ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ENVIRONMENTAL SCIENCE PROGRAM

Impact of *Eucalyptus globulus* Labill. (Myrtaceae) plantation on the regeneration of woody species at Entoto Mountain, Addis Ababa, Ethiopia

BY

FEKADU DEBUSHE HOMMA

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ADDIS ABABA

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List of Acronyms

a.s.l.: above sea level

ANOVA: Analysis Of Variance

Cal: Calculated

CEC: Cation Exchange Capacity

DBH: Diameter at breast height

EHT: Ethiopian Heritage Trust

EMSE: Ethiopian Meteorological Service Agency

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

ABSTRACT

This study was carried out at Entoto mountain Eucalyptus plantation, about 10 km north of the center of Addis Ababa, to assess the impact of Eucalyptus globulus Labill. plantation on the naturally regenerated woody species. Sixty plots of 400 m^2 (20 m X 20 m) size were established along a transect lines at every 300 m distance between them. Transects were laid in north–south directions at 500 m distance from each other. Seedlings, herbaceous species and soil samples were colleted from five sub-plots (4 m^2) within each major plot. A total of 68 plant species belonging to55 genera and 32 families were identified. Asteraceae (8 species) was the most dominant family. Out of a total of 68 plant species, 41 of them were naturally regenerated woody species recorded in Entoto E. globulus plantation. They represented 33 genera and 25 families. For the analysis of vegetation diversity, woody species density and soil environmental factors, the individual E. globulus plantation stands were used to classify the plots into three categories. These are C1 (plots with less than 154 E. globulus stands), C2 (plots consists of 154 to 199 E. globulus stands) and C3 (plots with greater than 199 E. globulus 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 E. globulus plantations. The species diversity and species richness increased with the decrease in E. globulus 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 E. globulus plantation and vice versa. Therefore, the density of E. globulus plantation was negatively correlated with density of naturally regenerated woody species. The study on vegetation and population structure showed that the density of tree species was high at the lower DBH class levels 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. There was no significant difference between the three categories of E. globulus plantations in their major soil nutrient contents.

1 Introduction

1.1 Background

Ethiopia is an important regional centre of biological diversity, and the flora and fauna have a rich endemic element (Sayer *et al*., 1992; WCMC, 1992). The country has the fifth largest flora in tropical Africa. The flora of Ethiopia is very heterogeneous and is estimated to include about 6000 species of higher plants, and about 10% of these are endemic (Vivero *et al*., 2005). Ethiopia's natural forest mainly consists of broad-leaved trees often mixed with conifer species such as *Juniperus procera and Podocarpus falcutus***.** The natural forests of the country particularly the *Juniperous – Podocarpus - Olea* forest around the capital city were depleted at faster rate for fuel and construction material. As a result the development of the capital city, Addis Ababa was threatened by a fuelwood scarcity. In 1895 King Menilek II introduced fifteen *Eucalyptus* species for a trial in and around the capital city to solve fuelwood shortage (Breitenbach, 1961; Davidson, 1995). The introduction of *Eucalyptus* species was a great success. Sooner or later the planting of *Eucalyptus* species for fuel, particularly, *Eucalyptus globulus* and *Eucalyptus camaldulensis* was expanding in the vicinity of Addis and other small towns in the country. *Eucalyptus globulus* (commonly called blue gum) was the most successful of the introduced *Eucalyptus* species and was quickly adopted by farmers. The reason for the widespread early popularity and success of the blue gum can be attributed to its fast growth, coppicing ability, the unpalatability of its leaves, and its adaptability to a wide range of site conditions (FAO, 1981). Although plantations have such, and many other benefits, they are widely viewed in a negative light in relation to biological diversity conservation, especially when intensive monocultures of exotic species are involved (Carnus *et al*., 2003).

Some of the criticisms associated with *Eucalyptus* species plantations are: *Eucalyptus* species are alleged to impede the establishment of other plants in their understory by out-competing them for the available soil moisture and nutrients, as well as by direct inhibition through phytotoxic exudates of its leaves and litter (Shiva and Bandyopadhyay, 1983; Poore and Fries, 1985; Florence, 1986). Furthermore, the species do not provide organic matter and depletes soil nutrients needed by agricultural crops, depletes water resources and competes with agricultural crops and suppresses ground vegetation and resulting unsuitability to soil erosion control. The leaves of *Eucalyptus* species are not palatable and cannot be used as fodder species, and finally people raise issues related with its allelopathic effect (Jagger and Pender, 2000).

In contrast to this view, the *E. globulus* understory has been found to have a high herbaceous species richness and biomass in the Ethiopian highlands and, moreover, naturally regenerated woody species have also been found in these plantations (Holgen and Svensson, 1990; Pohjonen and Pukkala, 1990; Michelsen *et al.*, 1996). Plantations can have also a catalytic effect on the regeneration of some species and can be used as a management tool for restoration of degraded lands (Lugo, 1997; Yitebtu Moges, 1998; Engelmark, 2001; Eshetu Yirdaw, 2002; Feyera Senbeta *et al*., 2002; Mulugeta Lemenih and Demel Teketay, 2004; Mulugeta Lemenih *et al*., 2004). Recent research on tropical forest plantations indicates that plantations may enhance the recruitment, establishment and succession of native woody species by functioning as foster ecosystems (Parrotta, 1992 & 1995; Lugo *et al*., 1993; Geldenhuys, 1997; Otsamo, 2000).

The controversy over the impacts of *Eucalyptus globulus* plantation on the regeneration of woody species is considered to be a serious barrier to take any feasible biodiversity management measures in the study area. Therefore, the study area is dominated by *Eucalyptus globulus* plantation and the distribution of *Eucalyptus globulus* plantation expanding from time to time while woody species becoming slow and land covered by naturally regenerated woody species is not promising. Despite this fact however, great emphasis will be given to assess the impact of *Eucalyptus globulus* plantations on the regeneration of woody species. Furthermore, this study will contribute to the decision on the conservation, use and management of biodiversity for the improvement of the livelihood of the local people and the nation at large.

1.2 Objectives of the Study

1.2.1 General Objective

The general objective of this research is: To assess the impact of *Eucalyptus globulus* plantations on the regeneration of woody species at Entoto Mountain, Addis Ababa, Ethiopia.

1.2.2 Specific Objectives

The specific objectives of the study are:

- To identify the vegetation composition of the study area;
- To compare species diversity, species richness and evenness under various categories of *Eucalyptus globulus* plantations of the study area;
- To assess the condition of vegetation and population structures of naturally regenerated woody species under *Eucalyptus globulus* plantation;
- To assess the current regeneration status of woody species under *Eucalyptus globulus* plantation;
- To determine the chemical properties of soil under various categories of *Eucalyptus globulus* plantations.

1.2.3 Research questions

1. What will be the impact of *Eucalyptus globulus* plantations on the regeneration of woody species?
2. What will be the current vegetation composition of the study area?
3. What will be the current condition of vegetation and population structures of naturally regenerated woody species under *Eucalyptus globulus* plantation?
4. What will be species diversity; species richness and evenness under various categories of *Eucalyptus globulus* plantations of the study area?
5. What will be the current regeneration status of woody species under *Eucalyptus globulus* plantation of the study area?
6. What will be the chemical properties of soil under various categories of *Eucalyptus globulus* plantations?

2 Review of Literature

2.1 *Eucalyptus* plantation 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 globulus*, 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 globulus*, *Eucalyptus camaldulensis*, *Cupressus lusitanica*, *Casuarina cunninghamiana*, *Pinus patula* and *Pinus radiata*. Nevertheless, forest plantations in Ethiopia are predominantly monocultures of *E. globulus*, 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.

2.2 *Eucalyptus globulus* plantation and naturally regenerated woody species

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 & 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 (*E. globulus, 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 (*E. globulus, 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 *E. globulus, 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.

2.3 Ecological Impacts of *Eucalyptus globulus*

2.3.1 *Eucalyptus globulus* 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 *E. globulus* (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 *E. globulus* 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 *E. globulus* 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 *E. globulus* and *J. procera* plantations. The four sites differed with respect to the rate of nutrient release from decomposing litter. The *E. globulus* 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 (*E. globulus, 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.

2.3.2 *Eucalyptus globulus* 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 m^3/ha/yr without drawing on water reserves (rainfall only) compared to 16.4, 16, 12.4 m^3/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 itself (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).

2.3.3 *Eucalyptus globulus* 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. The *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 *E. globulus* 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, E. globulus*, 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, E. globulus, 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 *E. globulus* 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 *E. globulus* 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.

3 Description of the Study Area

3.1 Geographical location

The study was conducted in Entoto-mountain range about 10 km north of the center of Addis Ababa between latitudes 9º04' to 9º05' N and longitudes 38º43' to 38º47' E. Entoto is located on the so-called Central plateau of Ethiopia. The altitude range in the study area is between 2596 and 2956 m a.s.l (Figure 1).

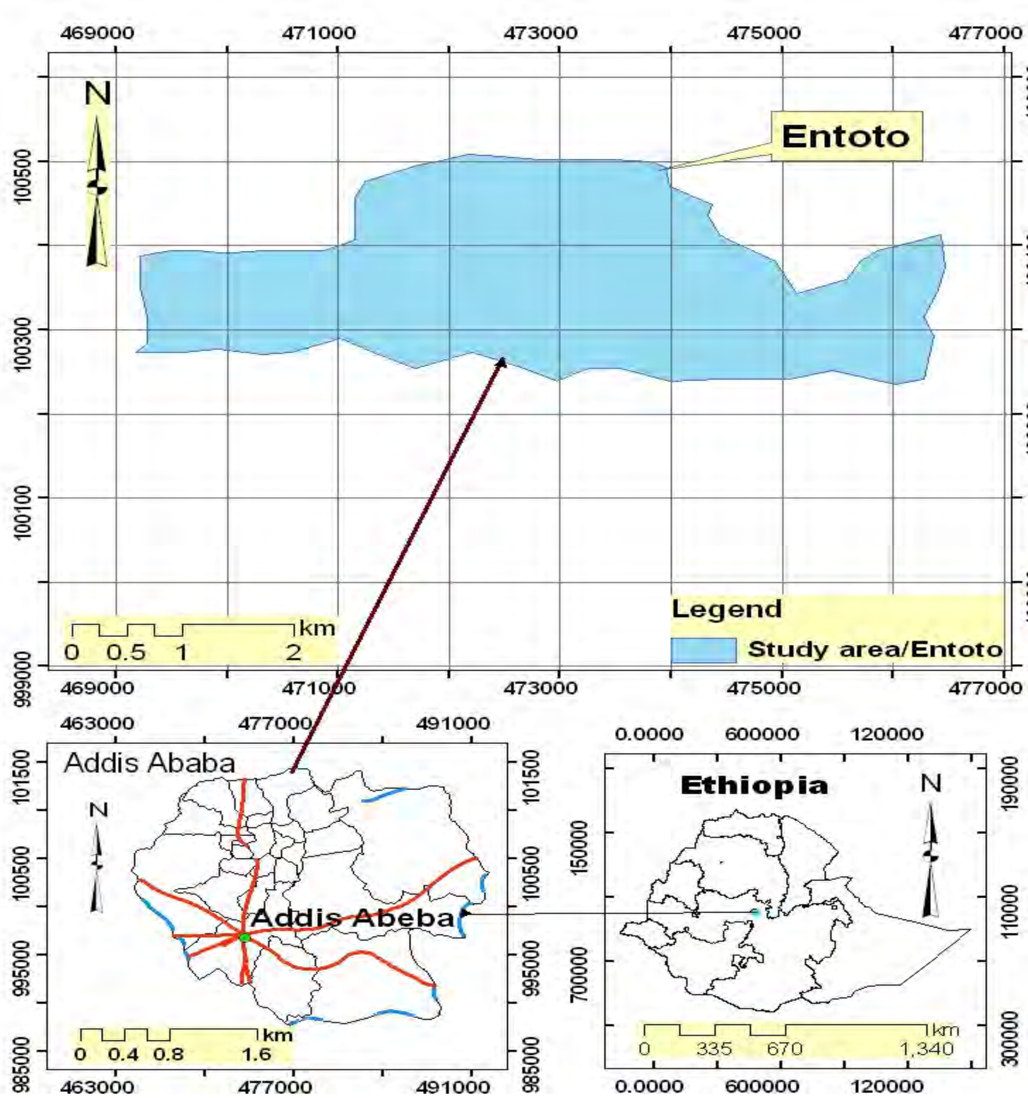

Figure 1: Map of the study area in the central highlands of Ethiopia within the city of Addis Ababa Administration

3.2 Geology and Soils

The basement upon which all the younger formations were deposited contains the oldest rocks in the country, the Precambrian, with ages of over 600 million years. The Precambrian contains a wide variety of sedimentary, volcanic and intrusive rocks, which have been metamorphosed to varying degrees. The younger geology of the study sites basically consists of Tertiary volcanic deposits formed from volcanic activity during the Cenozoic era some 11-71 million years ago. The typical catena in the mountain of Entoto is characterized by Nitisols at higher altitude. Further down the hills Cambisols have been formed from deposits of erosion material from the higher altitude Nitisols. Furthest down the mountain, and in depressions, Vertisols have been formed from the finest erosion material. All these soils are considered fertile. The color is blackish brown due to a high content of basalt, a rock type that generally has a considerable weathering potential (Tobias, 2004).

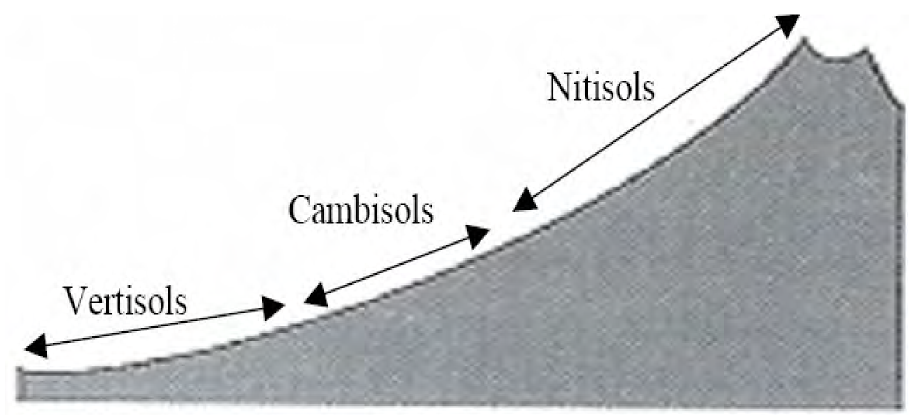

Figure 2: The typical catena at the study-site (Mt. Entoto)
Source: (Tobias, 2004)

Large areas at the study-site show severe erosion where the soil has been washed away and the bare bedrock is exposed. Sheep and cattle heavily graze the forest floor and their hoofs destroy the grass roots, which in combination with heavy rain showers during the rain season and dry topsoil the rest of the year, leads to a high risk of increased erosion.

3.3 Climate

Rainfall data and temperature data (1989-2004), collected by the Ethiopian Meteorological Service Agency (EMSA) from Entoto Station, at the boundary of the forest, was used to describe the climate of the area. Analysis of the meteorological data result showed that the mean annual temperature of the study area is about 13.1^{0}C, ranging from a mean minimum of 8.2^{0}C to mean maximum of 18^{0}C. The hottest month is May (mean maximum 20.1^{0}C) while the coldest month is December (mean minimum 7.0 ^{0}C). The mean annual rainfall of the area is 1233.1 mm year $^{-1}$. Generally, the study area has a bimodal type of rainy seasons. The short rainy season extends from March to May, and the long rainy season ranges from July to September. Most of the rain comes in July and August (Figure 3).

Entoto 2773 m 13.1 ^{0}C 1233.1 mm

[16]

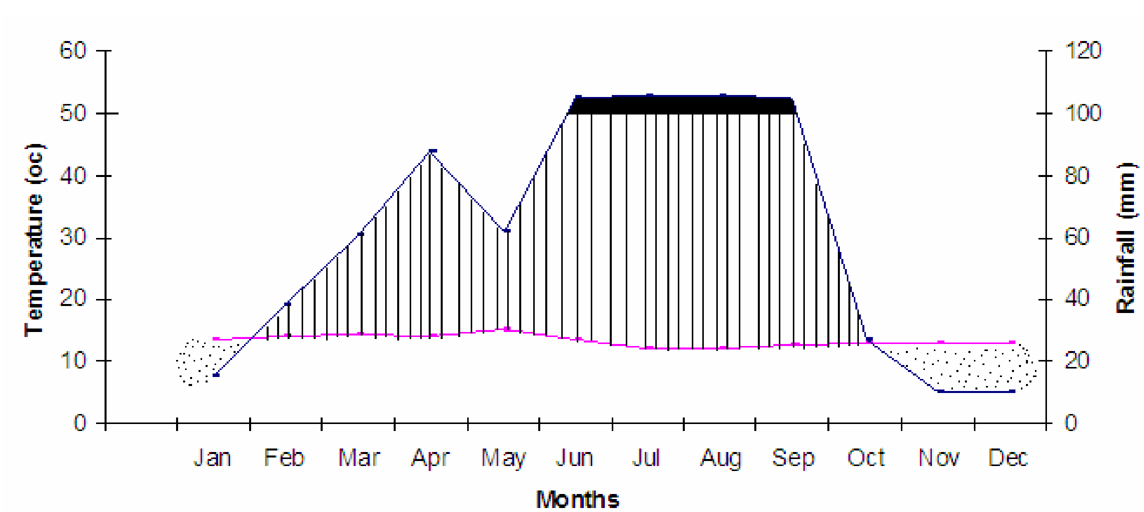

Figure 3: Climadiagram of Entoto Mountain depending on 16 years data (1989-2004) from Ethiopian Meteorological Service Agency (EMSA), dry periods are dotted and wet periods are blackened

3.4 Vegetation

The large area of Entoto, where the study area is located belongs to the Afromontane forest belt in the central highlands of Ethiopia. Formerly, indigenous trees such as *Juniperus procera*, *Olea europea* subsp. *cuspidata*, and *Podocarpus falcautus* were dominantly covering the 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 most dominating species in the area is *Eucalyptus globulus*.

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

4 Materials and Methods

4.1 Reconnaissance Survey

A reconnaissance survey was made from April 1–7, 2008 (one week before the actual data collection) to obtain information on the general vegetation patterns of the study area. The data collection was conducted from April 8–May 8, 2008. The study area was selected for data collection in Entoto *Eucalyptus globulus* plantation.

4.2 Sampling Design

In this study a systematic sampling design was used to collect data on vegetation and environmental variables. A total of 60 relevés of size 20 m x 20 m (400 m^2) were systematically laid in north–south directions using Compass and the distance between consecutive plots along the transect line was 300 m. Thirteen transects were laid at 500 m distance from each other. For the collection of herbaceous species, subplots of 2 m x 2 m (4 m^2) at the four corners and the center of the large relevé were laid. These subplots were also used for seedling count and collection of composite soil samples.

4.2.1 Vegetation 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 Department 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.

4.2.2 Environmental Data collection

Soil samples were collected with a soil auger from the top 1-30 cm depth in each of the subplots and mixed to make a composite and representative sample for each plot independently. The soil samples were bulked, air-dried and sieved (0.2 mm mesh) for laboratory analyses. Chemical analysis independently for each plot made in the Soil Laboratory of Water Works Design and Supervision Enterprise (WWDSE). The pH was measured with pH meter, Soil moisture (using hydrometer method), Exchangeable bases; Ca, Mg (using Volumetric method), K, Na & CEC (using Instrumental Finishing method), Nitrogen (following Kjeldahl method), organic carbon (Walkey and Black's titration method), available K (following ammonium acetate extraction method) and available phosphorus (following Olsen *et al.,* 1954) were determined in the laboratory. In each major plot altitude and geographical positions in degrees were taken using GPS (Global Position System). A Compass was also used for the alignment of transects.

4.3 Vegetation Data Analysis

4.3.1 Plant diversity analysis

For the analysis of vegetation diversity, woody species density and soil environmental factors the individual *Eucalyptus globulus* plantation stands were used to classify the plots in to three categories. These are C1 (plots with less than 154 *E. globulus* stands), C2 (plots consists of 154 to 199 *E. globulus* stands) and C3 (plots with greater than 199 *E. globulus* stands). 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 widely used approaches in measuring the diversity of species. The Shannon-Wiener Diversity Index (H') was computed using the following formula and the result was cross checked by using PC-ORD Version 4.20 Statistical Software Package (McCune and Mefford, 1999).

$$H = -\sum (Pi \ln Pi)$$

Where "H" is the Shannon and Wiener diversity index,

"Pi" is the ratio of a species average to the total species average and

"ln" is the natural logarism to base e ($\log_e$).

$$J = H/Hmax,$$

Where "J" is the species evenness,

"H" Shannon and Wiener diversity index and

"Hmax" is lnS, where S is the number of species.

Moreover, One-way ANOVA and LSD (Least Significant Difference) test was used to compare the species diversity (H') and species richness of each plot in the C1, C2 and C3 categories of *Eucalyptus globulus* plantation. Each major plot diversity index (H') and species richness of the three categories was considered as a replication. Similarity in species composition among the *Eucalyptus globulus* plantation categories was computed using Sorensen similarity index. It is used to measure similarities among three categories. Sorensen's coefficient is calculated using the following formula. The coefficient values range from 0 (complete dissimilarity) to 1 (total similarity) (Kent and Coker, 1992).

$$SC = 2a / (2a + b + c)$$

Where a = number of species common to both categories,

b = number of species present in the first category and absent from the second and,

c = number of species present in the second category and absent from the first.

SPSS (2007) Version 15.0, computer program was used for calculating Pearson Correlation Coefficient between species diversity, species richness and environmental factors and also to see the correlation between the density of *Eucalyptus globulus* plantation and the density of naturally regenerated woody species.

4.3.2 Structural data analysis

The tree/shrub 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 DBH and basal area.

$$\text{Basal area} = (\text{DBH}/2)^2 \times 3.14$$

Density: Density is defined as the number of plants 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 frequency of quadrats occupied by a given species. It is calculated with this formula:

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

The frequencies of the tree/shrub species in all the 60 relevés were computed. The higher the frequency, the more important 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:

$$R.F = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

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 useful to compare the ecological significance of species (Lamprecht, 1989). From the data, the tree and shrub population structure of the naturally regenerated woody species under *Eucalyptus globulus* 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 globulus* plantation.

4.4 Environmental data analysis

The numeric data of the soil were analyzed using statistical SPSS (2007) Version 15.0 software program. One-way ANOVA was used and mean differences were compared by LSD test at the same level of probability.

5 Results and Discussion

5.1 Vegetation Composition

A total of 68 plant species were recorded which belong to 55 genera and 32 families (see Appendix 1). 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. 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 (Table 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.

Table 1: List of family, number of species and proportion (%) in Entoto *Eucalyptus globulus* plantation.

Family	**Number of species**	**Proportion (%)**
Asteraceae	8	11.8
Fabaceae	6	8.8
Lamiaceae	5	7.4
Oleaceae	4	5.9
Poaceae	4	5.9
Rosaceae	4	5.9
Rubiaceae	4	5.9
Celastraceae	3	4.4
Flacourtiaceae	3	4.4
Acanthaceae	2	2.9
Asparagaceae	2	2.9
Myrsinaceae	2	2.9
Verbenaceae	2	2.9
Other families	19	27.9
Total	68	100

5.2 Diversity and Similarity of regeneration under *Eucalyptus globulus* plantations

Shannon-Wiener diversity index, species richness and species evenness, under the three categories of *Eucalyptus globulus* 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 *E. globulus* stands (< 154 individual stands of *E. globulus*/plot or C1) exhibited the highest mean values of Shannon species diversity (3.129), species richness (61) and evenness (0.761), C2 (between 154 and 199 individual stands of *E. globulus*/plot) also exhibited 2.872 species diversity, species richness (58) and evenness (0.701) while the highest *E. globulus* stands (>199 individual stands of *E. globulus*/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 one-way ANOVA 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 *E. globulus* 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 (Table 2). Plantation stands that had high Shannon-Wiener's diversity indices contained high mean species richness. Therefore, the less dense stands of *Eucalyptus globulus* harbors more regenerated plant species than the high dense stands of *Eucalyptus globulus*. 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, other site factors such as photosynthetically active radiation (PAR) reaching forest floor could have a substantial impact on ground flora regeneration and recolonization in forest plantations.

Table 2: Shannon-Wiener diversity index (H'), species richness and species evenness, under the three categories of *Eucalyptus globulus* plantation in Entoto. Where: C1 < 154 individual stands of *E. globulus*/plot, C2 between 154 – 199 individual stands of *E. globulus*/plot and C3 > 199 individual stands of *E. globulus*/plot).

Category codes	Shannon index (H)	Species richness (S)	Evenness (E)
C1	3.129	61	0.761
C2	2.872	58	0.701
C3	2.653	45	0.697

Highest similarity index was observed between the *Eucalyptus globulus* plantation of C1 and C2. On the other hand, C2 and C3 categories of *Eucalyptus globulus* plantation showed relatively weak similarity (Table 3).

Table 3: Sorensen similarity index among the *Eucalyptus globulus* plantations in Entoto.

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

5.3 Variation in Density of regenerated Woody species in *Eucalyptus globulus* plantations

Out of a total of 68 plant species, 42 of them were woody plant species including *E. globulus*. 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 globulus* plantation. The naturally regenerated woody species identified in *Eucalyptus globulus* plantation represented 33 genera and 25 families. Out of all identified naturally regenerated woody species in *Eucalyptus globulus* 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 globulus* were (55.5%) (See appendix 2). *Eucalyptus globulus* were 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 *E. globulus* 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) recorded 37 species under *E. globulus, E. saligna, Pinus patula* and *Cupressus lusitanica* on the central highlands of Ethiopia. The number of woody species recorded in the *Eucalyptus* plantations at Chancho and Menagesha were 20 and 22 respectively (Eshetu Yirdaw, 2001). The total number of regenerated woody species at the present study site (41 species) is very close to previous reports from Jirren forest, South-Western Ethiopia (40 species) (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 globulus* plantation stands were used to classify the plots into three categories. They are C1 (plots with less than 154 individual stands of *E. globulus*), C2 (plots consists of 154 to 199 individual stands of *E. globulus*) and C3 (plots with greater than 199 individual stands of *E. globulus*). Twenty plots were identified for each category (See appendix 3). Based on this the total density of *Eucalyptus globulus* in C1, C2 and C3 were 965.4 individuals ha^{-1}, 1411.3 individuals ha^{-1} and 2130.8, individuals ha^{-1} 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 globulus*. Pearson's correlation was computed to show the strength of the relationships between the density of *Eucalyptus globulus* plantation and density of naturally regenerated woody species, which has a strong negative correlation ($r = -0.967$ at $P < 0.05$).

Figure 5: Density distribution of naturally regenerated woody species and *Eucalyptus globulus* in various categories.

5.4 Vegetation structure

5.4.1 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 globulus* was 3217.1 stems ha^{-1}. In the Entoto plantation, the highest density of species was recorded for *Eucalyptus globulus* Labill., which was 2285 individuals ha^{-1}. 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 globulus* plantation were *Dovyalis abyssinica* (A. Rich.) Warb, *Podocarpus falcatus* (Thunb) Mirb. and *Maytenus gracilipes* (Welw.ex Oliv.) Exell. each contributing only 0.4 individuals 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 globulus* plantation. In the *Eucalyptus* plantation, lower diameter class (DBH = 2.6-17.5 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 globulus* plantation (Table 4). 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 globulus* 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 globulus* 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 globulus* 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 4: Relative density and number of species in each diameter class in the *E. globulus* 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 globulus* 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.

Table 5: Density of naturally regenerated woody individuals in Entoto *Eucalyptus globulus* plantation.

DBH (cm)	Density (stem/ha)	Percentage %
> 10 < 20 (a)	103.3	11.1
≥ 20 (b)	17.9	1.9
≤ 10	810.9	87
Ratio of a to b = 5.77		

5.4.2 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 globulus* 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 globulus* while the naturally regenerated woody species under these *Eucalyptus globulus* 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 globulus* plantations. In general, the densities of naturally regenerated woody species in lower, middle and upper story was found to be 831 individuals ha^{-1}, 99 individuals ha^{-1} and 2.1 individuals ha^{-1} respectively (Table 6).

Table 6: 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			

5.4.3 Frequency

The frequency gives an approximate indication of the homogeneity and heterogeneity 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 globulus* plantation was *Juniperus procera* (98.3%).

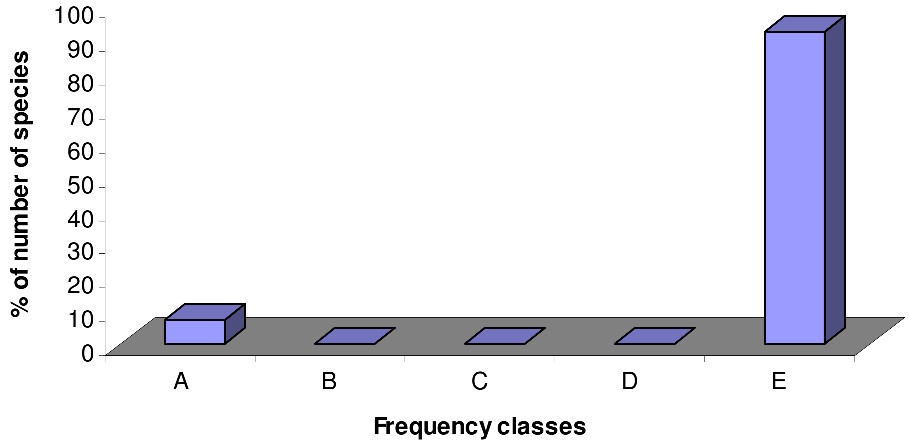

Figure 6: Frequency distribution of woody species in Entoto *Eucalyptus globulus* plantation.

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 globulus* 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.

5.4.4 Basal area

The basal area of all naturally regenerated woody species in Entoto *Eucalyptus globulus* plantation as calculated from DBH data is found to be 4.9 m^2/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^2/ha (Dawkins, 1959; cited in Lamprecht, 1989). Thus the total basal area value of naturally regenerated woody species in Entoto *Eucalyptus globulus* plantation is very low. This comparison may indicate that Entoto *Eucalyptus globulus* plantation is composed of relatively very smaller sized naturally regenerated woody species.

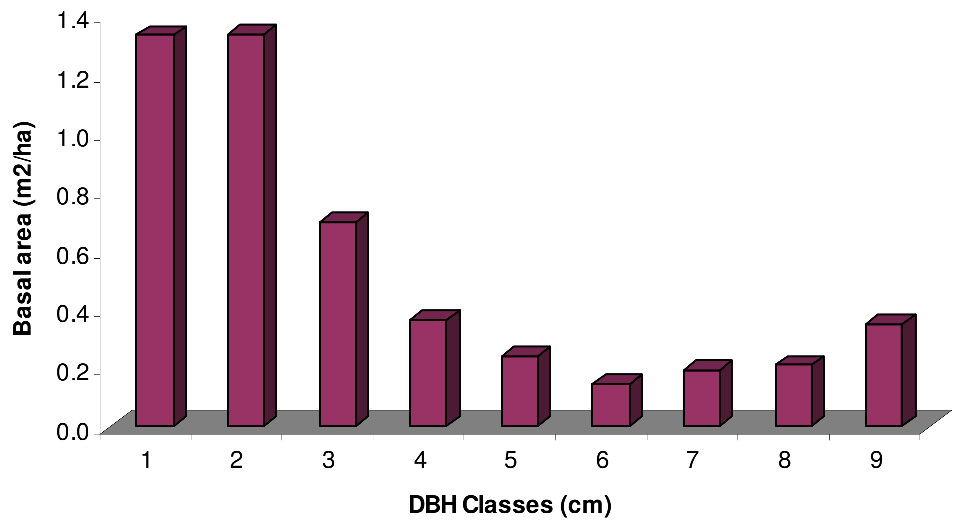

Figure 7: Basal area distribution of naturally regenerated woody species by DBH classes in Entoto *Eucalyptus globulus* plantation.

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 globulus* 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 *E. globulus.*

Some species with low density, low IVI and low frequency ranked among 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, indicating size difference between species. *Acacia abyssinica* represented 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 7).

Table 7: Basal area, density, IVI and frequency values for five most dominant species other than *Eucalyptus globulus*.

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 globulus* 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 globulus* 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 globulus* plantation.

5.4.5 Importance Value Index (IVI)

Importance value index combines data for three parameters (relative density, relative frequency and relative dominance). That is why ecologists consider it as the most realistic aspect in vegetation study (Curtis and McIntosh, 1951). They stated that species with the greatest importance value are the leading dominants of the forest. It is also useful to compare the ecological significance of species (Lamprecht, 1989). The importance value index for naturally regenerated woody species in Entoto *Eucalyptus globulus* 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 *E. globulus* plantation may not have a negative effect on *Juniperus procera*. High IVI value indicates that the species sociological structure in the community is high.

Table 8: The importance value index of tree and shrub species in Entoto *Eucalyptus globulus* plantation.

NO	Species	Relative Density %	Relative Dominance %	Relative Frequency %	IVI
1	*Juniperus procera* Endl.	93.02	94.9	57.3	245.2
2	*Maytenus arbutifolia* (A. Rich.)Wilczek	1.48	0.3	7.8	9.6
3	*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 Benth	0.27	2.8	3.9	7.0
6	*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.) Kalkm.	0.31	0.3	1.9	2.5
9	*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.) Warb	0.04	0	1	1.0
13	*Podocarpus falcatus* (Thunb) Mirb.	0.04	0	1	1.0
14	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	0.04	0	1	1.0

The IVI classes for the fourteen common naturally regenerated woody species and the list of species under each IVI conservation priority classes are presented in Tables 9 and 10 respectively. The classification of the fourteen common species under conservation priority classes revealed that 1 species and 13 species belong to class 1 and 4, respectively. None of the common species belong to class 2, 3 and 5 for both classification criteria.

Table 9: IVI classes and the number of species belonged to each class.

IVI class and value	No. of Species	Sum of IVI	Percentage
5 (<1)	0	0	0
4 (1-10)	13	54.6	18
3 (10.1-20)	0	0	0
2 (20.1-30)	0	0	0
1 (>30)	1	245.2	82

About 82% of the IVI is contributed by *Juniperus procera*. This species is abundant, frequent and dominant in the *Eucalyptus globulus* plantation. The remaining percentage was shared among the other species.

The criteria for classifying species under conservation priority placed the majority of the naturally regenerated woody species under priority class 4; this means that, although they appeared to be common species, their IVI showed highly insufficient stock in this *Eucalyptus globulus* plantation compared to *Juniperus procera*. According to this classification, those individual species falling in IVI priority class four have insufficient stocks and are recommended for conservation priority.

Table 10: List of species under each IVI priority class

Priority class				
5	4	3	2	1
Nil		Nil	Nil	
	Acacia abyssinica			*Juniperus procera*
	Bersama abyssinica			
	Carissa spinarum			
	Dovyalis abyssinica			
	Ekebergia capensis			
	Maesa lanceolata			
	Maytenus arbutifolia			
	Maytenus gracilipes			
	Olinia rochetiana			
	Podocarpus falcatus			
	Premna schimperi			
	Prunus africana			
	Rosa abyssinica			

5.5 Species population structure

The density distribution of individuals in the various size classes was not equal in Entoto *Eucalyptus globulus* plantations, but showed more or less uniform trend of decline (Figure 8). The number of individuals decreased as DBH classes increased up to the last DBH class (9^{th}). This relatively regular distribution of individuals indicated that the population structure was a reversed J-shape. The population structures of some natural forests of Ethiopia such as Chilimo, Menagesha-Suba, Wof-Washa, and Jibat have also been shown to follow the same pattern (Tamrat Bekele, 1994) and Dindin (Simon Shibru and Girma Balcha, 2004), and other forest species of Ethiopia have shown more or less uniform trend of decline and their relatively regular distribution of individuals indicated that the population structure was a reversed J-shape. However, several forests such as Masha-Anderacha (Kumelachew Yeshitela and Taye Bekele, 2003) and other forest species of Ethiopia have shown variation in their population structure; for example, some with little or no recruitment at middle or larger DBH classes implying hampered regeneration as a result of disturbance i.e. deviated from normal reversed J-shape distribution.

About 96.9% of the density was distributed in the diameter classes between 1 (2.6 cm) and 3 (17 cm), indicating the predominance of small-sized individuals in the *Eucalyptus globulus* plantation. This could be attributed to high rate of regeneration but poor recruitment in the *Eucalyptus globulus* plantation, which might have been caused by over exploitation of large-sized individuals. The presence of small-sized individuals in *Eucalyptus globulus* plantation acts as a reserve for replacing the losses of larger-sized individuals. Population structures of trees and shrubs have significant implications to their management, sustainable use, and conservation.

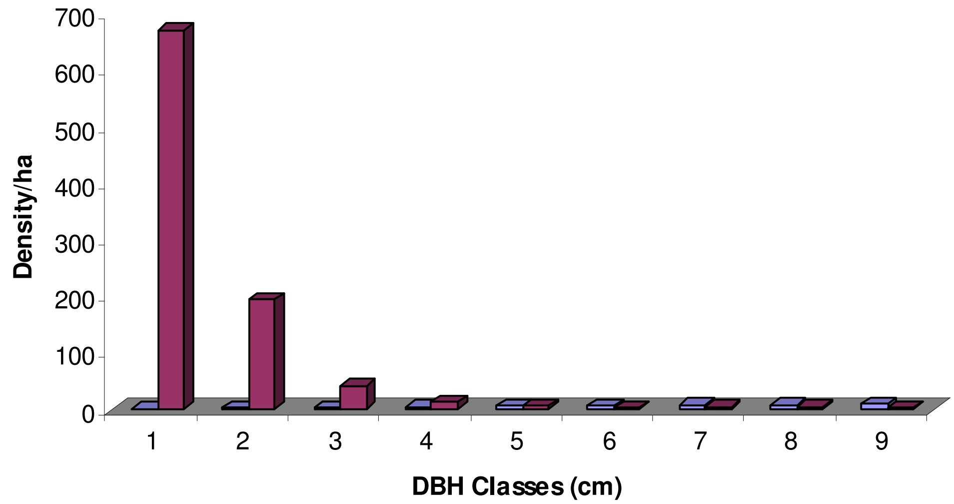

Figure 8: Tree/shrub density distribution by DBH classes in Entoto *Eucalyptus globulus* plantation; where (1) = 2.6-7.5, (2) = 7.6-12.5, (3) = 12.6-17.5, (4) = 17.6-22.5, (5) = 22.6- 27.5, (6) = 27.6-32.5, (7) = 32.6-37.5, (8) = 37.6-42.5 and (9) = > 42.5 cm.

Similar to the density distribution of DBH classes, the density distribution of height classes of trees and shrubs in Entoto *Eucalyptus globulus* plantation was not uniform (Figure 9). The number of individuals decreased as height classes increased.

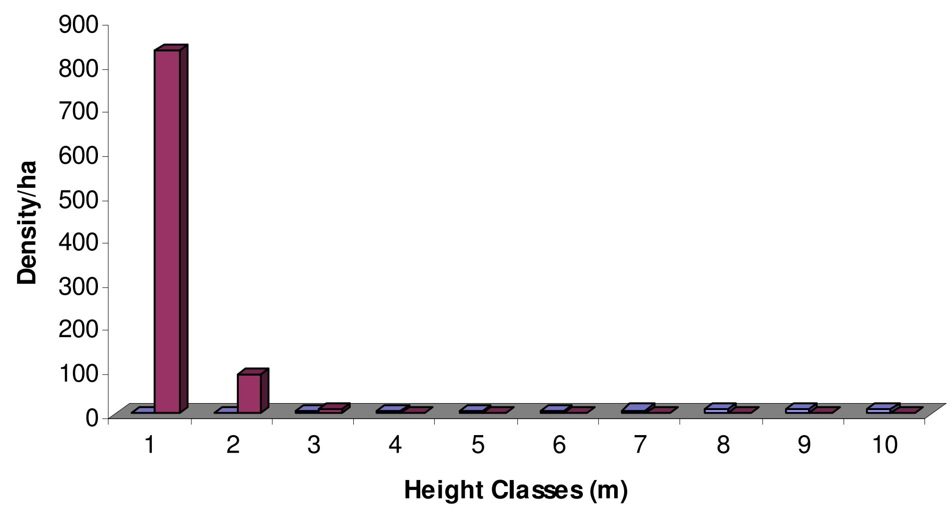

Figure 9: Tree/shrub density distribution by height classes in Entoto *Eucalyptus globulus* plantation Where: (1) = 1.5-6, (2) = 6.1-9, (3) = 9.1-12, (4) = 12.1-15, (5) = 15.1-18, (6) = 18.1-21, (7) = 21.1-24, (8) = 24.1-27, (9) = 27.1-30 and (10) = > 30 m.

Generally, four patterns of population structure of woody species occurring in Entoto *Eucalyptus globulus* plantations were analyzed. The analysis was expressed in density of individuals against the already established DBH classes. The emerging population structure of the various species could be interpreted as an indication of variation in population dynamics in the given forest (Popma *et al*., 1988). Based on the aforementioned facts, four general patterns of population structures were recognized from the selected species of the *Eucalyptus globulus* plantations.

The first pattern (Figure 10a) was formed by species with positively skewed distribution (inverted J- curve). These species had the highest density in the lower DBH classes with decrease in density towards the bigger classes, which suggests good reproduction and recruitment potential in the forest. *Juniperus procera* had such type of pattern.

The second pattern (Figure 10b) was exhibited by species with individuals represented only in the first DBH class (2.6 cm -7.5 cm). These species exhibited good reproduction but very bad recruitment. One of the possible reasons for the discontinuity in this type of structure could be the local disturbance (natural as well as human). This is particularly true for *Ekebergia capensis* Sparrm., *Podocarpus falcatus* (Thunb) Mirb., *Dovyalis abyssinica* (A. Rich.) Warb, *Carissa spinarum* L., *Maytenus arbutifolia* (A. Rich.) Wilczek, *Maytenus gracilipes* (Welw. ex Oliv.) Exell, *Rosa abyssinica* Lindley and *Bersama abyssinica* Fresen. They were highly affected by the disturbance in the plantation. On the other hand the low stocking level of mature trees and shrubs confirmed that the forest has been affected by collection of fuelwood, for household consumption, for sale and felling trees for construction poles.

The third pattern (Figure 10c) was exhibited by species with individuals well represented in the first, second and in some of them in the third DBH classes. These species exhibited very good reproduction but very poor recruitment. This pattern is exemplified by species like *Maesa lanceolata* Forssk., *Prunus africana* (Hook. F.) Kalkm., *Premna schimperi* Engl. and *Olinia rochetiana* A. Juss.

The fourth pattern (Figure 10d) is a pattern where few individuals are represented in the first, second and the last DBH classes, while being absent in the other classes. It might be possible to assume that such patterns are characterized by good reproduction, selective cutting of the medium sized individuals and poor recruitment. Only one species, *Acacia abyssinica,* belongs to this type.

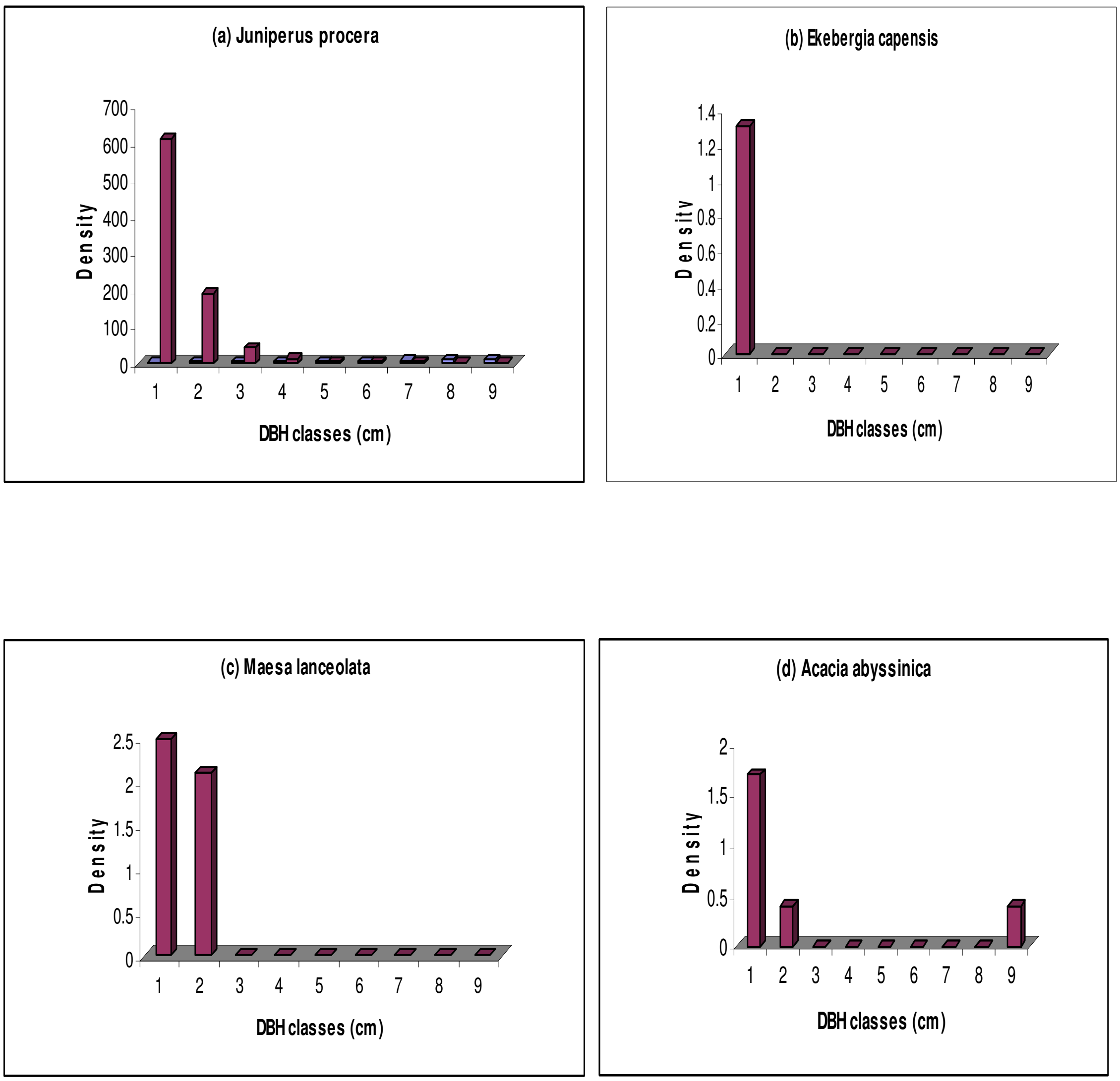

Figure 10: Representative Patterns of species population structures in Entoto *Eucalyptus globulus* plantation; where (1) = 2.6-7.5, (2) = 7.6-12.5, (3) = 12.6-17.5, (4)= 17.6-22.5, (5) = 22.6-27.5, (6) = 27.6-32.5, (7) = 32.6-37.5, (8) = 37.6-42.5 and (9) = > 42.5 cm.

Analysis of the population structure of the tree and shrub species can be summarized into two groups (Table 11). The first group includes those species whose reproduction is good but recruitment is hampered. The second group includes those species whose reproduction as well as recruitment is good. Hence, all species in the first group should accord the top priority for conservation measures.

Table 11: List of species according to population structure grouping.

Group 1	Group 2
Acacia abyssinica	*Juniperus procera*
Bersama abyssinica	
Carissa spinarum	
Dovyalis abyssinica	
Ekebergia capensis	
Maesa lanceolata	
Maytenus arbutifolia	
Maytenus gracilipes	
Olinia rochetiana	
Podocarpus falcatus	
Premna schimperi	
Prunus africana	
Rosa abyssinica	

5.6 Regeneration Status of Woody species: Composition and Density of Seedlings and Saplings

Composition and density of seedlings and saplings would indicate the status of regeneration in the study area. Information on the regeneration status of 41 naturally regenerated woody species occurring in Entoto *Eucalyptus globulus* 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 vulnerable to environmental hazards and biotic factors especially at the early stages of seedling establishment. 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 conservation endeavors, those species under class 1 and class 2 are recommended to be given the highest 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 composition, distribution and density of seedlings and saplings indicate the future status of the forest. Therefore, further studies and continuous monitoring of the natural regeneration in the Entoto *Eucalyptus globulus* 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 loss of forest results in soil erosion, land degradation, loss of biodiversity and impoverishment 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 12: 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. *cuspidata*
Lippia adoensis	*Laggera tomentosa*	*Rosa abyssinica*
Maytenus gracilipes	*Maesa lanceolata*	

Regeneration Status		
Class 1	Class 2	Class 3
Nuxia congesta	*Myrsine africana*	
Pentas lanceolata	*Olinia rochetiana*	
Pentas schimperiana	*Osyris quadripartita*	
Podocarpus falcatus	*Prunus africana*	
Premna schimperi	*Satureja punctata*	
Rhamnus staddo	*Sida tenuicarpa*	
Rhus vulgaris	*Vernonia filigera*	
Rubus apetalus		
Satureja imbricata		
Scolopia theiofolia		
Smilax aspera		

5.7 Soil Environmental Factors

Plants require nutrients in order to grow, develop and complete their life cycle. Research has shown that there are elements that are necessary for most plants to grow and develop properly. Among all these elements only nine elements are used in relatively large quantities and they are referred to as major elements or macronutrients. Carbon, hydrogen and oxygen are obtained mainly from the air and water. Three elements namely nitrogen, phosphorus and potassium are considered as the primary macronutrients because they are used in relatively large quantities by plants and are the elements most often deficient in soils; where as calcium, magnesium and sulphur are classified as secondary macronutrients. They are used in fairly large quantities by plants, but are less often deficient in soils (Poritchett & Fisher, 1987).

Very few comparative studies have been made on soil nutrient status of exotic plants plantations including *Eucalyptus* and adjacent natural forests in Ethiopia, among others Michelsen *et al.*, 1993 & 1996 and Betre Alemu, 1998. Michelsen *et al.* (1993) provided empirical evidence for soil nutrient depletion of *Cupressus lusitanica* and *E. globulus* by comparing with that of the indigenous *J. procera* and natural forest soils. The study result showed that soils of *C. lusitanica* and *E. globulus* were generally found to have the lowest nutrient content, mainly low in phosphorus and nitrogen. Michelsen *et al.* (1996) comparative study on soil fertility between plantations and adjacent natural forests in the Ethiopian highlands result showed that the soil characteristics of the natural forests differed from the plantations (*E. globulus, E. grandis, E. saligna, Cupressus lusitanica, and Pinus patula*). The overall result indicated that natural forest soil had higher content of total N, available P and exchangeable Ca than the plantation forests. Betre Alemu (1998) comparative study of soil nutrient status result revealed that plantation stands (*E. globulus, E. grandis, E. saligna, Pinus patula* and *C. lusitanica*) had significantly lower pH, total nitrogen, organic matter, exchangeable calcium and magnesium than the adjacent natural forest.

The three categories of *Eucalyptus globulus* plantations did not show any statistical significant ($P < 0.05$) impact on soil chemical properties such as moisture content, pH, exchangeable Na, exchangeable K, exchangeable Ca, exchangeable Mg, Cation exchange capacity, organic carbon, total nitrogen, available P and available K. The current study was carried out in uniform ecology and in the area where *Eucalyptus globulus* is a dominant species. This might have resulted in the soil test analysis that do not have a significant difference among the three categories of *Eucalyptus globulus* plantations. However, the soil test analysis result in this study indicated that there was mean difference in the soil chemical properties among the three categories of *E. globulus* plantations (Table 13). A study showed that when *Eucalyptus* was planted mixed with *Acacia* the concentration of N in the soil and *Eucalyptus* leaves increased (Noble and Randall, 1998). This may suggest that when there is much naturally regenerated vegetation in *E. globulus* plantation the soil fertility may not be affected.

Table 13: Mean values of soil environmental variables and three categories of *Eucalyptus globulus* plantations. Means and standard error (±SE) with the same letters are not significantly different at P = 0.05.

Parameters	Category			P in ANOVA
	C1	C2	C3	
Moisture content (%)	4.565 ± 0.204 a	4.416 ± 0.275 a	4.630 ± 0.236 a	0.813
pH (1:2.5) H_2O	4.739 ± 0.095 a	4.675 ± 0.093 a	4.510 ± 0.064 a	0.155
Exchangeable Na (meq/100gm of soil)	0.247 ± 0.014 a	0.254 ± 0.131 a	0.227 ± 0.010 a	0.297
Exchangeable K (meq/100gm of soil)	0.892 ± 0.075 a	1.073 ± 0.101 a	1.031 ± 0.731 a	0.283
Exchangeable Ca (meq/100gm of soil)	12.190 ± 1.230a	11.530 ± 1.088a	9.675 ± 0.840 a	0.232
Exchangeable Mg (meq/100gm of soil)	6.422 ± 0.959 a	5.854 ± 0.396 a	6.028 ± 0.405 a	0.815
CEC (meq/100gm of soil)	37.185 ± 2.467a	36.156 ± 3.031a	37.592 ±2.400 a	0.925
Organic Carbon (%)	3.161 ± 0.154 a	3.058 ± 0.193 a	2.988 ± 0.163 a	0.772
Total N (%)	0.223 ± 0.011 a	0.235 ± 0.011 a	0.211 ± 0.014 a	0.36
Available P (mg/kg soil)	2.874 ± 0.675 a	2.860 ± 0.399 a	4.661 ± 1.256 a	0.239
Available K (mg/kg soil)	351.885 ± 30.859 a	427.032 ± 39.911 a	420.120 ± 32.124 a	0.244

5.7.1 Environmental factors vis-à-vis species diversity and richness

The output of pearson`s correlation coefficient showed that the trend of correlation of species diversity, species richness and environmental factors (such as total N, available P, available K, exchangeable Ca and exchangeable Mg) under the three categories of *Eucalyptus globulus* plantations. Species diversity has a significant ($P < 0.05$) positive correlation with altitude ($r = 0.558$) in C1 *Eucalyptus globulus* plantation while in C2 and

C3, species diversity have a weak positive correlation with altitude. On the other hand, species richness has weak positive correlation with altitude in C1 *Eucalyptus globulus* plantation while in C2 and C3, species richness have a weak negative correlation with altitude.

The major soil nutrients for plant growth, namely, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) have no significant correlation with species diversity and species richness in the three categories of *Eucalyptus globulus* plantations. Soil pH has significant negative correlation with altitude in all categories of C1 ($r = -0.551$, at $P < 0.05$), C2 ($r = -0.462$, at $P < 0.05$) and C3 ($r = -0.600$, at $P < 0.01$). Even if there was no significance difference of pH among the three categories of *Eucalyptus globulus* plantations, there were mean value differences in soil analysis. For example, the mean values of C1, C2 and C3 were 4.739, 4.675 and 4.51 respectively. Lowest soil pH mean value indicated that relatively soil acidity was highest in C3 *Eucalyptus globulus* plantation than C1. Soil pH has an indirect effect on plant growth. Donahue *et al.* (1983) showed that nutrient solubility, organic matter decomposition and some physical properties of soil are affected by soil pH.

The soil pH decreases with increasing *Eucalyptus globulus* plantations and as a result the soil acidity increases with increasing *Eucalyptus globulus* plantations and this might affect the chemical reaction between plant roots and nutrients, the availability of nutrients in the soil for plant use, and microbial activity. These might be the possible reasons for declining of species richness and diversity within the highest *Eucalyptus globulus* plantations. Evans (1992), concluded that there is little evidence to suggest any consistent effect of tree plantation on soil acidity in the tropics. In addition to this, the increasing of *Eucalyptus globulus* plantations may increase the allelopathic effects on undergrowth vegetation diversity and species richness. 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 *E. globulus* has been attributed to the tree's allelopathic effects and impact on nutrient cycling.

The analysis of variance also showed significant (P < 0.05) difference among the three categories in relation to species richness and species diversity.

Table 24: Summary of ANOVA for species richness, diversity and altitude.

Treatments	Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Species richness	Between Groups	922.033	2	461.017	32.215	0.000
	Within Groups	815.700	57	14.311		
	Total	1737.733	59			
Species diversity	Between Groups	2.710	2	1.355	17.161	0.000
	Within Groups	4.500	57	0.079		
	Total	7.209	59			
Altitude	Between Groups	10940.933	2	5470.467	0.931	0.400
	Within Groups	334795.000	57	5873.596		
	Total	345735.933	59			

Table 15: Pearson's correlation coefficient showing the relationship of species diversity and richness with the environmental factors in category 1 *E. globulus* plantations.

	MC	pH	Na^+	K^+	Ca^{++}	Mg^{++}	CEC	OC	TN	Av. P	Av. K	Sr	Sd
MC													
pH	0.325												
Na^+	-0.181	0.045											
K^+	0.332	0.466(*)	-0.379										
Ca^{++}	0.507(*)	0.889(**)	0.084	0.470(*)									
Mg^{++}	.280	0.651(**)	-0.107	0.419	0.755(**)								
CEC	0.474(*)	0.664(**)	-0.008	0.306	0.621(**)	0.393							
OC	0.291	0.341	-0.086	0.177	0.428	0.285	0.196						
TN	-0.135	-0.274	-0.206	0.005	-0.187	-0.134	-0.193	0.243					
Av. P	0.026	-0.336	0.048	-0.464(*)	-0.327	-0.342	-0.268	-0.521(*)	0.169				
Av. K	0.249	0.358	-0.376	0.947(**)	0.352	0.303	0.233	0.073	-0.040	-0.463(*)			
Sr	-0.014	0.202	0.313	0.063	0.248	-0.162	0.043	0.202	0.064	0.086	-0.005		
Sd	-0.013	-0.162	-0.047	-0.065	-0.163	-0.388	-0.033	0.230	0.373	0.118	-0.043	0.528(*)	
Al	-0.087	-0.551(*)	0.023	-0.156	-0.516(*)	-0.362	-0.433	0.042	0.524(*)	0.358	-0.108	0.082	0.558(*)

(*) = Correlation is significant at the 0.05 level (2-tailed). (**) = Correlation is significant at the 0.01 level (2-tailed). MC = Moisture content %, pH = pH - H2O, Na^+, K^+, Ca^{++}, Mg^{++} = Exchangeable Na, K, Ca and Mg (meq/100gm of soil) respectively, CEC = Cation Exchange Capacity (meq/100 gm of soil), OC = Organic Carbon %, TN = Total N %, Av. P = Available P(mg /kg soil), Av. K = Available K(mg/kg soil), Sr = Species richness ,Sd = Species diversity and Al = Altitude.

Table 16: Pearson's correlation coefficient showing the relationship of species diversity and richness with the environmental factors in category 2 *E. globulus* plantations.

	MC	pH	Na^{+}	K^{+}	Ca^{++}	Mg^{++}	CEC	OC	TN	Av. P	Av. K	Sr	Sd
MC													
pH	0.314												
Na^{+}	0.348	0.158											
K^{+}	0.237	0.215	0.352										
Ca^{++}	0.415	0.895(**)	0.269	0.277									
Mg^{++}	0.239	-0.156	0.449(*)	0.429	-0.082								
CEC	0.296	0.544(*)	0.479(*)	0.544(*)	0.644(**)	0.344							
OC	0.286	-0.149	-0.004	0.305	-0.065	-0.052	-0.219						
TN	0.093	-0.257	0.159	0.206	-0.003	-0.103	-0.222	0.616(**)					
Av. P	-0.018	0.045	-0.284	-0.110	0.068	-0.594(**)	-0.202	0.468(*)	0.449(*)				
Av. K	0.177	0.248	0.294	0.973(**)	0.288	0.334	0.554(*)	0.289	0.148	-.104			
Sr	0.118	0.367	-0.056	-0.222	0.262	-0.351	-0.188	0.129	-0.070	.128	-0.161		
Sd	-0.151	0.221	-0.136	-0.251	0.131	-0.417	-0.156	-0.034	-0.171	.176	-0.137	0.807(*)	
Al	-0.454(*)	-0.462(*)	0.055	-0.020	-0.394	0.066	0.012	-0.068	0.119	-.080	-0.020	-0.117	0.151

(*) = Correlation is significant at the 0.05 level (2-tailed). (**) = Correlation is significant at the 0.01 level (2-tailed). MC = Moisture content %, pH = pH - H2O, Na $^{+}$, K $^{+}$, Ca $^{++}$, Mg $^{++}$ = Exchangeable Na, K, Ca and Mg (meq/100gm of soil) respectively, CEC = Cation Exchange Capacity (meq/100 gm of soil), OC = Organic Carbon %, TN = Total N %, Av. P = Available P(mg /kg soil), Av. K = Available K(mg/kg soil), Sr = Species richness ,Sd = Species diversity and Al = Altitude.

Table 17: Pearson's correlation coefficient showing the relationship of species diversity and richness with the environmental factors in category 3 *E. globulus* plantations.

	MC	pH	Na^+	K^+	Ca^{++}	Mg^{++}	CEC	OC	TN	Av. P	Av. K	Sr	Sd
MC													
pH	0.266												
Na^+	0.331	-0.292											
K^+	0.363	0.479(*)	-0.178										
Ca^{++}	0.630(**)	0.712(**)	-0.026	0.587(**)									
Mg^{++}	0.604(**)	0.750(**)	-0.082	0.535(*)	0.627(**)								
CEC	0.256	0.323	-0.169	-0.026	0.333	0.099							
OC	0.030	-0.145	0.343	0.195	-0.101	-0.009	-0.362						
TN	-0.313	-0.661(**)	0.210	-0.348	-0.549(*)	-0.685(**)	-0.302	0.446(*)					
Av. P	0.045	-0.067	0.362	0.276	0.164	-0.054	-0.634(**)	0.315	0.267				
Av. K	0.267	0.429	-0.306	0.924(**)	0.535(*)	0.410	-0.005	0.181	-0.211	0.302			
Sr	-0.075	0.390	-0.381	0.431	0.180	0.216	0.048	0.167	-0.085	-0.042	0.325		
Sd	-0.265	0.100	-0.445(*)	0.220	0.049	-0.244	0.253	-0.065	0.165	-0.146	0.213	0.783(*)	
Al	-0.434	-0.600(**)	0.370	-0.278	-0.427	-0.708(**)	-0.346	0.390	0.795(**)	0.414	-0.164	-0.204	0.022

(*) = Correlation is significant at the 0.05 level (2-tailed, (**) = Correlation is significant at the 0.01 level (2-tailed), MC = Moisture content %, pH = pH - H2O, Na^+, K^+, Ca^{++}, Mg^{++} = Exchangeable Na, K, Ca and Mg (meq/100gm of soil) respectively, CEC = Cation Exchange Capacity (meq/100 gm of soil), OC = Organic Carbon %, TN = Total N %, Av. P = Available P(mg /kg soil), Av. K = Available K(mg/kg soil), Sr = Species richness ,Sd = Species diversity and Al = Altitude.

6 Conclusion and recommendations

6.1 Conclusion

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, woody species density and soil environmental factors, the individual *Eucalyptus globulus* plantation stands was used to classify the plots in to three categories. These are C1 (plots with less than 154 *E. globulus* stands), C2 (plots consists of 154 to 199 *E. globulus* stands) and C3 (plots with greater than 199 *E. globulus* 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 globulus* plantations. The species richness was also significantly different ($P < 0.05$) among the three categories of *Eucalyptus globulus* plantations. Therefore, species diversity and species richness is highest in C1 (in the lowest *Eucalyptus globulus* stands) while species diversity and species richness is lowest in C3 (in the highest *Eucalyptus globulus* stands). The species diversity and species richness increased with the decreasing in *Eucalyptus globulus* stands and vice versa.

The densities of naturally regenerated woody species showed a decreasing trend with the increase in the density of *Eucalyptus globulus* plantation and vice versa. Therefore, the density of *Eucalyptus globulus* plantations was negatively correlated with the density of naturally regenerated woody species. The density of naturally regenerated woody species in Entoto *Eucalyptus globulus* 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 naturally regenerated woody species are in a good state of regeneration.

Three layers were identified from the study of vertical stratification of Entoto *Eucalyptus globulus* plantations (the upper, the middle and the lower storey). The tree in the upper layer was *Juniperus procera*. In Entoto *Eucalyptus globulus* 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 *E. globulus* plantations.

The naturally regenerated woody species population structure showed different dynamics. Most 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 globulus* plantations. The regeneration status showed that there is a good state of regeneration in Entoto *Eucalyptus globulus* plantations.

Contrary to arguments, regarding the nutrient depletion by *Eucalyptus globulus* plantations, there was no significant difference between the three categories of *Eucalyptus globulus* plantations in their major soil nutrient contents. Soil pH has significant negative correlation with altitude in all categories of *Eucalyptus globulus* plantations. The soil acidity increases with the increase in the density of *Eucalyptus globulus* plantations. Finally, in degraded high rainfall areas, *Eucalyptus globulus* plantations may play a role in fostering the regeneration of woody species such as *Juniperus procera.*

6.2 Recommendations

This research result gives a clue for further investigation to have a full picture on the interaction between *E. globulus* and naturally regenerated woody species. Therefore, to conserve naturally regenerated woody species in *Eucalyptus globulus* plantations appropriate management strategy is vital. For example, Silvicultural practices such as thinning in densely *Eucalyptus globulus* 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 globulus* plantations on the naturally regenerated woody species.

To decide an optimum number of *Eucalyptus globulus* 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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8 Appendices

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

No.	Botanical name	Family	Habit
1	*Acacia abyssinica* Hochst. ex Benth	Fabaceae	Tree
2	*Alchemilla pedata* A. Rich.	Rosaceae	Herb
3	*Asparagus africanus* Lam.	Asparagaceae	Shrub
4	*Asparagus setaceus* (Kunth) Jessop	Asparagaceae	Shrub
5	*Bersama abyssinica* Fresen.	Melianthaceae	T/S
6	*Carduus schimperi* Sch. Bip. ex A.Rich.	Asteraceae	Herb
7	*Carissa spinarum* L.	Apocynaceae	Shrub
8	*Clerododendrum* sp.	Verbenaceae	Shrub
9	*Clutia lanceolata* Forssk	Euphorbiaceae	Shrub
10	*Conyza pedunculata* (Oliv.) Wild.	Asteraceae	Herb
11	*Conyza pyrrhopappa* Sch. Bip. ex A. Rich	Asteraceae	Herb
12	*Crepis rueppllii* Sch. Bip	Asteraceae	Herb
13	*Cynodon* sp.	Poaceae	Herb
14	*Dichondra repens* J. R. & G. Forst.	Convolvulaceae	Herb
15	*Digitaria velutina* (Forssk.) P. Beauv.	Poaceae	Herb
16	*Dovyalis abyssinica* (A. Rich.) Warb	Flacourtiaceae	Shrub
17	*Dovyalis verrucosa* (Hochst.) Warb.	Flacourtiaceae	Shrub
18	*Dyschoriste radicans* Nees	Acanthaceae	Herb
19	*Ekebergia capensis* Sparrm.	Meliaceae	Tree
20	*Erica arborea* L.	Ericaceae	Shrub
21	*Eucalyptus globulus* Labill.	Myrtaceae	Tree
22	*Exotheca* sp.	Poaceae	Herb
23	*Helichrysum glumaceum* Dc.	Asteraceae	Herb
24	*Hypoestes forskaolii* (Vahl) R. Br.	Acanthaceae	Herb
25	*Jasminum abyssinicum* Hochest. ex Dc.	Oleaceae	Liana
26	*Jasminum grandiflorum* L. subsp. *floribundum* (R. Br. ex Fresen.) P. S. Green	Oleaceae	Liana
27	*Jasminum stans* Pax	Oleaceae	Shrub
28	*Juniperus procera* Endl.	Cupressaceae	Tree
29	*Lactuca inermis* Forssk.	Asteraceae	Herb
30	*Laggera tomentosa* (Sch. Bip. ex A. Rich.) Oliv. & Hiern	Asteraceae	Shrub

No.	Botanical name	Family	Habit
31	*Linum trigynum* L.	Linaceae	Herb
32	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Shrub
33	*Lotus corniculatus* L.	Fabaceae	Herb
34	*Maesa lanceolata* Forssk.	Myrsinaceae	T/S
35	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	T/S
36	*Maytenus gracilipes* (Welw. ex Oliv.) Exell	Celastraceae	Shrub
37	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	Shrub
38	*Myrsine africana* L.	Myrsinaceae	Shrub
39	*Nuxia congesta* R. Br. ex Fresen	Loganiaceae	T/S
40	*Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don) Cif., L'Olivicoltore	Oleaceae	Tree
41	*Olinia rochetiana* A. Juss.	Oliniaceae	T/S
42	*Osyris quadripartita* Decn.	Santalaceae	T/S
43	*Pennisetum squamulatum* Fresen.	Poaceae	Herb
44	*Pentas lanceolata* (Forssk) Defl.	Rubiaceae	Shrub
45	*Pentas schimperiana* (A. Rich.) Vatke	Rubiaceae	Shrub
46	*Podocarpus falcatus* (Thunb) Mirb.	Podocarpaceae	Tree
47	*Premna schimperi* Engl.	Lamiaceae	Shrub
48	*Prunus africana* (Hook. f.) Kalkm.	Rosaceae	Tree
49	*Rhamnus staddo* A. Rich.	Rhamnaceae	Shrub
50	*Rhus vulgaris* Meikle	Anacardiaceae	Shrub
51	*Rosa abyssinica* Lindley	Rosaceae	Shrub
52	*Rubia cordifolia* L.	Rubiaceae	Climber
53	*Rubus apetalus* Poir.	Rosaceae	Shrub
54	*Satureja abyssinica* (Benth.) Briq.	Lamiaceae	Herb
55	*Satureja imbricata* (Forssk.) Briq.	Lamiaceae	Shrub
56	*Satureja punctata* (Benth.) Briq.	Lamiaceae	Shrub
57	*Scabiosa columbaria* L.	Dipsacaceae	Herb
58	*Scolopia theiofolia* Gilg	Flacourtiaceae	Tree
59	*Sida tenuicarpa* Vollesen	Malvaceae	Shrub
60	*Smilax aspera* L.	Smilacaceae	Liana
61	*Sprmacoce sphaerostigma* (A. Rich.) Vatke	Rubiaceae	Herb
62	*Stephania abyssinica* (Dill. & A. Rich.) Walp	Menispermaceae	Herb
63	*Thymus schimperi* Ronniger	Lamiaceae	Herb
64	*Trifolium acaule* Steud. ex A. Rich.	Fabaceae	Herb

No.	Botanical name	Family	Habit
65	*Trifolium cryptopodium* Steud. ex A. Rich.	Fabaceae	Herb
66	*Trifolium rueppellianum* Fresen.	Fabaceae	Herb
67	*Trifolium semipilosum* Fresen.	Fabaceae	Herb
68	*Vernonia filigera* Oliv. & Hiern	Asteraceae	Shrub

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 globulus* 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

No.	Botanical Name	Family	Density %
25	*Olea europaea* L. subsp. *cuspidata* (Wall. ex G. Don) Cif., L'Olivicoltore	Oleaceae	0.79
26	*Olinia rochetiana* A. Juss.	Oliniaceae	1.54
27	*Osyris quadripartita* Decn.	Santalaceae	0.2
28	*Pentas lanceolata* (Forssk) Defl.	Rubiaceae	0.02
29	*Pentas schimperiana* (A. Rich.) Vatke	Rubiaceae	0.06
30	*Podocarpus falcatus* (Thunb) Mirb.	Podocarpaceae	0.09
31	*Premna schimperi* Engl.	Lamiaceae	0.16
32	*Prunus africana* (Hook. f.) Kalkm.	Rosaceae	0.28
33	*Rhamnus staddo* A. Rich.	Rhamnaceae	0.04
34	*Rhus vulgaris* Meikle	Anacardiaceae	0.08
35	*Rosa abyssinica* Lindley	Rosaceae	6.49
36	*Rubus apetalus* Poir.	Rosaceae	0.1
37	*Satureja imbricata* (Forssk.) Briq. Check	Lamiaceae	0.04
38	*Satureja punctata* (Benth.) Briq.	Lamiaceae	0.1
39	*Scolopia theiofolia* Gilg	Flacourtiaceae	0.07
40	*Sida tenuicarpa* Vollesen	Malvaceae	0.1
41	*Smilax aspera* L.	Smilacaceae	0.06
42	*Vernonia filigera* Oliv. & Hiern	Asteraceae	0.09

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

Releve No.	Altitudes	*Eucalyptus globulus* 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 globulus* 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 globulus* plantations and naturally regenerated woody species in category 2.

Releve No.	Altitudes	*Eucalyptus globulus* 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 globulus* plantations and naturally regenerated woody species in category 3.

Releve No.	Altitudes	*Eucalyptus globulus* 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 globulus* 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	*Clerododendrum* 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.) Briq. Check	3.3	0.0	0.0
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

Appendix 5: Summary of ANOVA for soil chemical properties.

Parameters	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Moisture content (%)	Between Groups	0.479	2	0.239	0.207	0.813
	Within Groups	65.743	57	1.153		
	Total	66.221	59			
pH – H_2O	Between Groups	0.560	2	0.280	1.926	0.155
	Within Groups	8.293	57	0.145		
	Total	8.853	59			
Exchangeable Na (meq/100gm of soil)	Between Groups	0.008	2	0.004	1.240	0.297
	Within Groups	0.181	57	0.003		
	Total	0.188	59			
Exchangeable K (meq/100gm of soil)	Between Groups	0.357	2	0.179	1.292	0.283
	Within Groups	7.885	57	0.138		
	Total	8.243	59			
Exchangeable Ca (meq/100gm of soil)	Between Groups	68.012	2	34.006	1.499	0.232
	Within Groups	1292.998	57	22.684		
	Total	1361.010	59			
Exchangeable Mg (meq/100gm of soil)	Between Groups	3.388	2	1.694	0.205	0.815
	Within Groups	471.397	57	8.270		
	Total	474.785	59			
CEC (meq/100gm of soil)	Between Groups	21.927	2	10.964	0.078	0.925
	Within Groups	7991.692	57	140.205		
	Total	8013.619	59			
Organic Carbon (%)	Between Groups	0.303	2	0.151	0.259	0.772
	Within Groups	33.276	57	0.584		
	Total	33.579	59			
Nitrogen (%)	Between Groups	0.006	2	0.003	1.039	0.360
	Within Groups	0.165	57	0.003		
	Total	0.171	59			
Available P (mg/kg soil)	Between Groups	42.914	2	21.457	1.467	0.239
	Within Groups	833.808	57	14.628		
	Total	876.723	59			

Parameters	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Available K (mg/kg soil)	Between Groups	69005.203	2	34502.602	1.447	0.244
	Within Groups	1359301.335	57	23847.392		
	Total	1428306.538	59			

Appendix 6: Releve characteristics and number of species in Entoto *Eucalyptus globulus* plantations.

Releve No.	Geographical location		Altitudes	No of species
1	N 09º 04.549'	E038º 44.344'	2750	21
2	N 09º 04.655'	E038º 44.360'	2767	15
3	N 09º 04.819'	E038º 44.368'	2824	14
4	N 09º 04.915'	E038º 44.346'	2876	12
5	N 09º 05.108'	E038º 44.248'	2878	8
6	N 09º 05.171'	E038º 44.113'	2915	21
7	N 09º 05.165'	E038º 44.445'	2923	11
8	N 09º 05.038'	E038º 44.472'	2866	24
9	N 09º 04.783'	E038º 44.537'	2846	14
10	N 09º 04.621'	E038º 44.576'	2788	13
11	N 09º 04.458'	E038º 44.526'	2740	11
12	N 09º 04.295'	E038º 44.468'	2725	9
13	N 09º 04.428'	E038º 44.691'	2743	19
14	N 09º 04.610'	E038º 44.776'	2723	9
15	N 09º 04.729'	E038º 44.774'	2728	9
16	N 09º 04.944'	E038º 44.669'	2811	19
17	N 09º 05.119'	E038º 44.680'	2894	23
18	N 09º 05.192'	E038º 44.686'	2928	12
19	N 09º 05.365'	E038º 45.135'	2956	9
20	N 09º 05.181'	E038º 45.146'	2851	23
21	N 09º 05.101'	E038º 45.104'	2776	19
22	N 09º 04.982'	E038º 45.090'	2805	20
23	N 09º 04.852'	E038º 45.046'	2775	28
24	N 09º 04.656'	E038º 45.032'	2693	24
25	N 09º 04.695'	E038º 45.619'	2728	20
26	N 09º 04.825'	E038º 45.641'	2738	17
27	N 09º 04.839'	E038º 45.772'	2758	24

Releve No.	Geographical location		Altitudes	No of species
28	N 09º 04.692'	E038º 45.788'	2719	27
29	N 09º 04.610'	E038º 45.920'	2709	25
30	N 09º 04.780'	E038º 45.831'	2762	27
31	N 09º 05.005'	E038º 45.830'	2808	29
32	N 09º 05.094'	E038º 45.938'	2833	16
33	N 09º 05.158'	E038º 46.165'	2811	14
34	N 09º 05.002'	E038º 46.198'	2745	22
35	N 09º 04.806'	E038º 46.186'	2753	19
36	N 09º 04.624'	E038º 46.161'	2713	15
37	N 09º 04.698'	E038º 46.534'	2608	24
38	N 09º 04.802'	E038º 46.612'	2685	19
39	N 09º 05.018'	E038º 46.709'	2731	21
40	N 09º 05.158'	E038º 46.746'	2833	22
41	N 09º 05.137'	E038º 46.922'	2863	16
42	N 09º 05.100'	E038º 47.014'	2821	18
43	N 09º 05.071'	E038º 47.110'	2796	15
44	N 09º 04.923'	E038º 47.063'	2814	14
45	N 09º 04.761'	E038º 47.007'	2804	13
46	N 09º 04.565'	E038º 47.008'	2776	13
47	N 09º 04.367'	E038º 47.004'	2705	20
48	N 09º 04.170'	E038º 47.057'	2657	19
49	N 09º 04.312'	E038º 43.196'	2596	16
50	N 09º 04.546'	E038º 43.159'	2657	17
51	N 09º 04.717'	E038º 43.152'	2743	17
52	N 09º 04.926'	E038º 43.210'	2832	20
53	N 09º 04.917'	E038º 43.437'	2789	19
54	N 09º 04.688'	E038º 43.430'	2745	16
55	N 09º 04.551'	E038º 43.495'	2708	20
56	N 09º 04.340'	E038º 43.529'	2672	14
57	N 09º 04.544'	E038º 43.778'	2701	13
58	N 09º 04.702'	E038º 43.826'	2718	7
59	N 09º 04.784'	E038º 43.874'	2739	26
60	N 09º 04.821'	E038º 43.780'	2751	23

Declaration

I, the undersigned, do hereby honestly declare to the Senate of Addis Ababa University, that the content of this thesis is my original work and it has never been submitted for any Degree in any other academic institution to fulfill a similar purpose. All sources of material used for the Thesis have been duly acknowledged.

Fekadu Debushe Homma

Signature ______________

Place and date of submission

Addis Ababa University

November 2008