex	0.27	2.8	3.9	7.0
6	Benth *Rosa abyssinica* Lindley	0.89	0.2	5.8	6.9
7	*Maesa lanceolata* Forssk.	0.49	0.4	3.9	4.8
8	*Prunus africana* (Hook. F.)	0.31	0.3	1.9	2.5
9	Kalkm. n*Premna schimperi* Engl.	0.13	0.1	1.9	2.1
10	*Bersama abyssinica* Fresen.	0.09	0.1	1.9	2.1
11	*Ekebergia capensis* Sparrm.	0.13	0	1	1.1
12	Dovyalis abyssinica (A. Rich.)	0.04	0	1	1.0
	Warb				
13	*Podocarpus falcatus* (Thunb)	0.04	0	1	1.0
14	Mirb. *Maytenus gracilipes* (Welw. Ex	0.04	0	1	1.0
	Oliv.) Exell				

4.5. Regeneration Status of Woody species

Composition and density of seedlings and saplings would display the status of regeneration in the Entoto area. Information on the regeneration status of 41 naturally regenerated woody species occurring in Entoto *Eucalyptus* plantation is presented in Appendix 4, together with the information on population structure. A total of 39 species were represented in the seedling class, representing 32 genera and 24 families. The total seedling density of naturally regenerated woody species was 1172 individuals' ha^{-1}. The sapling class was composed of 28 species representing 25 genera and 21 families. The total sapling density of naturally regenerated woody species was 1512 individuals' ha^{-1}. A total of 14 woody species were represented in the mature tree/shrub class, representing 13 genera and 12 families. The total mature tree and shrub density was 932.1 individuals ha^{-1}.

The ratio of woody species seedlings to mature tree/shrub (1.26:1) and seedlings to saplings (0.78:1) and saplings to mature tree/shrub (1.62:1) showed the distribution of more sapling population than that of seedling and mature tree/shrub. The less seedling population compared to that of sapling population implying the perishing of most seedlings before reaching sapling stage. Seedlings are more sensitive to environmental hazards and biotic factors especially at the early stages of seedling organization. Potential causes of seedling mortality include abiotic stresses such as shade, drought and trampling, and biotic influences such as herbivory, disease or root competition (Demel Teketay, 1997). To use the regeneration analysis for priority setting, the species considered in the forest were classified into three groups based upon the seedling density ha^{-1} (Table 12).

Accordingly, those species having seedlings density ha^{-1} between 0 and 5 were grouped under class 1; others whose seedlings density ha^{-1} greater than 5 but less than 50.1 were grouped under class 2, and those species having seedlings density ha^{-1} greater than 50.1 were grouped under class 3. For the sake of preservation endeavors, those species under class 1 and class 2 are recommended to be given the maximal priority. The results showed gaps between the floristic composition of the mature stand and the regeneration.

There were most seedlings and/or saplings that lacked mature woody species. This might suggest that there was over exploitations of mature individuals. The distribution, composition and density of seedlings and saplings show the future status of the forest. Therefore, further studies and continuous monitoring of the natural regeneration in the Entoto *Eucalyptus* plantation is required, particularly the status of soil seed banks has to be investigated to know whether or not regeneration potential, other than seedlings and saplings, exist.

The plantations have been and continue to be subjected to natural and human-induced disturbances, which resulted in their degradation or complete destruction. The deficit of forest results in soil deterioration, land degradation, loss of biodiversity and depletion of ecosystems. In most of the woody plants in dry Afromontane forests the lack of persistent soil seed banks affect the formation of populations of seedlings on the forest floor (Demel and Granstrom, 1995). Conservation of this plantation site is not only restoring woody species but also rehabilitating the degraded land and allowing germination and successful growth of seedlings to mature individuals.

Table 10: List of species under regeneration status group

Regeneration Status

Class 1	Class 2	Class 3
Acacia abyssinica	*Asparagus africanus*	*Carissa spinarum*
Clutia lanceolata	*Asparagus setaceus*	*Jasminum grandiflorum*
Dovyalis abyssinica	*Bersama abyssinica*	*Juniperus procera*
Dovyalis verrucosa	*Clerododendrum* sp	*Maytenus arbutifolia*
Erica arborea	*Ekebergia capensis*	*Maytenus senegalensis*
Jasminum abyssinicum	*Jasminum stans*	*Olea europaea* subsp.
Lippia adoensis	*Laggera tomentosa*	*Cuspidate Rosa abyssinica*
Maytenus gracilipes	*Maesa lanceolata*	

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Entoto Mountain and its surrounding area are characterized by high density of naturally regenerated woody species and relatively in good state of regeneration. The potential role of Eucalyptus plantations in recovering the native tree species under their canopy has been studied comparing the cleared evergreen forests through evaluation of succession status of the tree species, modes of seed dispersal, nature of species occurrence in three regeneration stages: adult, sapling and seedling and endemism, apart from floristic richness and density. If Eucalyptus plantations are left undisturbed for a period of time, it can recover the native species, and accelerate the natural succession processes at faster rate by providing complex habitat that increases the seed movement from the surrounding forests by attracting more dispersal agents. Moreover, large spacing of over 4 m is usually used when eucalyptus trees are to be mixed with other trees species.

From the study of vegetation composition of Entoto, 68 species of plants belonging to 32 families and 55 genera were identified. Asteraceae (8 species) was the most dominant family. Out of a total of 68 plant species, 42 of them were woody plant species including *Eucalyptus globulus*. However, a total of 41 naturally regenerated woody species were recorded in Entoto *Eucalyptus globulus* plantation. The naturally regenerated woody species identified in *Eucalyptus globulus* plantation represented 33 genera and 25 families.

For the analysis of vegetation diversity and woody species density the individual *Eucalyptus* plantation stands was used to classify the plots in to three categories. These are C1 (plots with less than 64 *Eucalyptus stands*), C2 (plots consists of 64 to 82 *Eucalyptus stands*) and C3 (plots with greater than 82 *Eucalyptus stands*). Twenty plots were identified for each category. The species diversity was significantly different ($P < 0.05$) between C1 and C2, as well as between C1 and C3 while there was no significance difference between C2 and C3 of *Eucalyptus* plantations. The species richness was also significantly different ($P < 0.05$) among the three categories of *Eucalyptus* plantations. Therefore, species diversity and species richness is highest in C1 (in the lowest *Eucalyptus* stands) while species diversity and species richness is lowest in C3 (in the highest *Eucalyptus* stands). The species diversity and species richness increased with the decreasing in *Eucalyptus* stands and vice versa.

The densities of naturally regenerated woody species showed a decreasing trend with the increase in the density of *Eucalyptus* plantation and vice versa. Therefore, the density of *Eucalyptus* plantations was negatively correlated with the density of naturally regenerated woody species. The density of naturally regenerated woody species in Entoto *Eucalyptus* plantation decreased with increasing DBH and Height classes.

The Entoto *Eucalyptus* plantation is characterized by high density of naturally regenerated woody species in the lower class than in the higher. Thus, the typically regenerated woody species are in a good state of regeneration status.

Three layers were identified from the study of vertical stratification of Entoto *Eucalyptus* plantations (the upper, the middle and the lower storey). The tree in the upper layer was *Juniperus procera*. In Entoto *Eucalyptus* plantations there was high value (high number of species) in lower frequency classes and low values (low number of species) in higher frequency classes indicate high degree of floristic heterogeneity. *Juniperus procera* had an overriding dominance in terms of basal area and IVI. This result may indicate that *Juniperus procera* is eco-friendly and competent with *Eucalyptus plantations*.

The naturally regenerated woody species population structure showed different dynamics. Majority of the species have high population in the lower DBH and Height classes. Only *Juniperus procera* occurs in all DBH and Height classes showing variation in population size in Entoto *Eucalyptus* plantations. The regeneration status showed that there is a good state of regeneration in Entoto *Eucalyptus* plantations.

5.2. Recommendations

To conserve the Entoto park and its surrounding area and to improve the natural diversity and structure of church forest and to provide optimal support for development of Entoto park and its surrounding area for ecological, economical and spiritual benefits the following general recommendations were made:

- The study area provides important economic and social value to the communities living around the area, by its attraction to domestic and international tourists. To reduce the current human influence on the study area and for the future management of the area in a sustainable manner, preservation and management tasks must be immediately implemented by the responsible stakeholders such as Environmental Protection Authority, Ethiopian Biodiversity Institute, Forest Research Center, Forest, Environment and Climate Change Commission, and other institutions working on the related issues.
- Participatory management programmes should be introduced and implemented to protect locally threatened and the most economically important species from local extinction.
- Few of the species conservation focus in the area include Croton macrostachyus, Ficus sur, Ficus vasta, Olea europaea L. subsp. cuspidata, Hagenia abyssinica, Podocarpus falcatus, and Prunus africana. Raising public awareness on the use, conservation, and management of plant resources and vegetation is very important through extension programmes.
- Moreover, it is highly required by the responsible bodies to explore indigenous knowledge and other ethnobotanical matters on the diverse uses of plant resources to promote the sustainable use of the plant resources around Mount Entoto and the surroundings of Addis Ababa City.This research result gives a clue for further investigation to have a full picture on the interaction between *Eucalyptus and* naturally regenerated woody species. Therefore, to conserve naturally regenerated woody species in *Eucalyptus* plantations appropriate management strategy is vital. For example, Silvicultural practices such as thinning in densely *Eucalyptus* plantations should be practiced to allow light to reach the ground and to encourage natural regeneration of woody species.

- Conservation and management activities should be immediately implemented to protect the most threatened and the most economically important species like, *Podocarpus falcutus*, from its local extinction.

- It would be advisable to initiate further research related to the allelopathic effects of more and less dense of *Eucalyptus* plantations of the naturally regenerated woody species.

- To decide an optimum number of *Eucalyptus* plantation per unit area spacing research has to be initiated.

- The status of soil seed bank has to be investigated to know whether or not regeneration potential, other than seedlings and saplings, exist.

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APPENDICES

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

No.	Family	Number of species	Proportion (%)
GE 01	Asteraceae	8	11.8
GE 02	Fabaceae	6	8.8
GE 03	Lamiaceae	5	7.4
GE 04	Oleaceae	4	5.9
GE 05	Poaceae	4	5.9
GE 06	Rosaceae	4	5.9
GE 07	Rubiaceae	4	5.9
GE 08	Celastraceae	3	4.4
GE 09	Flacourtiaceae	3	4.4
GE 10	Acanthaceae	2	2.9
GE 11	Asparagaceae	2	2.9
GE 12	Myrsinaceae	2	2.9
GE 13	Verbenaceae	2	2.9
GE 14	Other families	19	27.9
	Total	68	100

Appendix 2: List of woody species, families and density recorded from Entoto Mountain.

No.	Botanical Name	Family	Density %
1	*Acacia abyssinica* Hochst. ex Benth	Fabaceae	0.34
2	*Asparagus africanus* Lam.	Asparagaceae	0.35
3	*Asparagus setaceus* (Kunth) Jessop	Asparagaceae	0.32
4	*Bersama abyssinica* Fresen.	Melianthaceae	0.56
5	*Carissa spinarum* L.	Apocynaceae	3.41
6	*Clerododendrum* sp	Verbenaceae	0.11
7	*Clutia lanceolata* Forssk	Euphorbiaceae	0.06
8	*Dovyalis abyssinica* (A. Rich.) Warb	Flacourtiaceae	0.04
9	*Dovyalis verrucosa* (Hochst.) Warb.	Flacourtiaceae	0.06
10	*Ekebergia capensis* Sparrm.	Meliaceae	0.42
11	*Erica arborea* L.	Ericaceae	0.04
12	*Eucalyptus* Labill.	Myrtaceae	55.49
13	*Jasminum abyssinicum* Hochest. ex Dc.	Oleaceae	0.03
14	*Jasminum grandiflorum* L. subsp.*floribundum* (R. Br. ex Fresen.) P. S. Green	Oleaceae	0.81
15	*Jasminum stans* Pax	Oleaceae	0.12
16	*Juniperus procera* Endl.	Cupressaceae	22.46
17	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	0.15
18	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	0.09
19	*Maesa lanceolata* Forssk.	Myrsinaceae	0.73
20	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	2.58
21	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	Celastraceae	0.07
22	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	0.77
23	*Myrsine africana* L.	Myrsinaceae	0.62
24	*Nuxia congesta* R. Br. ex Fresen	Loganiaceae	0.07

Appendix 3a: Density/ha of *Eucalyptus* plantations and naturally regenerated woody species in category 1

Releve No.	Altitudes	*Eucalyptus* stands	Naturally Regenerated Woody Species
6	2915	52.9	25.0
8	2866	57.9	65.8
13	2743	21.7	55.8
16	2811	57.9	17.9
17	2894	55.4	21.3
20	2851	42.1	24.6
23	2775	57.5	68.8
28	2719	41.3	77.9
29	2709	60.4	63.3
30	2762	54.2	83.3
31	2808	41.3	81.3
34	2745	17.1	52.9
35	2753	57.1	60.8

Releve No.	Altitudes	*Eucalyptus* stands	Naturally Regenerated Woody Species
37	2608	47.5	80.8
39	2731	54.6	53.3
47	2705	62.9	165.4
48	2657	47.9	95.4
55	2708	31.7	60.8
59	2739	40.4	60.0
60	2751	63.8	76.3
Total		965.4	1290.8

Appendix 3b: Density/ha of *Eucalyptus* plantations and naturally regenerated woody species in category 2.

Releve No.	Altitudes	*Eucalyptus* stands	Naturally Regenerated Woody Species
1	2750	68.3	47.5
2	2767	78.3	45.4
3	2824	68.3	30.8
4	2876	67.5	10.0
9	2846	82.5	63.8
10	2788	64.6	45.4
11	2740	77.5	53.8
14	2723	66.3	37.9
22	2805	72.1	65.0
24	2693	82.1	104.2
25	2728	64.2	117.5
26	2738	70.8	32.9
27	2758	65.4	71.3
32	2833	65.8	48.8
36	2713	75.8	60.0
38	2685	65.0	113.8
40	2833	73.3	82.9
46	2776	67.1	73.3
49	2596	69.2	72.1
52	2832	67.1	82.5
Total		1411.3	1258.8

Appendix 3c: Density/ha of *Eucalyptus* plantations and naturally regenerated woody species in category 3.

Releve No.	Altitudes	*Eucalyptus* stands	Naturally Regenerated Woody Species
5	2878	92.1	22.9
7	2923	83.3	40.0
12	2725	109.2	25.8
15	2728	98.8	45.0
18	2928	105.4	12.5
19	2956	116.7	26.3
21	2776	95.4	61.3
33	2811	171.3	30.8
41	2863	97.1	74.2
42	2821	90.4	69.6
43	2796	87.1	120.0
44	2814	85.0	68.8
45	2804	83.8	80.0
50	2657	144.6	77.9
51	2743	94.2	86.7
53	2789	110.4	50.8
54	2745	87.5	58.8
56	2672	119.6	42.1
57	2701	161.7	38.8
58	2718	97.5	33.8
Total		2130.8	1065.8

Appendix 4: Regeneration Status of Woody species: Density/ha of Seedlings, Saplings and Mature tree/shrubs in Entoto *Eucalyptus* plantations.

No.	Botanical Name	Seedlings	Saplings	Tree/Shrub
1	*Acacia abyssinica* Hochst. ex Benth	5.0	20.4	2.5
2	*Asparagus africanus* Lam.	28.8	0.0	0.0
3	*Asparagus setaceus* (Kunth) Jessop	25.8	0.0	0.0
4	*Bersama abyssinica* Fresen.	20.8	23.8	0.8
5	*Carissa spinarum* L.	100.4	158.3	17.9
6	*Clerodendrum* sp.	9.2	0.0	0.0
7	*Clutia lanceolata* Forssk	0.0	5.0	0.0
8	*Dovyalis abyssinica* (A. Rich.) Warb	0.8	1.7	0.4

No.	Botanical Name	Seedlings	Saplings	Tree/Shrub
9	*Dovyalis verrucosa* (Hochst.) Warb.	2.1	2.9	0.0
10	*Ekebergia capensis* Sparrm.	15.4	17.1	1.3
11	*Erica arborea* L.	2.9	0.0	0.0
12	*Jasminum abyssinicum* Hochest. ex Dc.	2.1	0.0	0.0
13	*Jasminum grandiflorum* L. subsp. *floribundum* (R. Br. ex Fresen.) P. S. Green	61.3	4.6	0.0
14	*Jasminum stans* Pax	10.0	0.0	0.0
15	*Juniperus procera* Endl.	234.6	722.9	867.1
16	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	8.8	3.3	0.0
17	*Lippia adoensis* Hochst. ex Walp.	4.2	3.3	0.0
18	*Maesa lanceolata* Forssk.	25.4	29.2	4.6
19	*Maytenus arbutifolia* (A. Rich.) Wilczek	121.7	74.2	13.8
20	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	2.9	2.1	0.4
21	*Maytenus senegalensis* (Lam.) Exell	54.6	7.9	0.0
22	*Myrsine africana* L.	50.0	0.0	0.0
23	*Nuxia congesta* R. Br. ex Fresen	4.2	1.3	0.0
24	*Olea europaea* L. subsp. *cuspidate* (Wall. ex G. Don) Cif., L'Olivicoltore	63.3	0.8	0.0
25	*Olinia rochetiana* A. Juss.	45.8	69.2	10.4
26	*Osyris quadripartita* Decn.	8.8	7.5	0.0
27	*Pentas lanceolata* (Forssk) Defl.	0.0	1.7	0.0
28	*Pentas schimperiana* (A. Rich.) Vatke	5.0	0.0	0.0
29	*Podocarpus falcatus* (Thunb) Mirb.	3.8	2.9	0.4
30	*Premna schimperi* Engl.	4.2	7.9	1.3
31	*Prunus africana* (Hook. f.) Kalkm.	8.8	10.8	2.9
32	*Rhamnus staddo* A. Rich.	1.3	1.7	0.0
33	*Rhus Vulgaris* Meikle	5.0	1.7	0.0
34	*Rosa abyssinica* Lindley	198.8	320.4	8.3
35	*Rubus apetalus* Poir.	3.3	5.0	0.0
36	*Satureja imbricata* (Forssk.)	3.3	0.0	0.0

	Briq. Check			
37	*Satureja punctata* (Benth.) Briq.	8.3	0.0	0.0
38	*Scolopia theiofolia* Gilg	1.7	4.2	0.0
39	*Sida tenuicarpa* Vollesen	7.9	0.0	0.0
40	*Smilax aspera* L.	4.6	0.0	0.0
41	*Vernonia filigera* Oliv. & Hiern	7.1	0.0	0.0
	Total	1172	1512	932.1