June 2006

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FLORISTIC COMPOSITION AND ECOLOGICAL STUDY OF BIBITA FOREST (GURA FERDA), SOUTHWEST ETHIOPIA

BY

DEREJE DENU

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A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Biology, Botanical science stream

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June 2006

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Table of contents

List of Tables

List of Figures

List of Plates

List of Appendices

Abstract

This study was carried out at Bibita Forest (Gura Ferda), southwest Ethiopia to determine floristic composition, vegetation structure and to identify community types and to investigate the role of environmental factors in the distribution of the vegetation.

60 relevés, 20 m x 20 m at 25 m altitudinal drop along an altitudinal gradient were laid to collect the data on cover–abundance (for trees and shrubs), DBH, height, density, seedling and sapling count (for trees only). The data on herbaceous species were collected from five, 5 m x 5 m subplots laid at four corners each and one at the centre of the large relevé. Two soil samples were taken from each relevé at a depth of 0–10 cm (topsoil) and 30–50 cm (subsoil). The analysis for soil pH, % sand, % clay, % silt, and Electrical Conductivity (EC) were done.

A total of 196 plant specimens belonging to 74 families and 170 genera were identified. The five most dominant families were ***Rubiaceae*** *and* ***Asteraceae*** *(13 species each),* ***Euphorbiaceae*** *and* ***Acanthaceae*** *(9 species each) and* ***Fabaceae*** *(8 species). Out of 196 species 13 were endemic to Ethiopia.* ***Ipomoea involucrata Beauv.*** and *?* ***Harungana madagascariensis Lam. ex Poir.*** *belonging to the families Convolvulaceae and Clusiaceae respectively were found to be new records for Ethiopia. Six community types were identified at 0.65 to 0.75 dissimilarity levels and each community was named after dominant tree and/or shrub species.*

The study on vertical stratification showed that Bibita Forest(Gura Ferda) has the upper storey (above 29 m), middle storey (15–29 m) and lower storey (below 15 m). The study on vegetation and population structure showed that the density of tree species was high at the lower class levels. Density of trees greater than 2 cm DBH (ca. 777/ha), for height greater than 6 m the tree density (ca. 673/ha), basal area (ca. 70/ha), frequency of all the tree species (716/ha) and the respective IVI values for each tree species were also calculated. The comparison of Bibita Forest (Gura Ferda) with other forests in Ethiopia with respect to tree densities, percentage distribution of tree species, basal area and phytogeographical comparison was done.
Soil environmental factors such as pH of the top and subsoils, clay and sand particles of both the top and subsoils showed significant relations with altitude, species richness and diversity.

1 INTRODUCTION

The most commonly accepted definition of forests in Africa is that of Greenway (1973; cited in Friis, 1992). He defined forest as “a continuous stand of trees, which may attain a height from 10 m to 50 m or more, with crowns touching or intermingling and often interlaced with lianas”. The canopy usually consists of several distinct layers or storeys. Epiphytic plants, including orchids, ferns, and mosses are characteristic, especially in the moist montane forest type. The trees have simple or buttressed boles, and in most forests the majorities are evergreen, although semi-deciduous types also exist.

Forest ecosystems provide habitat for wildlife, fuel wood, fodder, fiber, fruit, herbal medicines, timber, and several raw materials, which are primarily used in wood-based industries.

At present tropical forest is a home for 50-90% of all organisms. The vertical stratification of the forest community influences the distribution of animal populations. Forests are ecologically important in influencing climate and maintaining global balances of carbon and atmospheric pollutants. They regulate climatic factors such as rainfall, humidity and temperature regime of a given area. They also protect the soil and landscape from wind and erosion. This clearly shows that forests have three broad functions-productive, regulative and protective.

Ethiopia is found in the horn of Africa and located between 3°24´and 14°53´ N and 32°42´ and 48°12´ E with a total area of 1,120,000 km^2 (MoA, 2000). When one considers the physical feature, it ranges from the depression at Kobar sink in Afar, which is about 110 m below sea level to the highest peak of Ras Dejen, 4620 m a.s.l. The highland plateau of Ethiopia with an altitude of above 2500 m covers 40% of the country (EFAP, 1994; Demel Teketay, 1999; Zerihun Woldu, 1999). The greatest East African Rift Valley bisects the plateau into western and eastern parts. The uplands and highlands west of the Rift Valley are collectively termed the North-Western Highlands and large massifs east of the Rift Valley termed South-Eastern Highlands (Mesfin Wolde-Mariam, 1972). A wide range of habitats that Ethiopia has is due to the different topographies of the country. The Variation of the physical features couples with other environmental factors has contributed to the different vegetation types in Ethiopia.

Different authors have made attempts to describe vegetation types in the country. Some authors such as Breitenbach (1963), Beals (1969), Wilson (1977), Friis (1992), Zerihun Woldu (1999), Friis and Sebsebe Demissew (2001) have attempted to describe vegetation types and propose conservation measures. Sebsebe Demissew (1980), Hailu Sharew (1982), Lisanework Nigatu (1987), Tamrat Bekele (1993), Teshome Sormesa (1997), Kumelachew Yeshitela (1997), Sebsebe Demissew (1998) contributed their share in the study of some of the forest patches found in different parts of the country.

In Ethiopia, forest cover has been declining steadily. The forests in Ethiopia were poorly known in the 1950's (Pichi-Sermolli, 1957). White (1970; in Friis, 1992) made a comparison of the forests of Malawi with forests else where in Africa and concluded that, the forests of Ethiopia were not perfectly known. About 35– 40% of the Ethiopia's land area was covered with high forests by the turn of 19 century (Breitenbach, 1961). EFAP (1994) indicated that 16% of the land area of Ethiopia was covered with forests in the early 1950's. This number was reported to decline to 3.1% in 1982, 2.7% in 1989 and less than 2.3% in 1990 (EFAP, 1994).

Most of the remaining forests of Ethiopia are confined to the south and southwest parts of Ethiopia, which are less accessible and/or less populated (Tilaye Nigussie, 1997; Kumelachew Yeshitela and Tamrat Bekele, 2002). Nowadays, even the remnant natural forests in these areas are continuously threatened by human activities.

There are different factors for the declining forest cover in Ethiopia at such an alarming rate. Rapid human population growth, poverty, forest clearing for cultivation, over-grazing, exploitation of forests for fuel wood and construction materials without replantation and lack of proper policy framework are some of the major factors that contribute to the loss of the entire forest resources. All these factors are inter-related and cannot be seen separately. The rapid population growth for example, leads to expansion of agricultural land, over grazing, increased exploitation of fuel wood and construction material. These in turn lead to loss of vegetation (deforestation). According to the report of EFAP (1994), one reason for the decline of Ethiopian forests is attributed to energy requirement. About 94% of the energy requirement of Ethiopia relies on biomass alone, of which trees and shrubs contribute the largest proportion (Haileleul Tebicke, 2002).

Most of the existing forest patches in Ethiopia are in a secondary state of development (Friis and Mesfin Tadesse, 1990; Tamrat Bekele, 1993). The area of closed forests cleared annually in Ethiopia is about 10,000 ha (Landon, 1996). Recent estimate indicates that between 160,000 and 200,000 hectares of natural vegetation is cleared annually (Konemund *et al.*, 2002).

The Southwestern Ethiopia is rich in remnants of natural forests, but they are disappearing at an alarming rate because of encroachment by agricultural activities and the pressure from investors. The new investment opportunities being undertaken in southwest Ethiopia are converting the few remaining moist montane forests into other land use systems such as coffee and tea plantation (Taye Bekele *et al*., 2001-02). The study on Chewaka-Utto showed that the natural forests of the area changed from 85% in 1996 to 76.3% in the year 1999 (Kumelachew Yeshitela, 2001) due to clearing of the forest for tea and *Eucalyptus* plantation. The unregulated harvesting of *Phoenix reclinata* leaves for nursery shade and the tree ferns for poles is already threatening the Chewaka-Utto forest (Kumelachew Yeshitela, 2001). Regenerating and open forests in the area are already experiencing a high degree of disturbances and may probably be cleared as construction site and for plantation (Kumelachew Yeshitela, 2001). New settlements in forests are increasing and have resulted in the conversion of forestland into agriculture and other land use systems.

Bibita Forest is part of Gura Ferda Forest which is found in southwestern Ethiopia. Gura Ferda is one of the Forest Priority Areas (FPA) in Ethiopia with total area coverage of 140,000 ha. It ranks 9^{th} among the FPA in occupying the large area of land. Gura ferda Forest is among the forests in the country, which have not been studied before. Bibita Forest, which is the concern of this study, is part of the whole Gura Ferda Forest. It is clear that any plausible conservation or management strategy needs information of the floristic composition together with ecological knowledge.

The increase in population number, the need for new settlement area and the expansion of unplanned investment for coffee and tea plantations are some of the serious threats to the southwestern Ethiopia where the remnants of natural forests are found. The trend is also seen in the study area, and cause the destruction of the natural forest in Bibita, part of Gura Ferda forst.

2. Objective of the study

2.1 General objective

The general objective of this study was to investigate the floristic composition and ecology of Bibita Forest (Gura Ferda).

2.2 Specific Objective

The specific objectives of this study were:

To determine the floristic composition of Bibita Forest (Gura Ferda)

To determine plant community types of Bibita Forest (Gura Ferda)

To investigate the vegetation structure, tree species population structure and regeneration status of Bibita Forest (Gura Ferda)

To investigate the similarity of Bibita Forest (Gura Ferda) with some other forests in Ethiopia regarding its floristic composition

To investigate the influence of some environmental factors (altitude, soil texture, pH and electrical conductivity of the soil) on species diversity and richness

3 THE STUDY AREA

3.1 Geographical location

Gura Ferda is found in the southwest part of Ethiopia at about 630 km southwest of Addis Ababa, in Bench Maji Zone of the Southern Ethiopia Nations and Nationalities People's Regional State (Fig. 1). It is located between $35^{o}00´$ to $35^{o}15´$ E and 6^{o} $45´$ to $7^{o}00´$ N (EMA, 1976). After the downfall of Derg regime, Gura Ferda was merged with other nearby areas and became part of Sheko Woreda. Most recently Gura Ferda is separated from sheko Woreda and organized on the Woreda level.

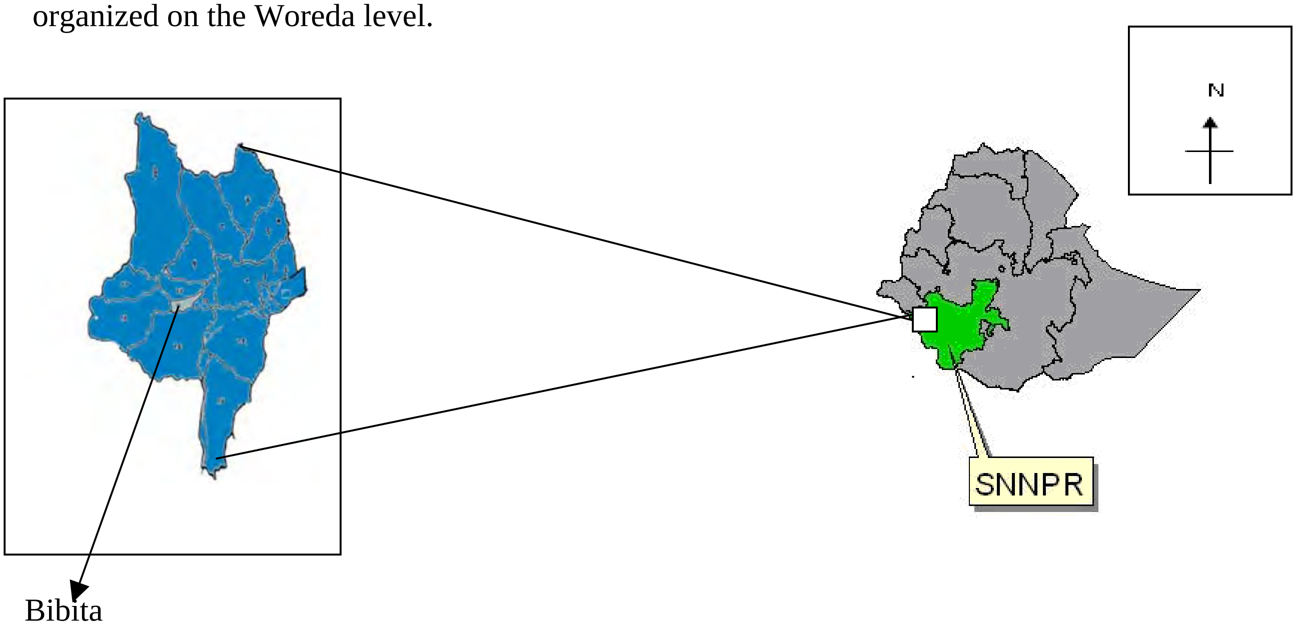


Figure 1: Location map of the study area

3.2 The people and economy

The human population of Bench Maji zone was 325,676 (CSA, 1998). The human population in Gura Ferda was estimated to be 17,325 out of which 9,056 were males and 8,319 females. The indigenous people of this Woreda are Sheko, Menit and Mejengir. Recently people from Amhara, Sidama, Gedeo and other places came to the area by planned as well as volunteer settlements. Of the total population in the Bench Maji Zone 10,308 were migrants to the area. According to the annual report of Gura Ferda Woreda (ARGW) (2006) the number of recent settlers was 2297 (1615 females and 683 males) and is increasing steadily. In the year 2006/7 the settlement site near Kuki village, found at the edge of the natural forest, has already been selected for 2000 householders.

As in most parts in the southwest highlands the cultivation of enset, yam, other tubers and coffee is practiced in the study area (Huffnagel, 1961; Westphal, 1975). According to the annual report of Bench Maji Zone (ARBMZ) (2006) the annual crops in Bench Maji Zoze occupies 199,684.55 ha, coffee and tea plantations occupy 19,770.6 ha and rangeland occupies 79,247.69 ha. The total area cultivated in Gura Ferda was 1,950 ha. The natural forest occupies 50, 0514.4 ha; bushland and savana grassland together occupy 31, 5035.14 ha of the total area of land in Bench Maji zone. The area of land with potential for the future use in cultivation is 487,466 ha and 150,000 ha of land cannot be cultivated (ARBMZ, 2006).

The traditional way of cultivation by Sheko people in Gura Ferda is rapidly changing due to adoption of crops from other parts of Ethiopia. Nowadays, farmers in the study area are changing to cash crop cultivation such as coffee. This may bring a change in the way the farmers exploit their natural environment. The people of Gura Ferda and neighboring areas (Dizis) use wild plants as a source of food. Hildebrand (2003) reported eight wild plants the people use as food (example, *Zehneria scabra)*, ten wild edible fruits (example, *Carissa spinarum* and *Manilkara butugi*), three wild oil seeds (*example, Maesa lanceolata*) and six plant species with starchy tubers (*Rumex abyssinicus*). This is clear evidence on how indigenous people depend on the natural environment without causing any harm. It is true that the farming system they utilize to produce cash crops is obviously different from the traditional ones and usually require an extended area of land for cultivation, which may be a threat to the natural forest in the area.

Gura Ferda has a high potential for honey production. Honey is an important forest product in the area and means of earning cash for Shekos living in Gura Ferda. The people know the types and values of different plants in the forest as the potential source for honey production. Hildebrand (2003) reported about 20 plant species, which are important in honey production. These are *Polyscias fulva, Vernonoa amygdalina, Cordia Africana, Croton macrostachyus* and *Gauania longispicata*. Some of these plant species show marked difference in their distribution along the altitudes. Ecological work relating altitude and distribution of vegetation has not been done so far in the study area.

The road between Mizan and Dima is poor and there is no public transport in the area. It takes at least 5 hours to walk from the main road to the first village (Bibita), which is at the edge of the forest. To travel from one village to the next it takes about 5–7 hours.

3.3 Topography

Gura Ferda massif rises from the surrounding lowland at 900 m a.s.l. to steep slopes stretching from 1750 m to 2200 m (Hildebrand, 2003). Hildebrand (2003) also reported that the massif above 2000 m has stony and rocky surfaces and between 1500 and 2000 m, somewhat stony and the soil is either loam or clay. The plains are characterized by silt and loam soils. The soils of southwestern plateau reflect the change of topography and the drop in temperature and increased rainfall associated with higher altitude. Soils, which have developed on the steep lands of escarpments and along ridges, are thin and young. The rolling terrain at altitudes between 1200 and 1800 m a.s.l., in southwestern Ethiopia favors the formation of deep, reddish well-drained soils (Hildebrand, 2003). According to Hildebrand (2003), some of the high, flat areas of Gura Ferda are poorly drained.

3.4 Climate

Southwestern part of Ethiopia is the wettest with eight rainy months that extend from March to October (Kumelachew Yeshitela and Tamrat Bekele, 2002). The annual rainfall on the Ethiopian highlands, in the southwest, ranges from 1400 mm to 2200 mm (Daniel Gemechu, 1977). This part of Ethiopia has even distribution of rainfall throughout the year (Friis, 1992), for the following two reasons.

1. Moist Atlantic winds damp abundant moisture when they encounter the first major topography in thousands of kilometers.
2. The southwest Ethiopia highlands lie not at the extreme northern edge of the Inter Tropical Convergence Zone (ITCZ) but near the boundary of summer and bimodal rainfall system.

Rainfall is heaviest at elevations of about 2200 m a.s.l and drops off considerably at lower elevations on the southwest slope of the Ethiopian highlands (Taylor, 1996; cited in Hildebrand, 2003).

The mean annual temperatures are between 15^{o}C to 25^{o}C, the mean daily temperature minima range from 9.7 to 16.3^{o}C and the corresponding maxima from 20^{o}C to 30.4^{o}C (Kumelachew Yeshitela and Tamrat Bekele, 2002).

The elevation of the study area in Bibita ranges from about 1650 to 2055 m and this is within the elevation that gets more rainfall in the area. The nearest area to Gura Ferda is Bebeka coffee plantation.

Gura Ferda is about 55 km away from Bebeka Coffee Plantation. The rainfall and temperature data at this site were collected by National Meteorological Service Agency from the year 1988–1995 before ten years and was disrupted since then. The average annual rainfall at Bebeka for eight consecutive years was 1888.3 mm; monthly mean minimum and maximum temperature was 15.9 ^{0}C and 27.5 ^{0}C respectively. The climate diagram of this site is given in (Fig. 2).

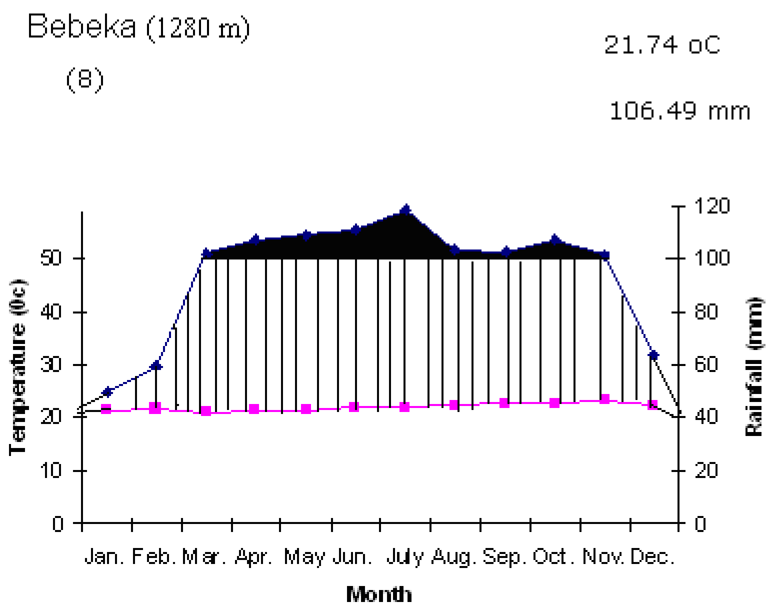


Fig.2: Climate diagram of Bebeka Coffee Plantation
(After Walter, 1985)

3.5 Geology

The basement rock of the study area contains Precambrian basement rocks with tertiary lavas that lie directly on the crystalline basement. According to Davison (1983), the Precambrian basement complex is made up of different kinds of metamorphic rocks in three domains: the Hamer domain high grade metamorphic which probably under went two metamorphic episodes, Young Akobo domain lower-grade metamorphic to the west and south which probably under went only the second phase of metamorphic activity and Surma domain which is high grade metamorphic. The Gura Ferda area is characterized by young Akobo domain.

3.6 Vegetation

Three forest types characterize Southwestern Ethiopia (Friis, 1992). These are

1. Lowland dry peripheral semi evergreen Guineo-Congolean forest that extends from 450 to 600 m
2. Afromontane rainforest that extends from 1500 to 2600 m a.s.l
3. Transitional Afromontane rainforest type that extends from 500 to 1500 m a.s.l.

3.7 Forest management

Gura Ferda Forest is one of the 58 Forest Priority Areas in Ethiopia with a total area of 140,000 ha. The experience with forest conservation in Ethiopia is not encouraging as exemplified by the decline of forest cover from 16% in 1950's to 3.6% in the early 1980's and 2.4% in 1989 (EFAP, 1994). This is contrary to aims included in the proclamations and policies formulated by the country since the 1960's. This is in agreement with Schmithusen (1981), which clearly stated that the forest laws in Africa look good on papers, but are not enforced.

The human population increase in Ethiopia is a great threat to the remnant forests of the country. The settlement programs being undertaken in and around the forested areas pose a serious theat to forest conservation. Planned and un-planned (volunteer settlement) in Gura Ferda area is threatening the existence of Bibita Forest. During my stay at Bibita village while conducting my study, I have observed many people cutting medium sized trees for different domestic uses.

Although a boundary demarcation was made for natural forest conservation by the natural resource conservation office of the Woreda (information from local agricultural workers and field observation), this demarcation was never respected.

The agricultural practice in Sheko and the life style of the people is changing. Coffee plantation practice in Gura Ferda by the indigenous people and the new coming settlers, especially the volunteer ones is also becoming a threat to the survival of the forest. Thus, if the present trend is not checked, the forest in Bibita (part of Gura Ferda Forest) will disappear very quickly.

4 MATERIALS AND METHODS

4.1 Reconnaissance Survey

A reconnaissance survey was made from November 1–7, 2005 (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 November 8–December 5, 2005. The study area was selected for data collection in Gura Ferda mountain range near Bibita village.

4.2 Sampling Design

Systematic sampling was used for this study. Relevés of 20 m x 20 m (400 m^2) were placed at 25 m altitudinal drop between each relevés. Four transects were laid at about 1 km distance from each other. For the collection of herbaceous species, subplots of 5 m x 5 m at the four corners and the center of the large relevé were laid. These subplots were also used for seedling and sapling count and collection of soil samples.

4. 2.1 Vegetation data collection

All the plant species in the relevés were recorded. The cover abundance of all the vascular plants in each relevé was estimated and rated according to modified Braun Blanquet approach (Van der Maarel, 1979). Each individual of the tree species was counted, their circumference was measured and the height of each tree above 2 m was estimated. The plant specimens collected were brought to the National Herbarium of Addis Ababa University for identification. The specimens were dried in the dryer and identified using authenticated specimens, consulting experts and referring the published volumes of Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989 &1995; Edwards *et al.*, 1995, 1997, 2000; Hedberg *et al.*, 2003, 2006; Mesfin Tadesse, 2004;) and Flora of Tropical East Africa (Verdcourt, 1963; Milne-Redhead, 1953). Seedlings and saplings of each tree species were counted to estimate the regeneration status of the forest.

4. 2.2. Environmental data collection

The environmental parameters recorded in this study were altitude, aspect, soil pH, soil texture (sand, silt, clay), and soil electrical conductivity (EC). Altitude was measured by Everest altimeter; the exposure of the site in relation to the sun was visually determined and was found facing northeast. Two soil samples were taken from each relevé, one from 0–10 cm (topsoil) and the other from 30–50 cm depth (subsoil). The soil samples from both depths were taken from four corners and one from the center of the relevé. The soils taken from these five areas in the large relevé were mixed together to take one kilogram for each depth and brought to eco-physiology laboratory of Addis Ababa University for analysis.

4.3 Vegetation data analysis

4.3.1 Plant community determination

The vegetation data analysis was made following Gauch (1982), Jongman *et al.* (1987) based on species abundances. Vegetation classification was made using cover abundance values as class labels. Object group averages; Product moment correlation and squared distance were used to quantify dissimilarities among the different relevés. The computer programme, SYNTAX: Programme NCLAS Hierarchical clustering by distance optimization (Podani, 1988) was used to classify the vegetation into communities. The community name was derived based on the tree and/or shrub with high synootic value.

4.3.2 Structural data analysis

All tree species recorded in all the 60 relevés were used in the analysis of the vegetation structure. The tree density, height, diameter at breast height (DBH), and basal area were used for description of vegetation structure.

Diameter at breast height (DBH): DBH measurement is taken at about 1.3 m from the ground using a measuring 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 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 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 abundance). 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).

4.3.3 Plant diversity analysis

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.

$H = -\sum (Pi \ln Pi)$, Where "H" is the Shannon and Wiener diversity index, "Pi" is the ratio of a species average to the total species average, "ln" 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.

Analysis of variance for environmental variables (altitude, pH, EC, % sand, % clay, and % silt) between different community types was computed. The computer program used for this computation was SPSS (SPSS, 1989 – 96). MINITAB computer program (Minitab, 1995) was used for calculating Pearson's correlation matrix between the environmental factors.

4.3.4 Phytogeographical association

The association of Bibita Forest (Gura Ferda), with other five forests in Ethiopia was made. The similarity index used for this comparison was Sorensen's coefficient (SC). It is used to measure similarities between two habitats. Sorensen's coefficient is calculated using the following formula.

SC =2a / 2a + b + c

Where a = number of species common to both habitats.

b = number of species present in the first habitat and absent from the second.

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

4.4. Environmental data analysis

The environmental parameters in this study are altitude, soil texture (sand, silt, and clay), soil electrical conductivity (EC) and soil pH. The average values of these environmental variables for each community types were calculated.

Soil pH was determined using 1:2.5 soil - water ratio (Sahlemedhin Sertsu and Taye Bekele, 2000). The soil was passed through a 2 mm sieve and 10 gm soil was mixed with 25 ml of distilled water in 50 ml beaker. The suspension was stirred occasionally and the pH was determined after 30 minutes. The pH measure was taken using Digital pH meter, Model - NIG333, AN ISO - 9001 certified CD. The pH meter was standardized using buffer solutions of pH 4.0 and 9.2.

Electrical conductivity (EC) is a measure of soluble salts in soil. Soil – water suspension was made mixing 10 gm of soil in 25 ml of distilled water (Sahlemedhin Sertsu and Taye Bekele, 2000). The suspension was stirred for 30 minutes using glass rod. The reading was taken using YIS model 5000 and 51009 USA made conductometer.

Soil texture (sand, silt and clay) was determined using Hydrometer method of mechanical analysis (Juo, 1978; Sahlemedhin Sertsu and Taye Bekele, 2000). Sodium hexametaphosphate (40 gm) and calcium carbonate (10 gm) were used as dispersing agent.

The percentage of different soil particles was determined using the following formula.

$\% \text{ Sand} = 100 – (H_1 + 0.2(T_1 – 68) – 2.0)2$

$\% \text{ Clay} = H_2 + (0.2(T_2 – 68 – 2.0)2$

$\% \text{ Silt} = 100 – (\% \text{ Sand} + \% \text{ Clay})$

Where: H_1 = First hydrometer reading

H_2 = Second hydrometer reading

T_1 (in ^oF) = First temperature reading

T_2 (in ^oF) = Second temperature reading

5 RESULTS AND DISCUSSION

5 1 Floristic composition

One hundred ninety six specimens of plants (Ferns, herbs, shrubs, lianas and trees) were collected from Bibita Forest (Gura Ferda), southwest Ethiopia (Annex 1). Out of these, 192 were identified to the species level, 3 to the genus, and 1 to the Family level. The specimens identified belong to 170 genera and 74 families. Rubiaceae was represented by 13 species belonging to 12 genera, Asteraceae by 13 species belonging to 9 genera, Euphorbiaceae and Acanthaceae by 9 species each belonging to 8 genera in Euphorbiaceae and 7 genera in Acanthaceae. Fabaceae comprised 8 species representing 7 genera. The genus *Vernonia* was represented by 4 species, *Dracaena* and *Ficus* by 3 species each, and *Isoglossa, Asplenium, Hippocratea*, *Commelina, Phyllanthus*, *Albizia*, *Hibiscus*, *Trichilia*, *Dorstenia*, *Piper*, *Peperomia*, *Oxyanthus*, *Pentas*, *Allophylus*, *Smilax*, *Solanum* and *Pilea* by 2 species each and the rest contained a single species each. Rubiaceae and Asteraceae represent 6.6% each of the total floristic composition. Acanthaceae and Euphorbiaceae occupy the second position with 4.6% each of the total species collected. Fabaceae consisted 4.1%, and Cucurbitaceae 3.6%, and Moraceae, Urticaceae and Poaceae 3% each. The remaining families consist of species less than 3% each.

Trees, shrubs, herbs, trees/shrub, Climbers/lianas, ferns and epiphytes constitute 20, 23, 36, 2, 13, 5, and 2% respectively. Herbs occupied the highest floristic composition followed by shrubs and trees. Trees and shrubs together contributed to 45% of the floristic composition. Liana/climber was 13% of the total collection in the forest. Ferns covered 5% of the forest floor of many relevés in composition; epiphytes were about 2% of the total species composition in Bibita Forest, (Gura Ferda).

A plant species, *Ipomoea involucrata* was a new record for Ethiopia (Annex 2a-Plate 2). No other species belonging to the family Convolvulaceae has been found in the study area. Other tree species belonging to the family Clusiaceae was identified to be most probably *Harungana madagascariensis* (Annex 2b-Plate 3), which is also a new record for Ethiopia. The study was restricted to the plant species in the relevés.

The endemic species (Ensermu Kelbessa, unpublished data; Ensermu Kelbessa, *et al*., 1992; Vivero *et al.*, 2005) were recorded from Bibita Forest (Gura Ferda). Nine endemic species and three endemic subspecies were encountered in Bibita Forest (Gura Ferda) (Table 1). This is 6.25% of the total floristic composition of this forest. Herbs were found to be 58.3%, shrubs 16.7%, trees 16.7% and climbers 8.3%. The woody species together contributed to 41.7% of the endemic species. Compared to dry afromontane forests, the southwest moist montane forests are poor in trees/shrubs endemicity (Kumelachew Yeshitela and Simon Shibru, 2002). This is in agreement with the result of this study. *Vepris dainellii* (Pichi-Serm.) Kokwaro, *Solanecio gigas* (Vatke) C. Jeffrey and *Phyllanthus limmuensis* Cufod. are already in the Red List of endemic species. Among these, *V. dainellii* and *Solanecio gigas* were species with least concern while *Phyllanthus limmuensis* is in the vulnerable category (Vivero *et al.*, 2005).

Of the endemic species, *Amorphophallus gallaensis* is distributed in central (Shewa), northwestern (Gogam), and south (Sidamo) and southwestern (Ilubabor and Keffa) Ethiopia. *Tiliacora troupinii* is also distributed in all the above flora areas in Ethiopia except in Gojam. Comparatively these endemic species have narrower distribution than the rest

Table 1: Endemic taxa records in Bibita Forest (Gura Ferda).(SU = Shewa, IL = Ilubabor, WG = Wellega, AR = Arsi, KF = Keffa, GG = Gamogofa, SD = Sidamo, GD = Gonder, GJ = Gojam, WU = Welo, BA = Bale, HA = Harar, TU = Tigray

Endemic Species	**Family**	**Habit**	**Distribution**
Justicia diclipteroides Lindau subsp. *aethiopica* Hedren	Acanthaceae	Herb	SU,IL,WG,AR,KF,GG,SD
Brillantaisia grotanellii Pichi-Serm.	Acanthaceae	Herb	GD,GJ,WG,IL,KF,GG,SD
Amorphophallus gallaensis (Engl.) N. E. Br.	Araceae	Herb	GJ,SU,IL,KF
Solanecio gigas (Valke) C. Jeffrey	Asteraceae	Shrub	GD,GJ,WU,SU,AR,SD,IL, KF,BA,HA
Mikanopsis clematoides (Sch. Bip. ex A. Rich.) Milne-Redh.	Asteraceae	Herb	TU,GD,WU,SU,AR,KF, BA,HA
Phyllanthus limmuensis Cufod.	Euphorbiaceae	Shrub	GD,GJ,WG,IL,KF
Phyllanthus mooneyi M.Gilbert	Euphorbiaceae	Herb	SU,AR,IL,KF,GG,SD
Millettia ferruginea (Hochst.) Bak.	Fabaceae	Tree	TU,GD,GJ,SU,WG,HA,IL
Tiliacora troupinii Cuf.	Menispermaceae	Climber	SU,IL,KF.SD
Pentas tenuis Verdc.	Rubiaceae	Herb	SU,WG,KF,SD,BA
Vepris dainellii (Pichi-Serm.) Kokwaro	Rutaceae	Tree	GJ,SU,WG,IL,KF,SD,BA
Pilea bambuseti Engl. subsp. *aethiopica* Friis	Urticaceae	Herb	WG,KF,IL

5.2 Plant community types

Six community types were distinguished at 0.65 to 0.75 dissimilarity levels (Fig. 3). The name for each community type was given based on high synoptic values of tree and/or shrub species (Table 2). Relevés with their characteristics and communities with the number of relevés they contained are given in Annex 3 and 4 respectively.

1. *Olea welwitschii - Clausena anisata* type community

This community type is distributed between the altitudinal ranges of 1950 - 2055 m a.s.l. It is dominated by *Olea welwitschii, Vepris dainellii, Ilex mitis, Chionanthus mildbraedii, Galinieria saxifraga* among the tree species and *Oxyanthus speciosus* (Tree/Shrub). *Clausena anisata, Dracaena afromontana, Hymenodictyon floribundum* and *Maytenus gracilipes* are among the shrub species. The herb layer is dominated by *Desmodium repandum, Sanicula elata, Piper capense* and *Oplismenus compositus.* The common climbers/lianas of this community are *Hippocratea goetzei, Landolphia buchananii*. *Asplenium dregeanum, Asplenium sandersonii* are some of the ferns found in this community. *Olea welwitschii* is the emergent tree of this community as well as all the communities recognized in this forest.

2. *Olea welwitschii - Lepidotrichilia Volkensii – Ficus su* type community

This community is found between 1730-1970 m a.s.l. The most dominant species in the upper canopy of this community are *Ficus sur, Lepidotrichilia volkensii, Polyscias fulva* and *Olea welwitschii, Chionanthus mildbraedii, Rothmannia urcelliformis* and *Vepris dainellii* are other tree species in this community. The dominant climbers in this community are *Cissus petiolata, Combretum paniculatum, Hippocratea goetzei, Jasminum abyssinicum, Landolphia buchananii, Momordica foetida, Oncinotis tenuiloba* and *Tiliacora troupinii.*

The shrub layer includes *Clausena anisata, Combretum paniculatum* and *Rhamnus prinoides.* The dominant herbs are *Desmodium repandum* and *Sanicula elata*. *Oplismenus compositus* is the dominant grass in this community.

3. *Rubus steudneri - Vernonia auriculifera - Solanecio gigas* type community

This community is found between 1860 and 1960 m a.s.l. The trees in this community are found scattered forming an open canopy. The canopy gap was formed dueto tree fall by wind, combined effect of wid and climber and natural death of standing trees (Annex 5-Plate 4-7). Some of the trees in this community are *Croton macrostachyus*, *Alangium chinense, Lepidotrichilia volkensii*, *Millettia ferruginea* and *Polyscias fulva.* Shrubs dominate this community and hence the community name is derived from these shrub species. *Vernonia auriculifera*, *Solanecio gigas* and *Rubus steudneri* are the dominant shrubs of this community and are dominant in the open canopies. *Solanecio gigas* is found in wet and plane areas between two consecutive slopes with complete exposure to the sun (Plate 1). *Combretum paniculatum* and *Clausena anisata* are also among the shrub species in this community.

Plate 1: *Solanecio gigas* in open canopy and wet area at the middle of the forest

The climbers dominating this community are *Gouania longispicata, Ipomoea involucrata, Jasminum abyssinicum, Momordica foetida, Cyphostemma cyphopetalum, Basella alba* and *Oncinotis tenuiloba*.

The dominant herbs of this community are *Acalypha racemosa, Brillantaisia grotanellii, Desmodium repandum, Isoglossa punctata, Phaulopsis imbricata, Pilea bambuseti, Piper capense* and *Setaria megaphylla*. Ferns are also found throughout this community.

4. *Combretum paniculatum - Rothmannia urcelliformis - Polyscias fulva* community type

The relevés in this community are distributed in the altitude range of 1760–2015 m a.s.l. The dominant tree species in the community are *Rothmannia urcelliformis, Cordia africana* and *Polyscias fulva. Chionanthus mildbraedii, Ficus sur, Croton macrostachyus, Galinieria saxifraga, Alangium chinense, Allophylus abyssinicus* and *Vepris dainellii* are also some of the tree species in this community.

Combretum paniculatum and *Ehretia cymosa* are the dominant shrubs in this community. *Clausena anisata, Maytenus gracilipes, Rubus steudneri, Solanecio gigas* and *Vernonia auriculifera* are also among the shrub species in this community. The field layer is dominated by *Acalypha racemosa, Desmodium repandum, Oplismenus compositus, Piper capense, Sanicula elata, Setaria megaphylla and Triumfetta brachyceras. Ferns such as Thelypteris longicaspis, Pteris pteridioides* and *Asplenium dregeanum* are also dominant in the herb layer.

The climbers/lianas found in this community type are *Cissus petiolata, Clematis hirsuta, Culcasia falcifolia, Cyphostemma cyphopetalum, Gouania longispicata, Hippocratea goetzei, Ipomoea involucrata, Jasminum abyssinicum, Landolphia buchananii, Momordica foetida, Oncinotis tenuiloba, Pergularia daemia* and *Urera hypselodendron.*

5. *Vepris dainellii - Chionanthus mildbraedii - Galinieria saxifraga* type community

This community is found between 1735–1775 m a.s.l. The tree species dominating this community are *Vepris dainellii, Galinieria saxifraga* and *Chionanthus mildbraedii*. *Ficus sur, Ficus thonningii, Lepidotrichilia volkensii* and *Rothmannia urcelliformis* are also some of the tree species found in this community. The common shrubs of this community are *Combretum paniculatum, Ehretia cymosa* and *Maytenus gracilipes*.

The common climbers/lianas of this community are *Tiliacora troupinii, Oncinotis tenuiloba, Landolphia buchananii, Hippocratea goetzei, Gouania longispicata, Embelia schimperi, Culcasia falcifolia, Jasminum abyssinicum* and *Cissus petiolata.*

The species dominating the herb layer are *Asplenium dregeanum, Desmodium repandum, Justicia diclipteroides, Oplismenus compositus, Peperomia abyssinica, Piper capense, Pteris pteridioides, Sanicula elata* and *Thelypteris longicaspis.*

6. *Croton macrostachyus - Rhamnus prinoides – Combretum paniculatum* type community

This community is located between the altitudinal range of 1800 and 1815 m a.s.l. The tree species dominating the upper canopy are *Croton macrostachyus*, *Cordia africana, Ficus sur, Polyscias fulva* and *Lepidotrichilia volkensii. Olea welwitschii*, which is a well-known emergent tree in all the community types, is absent from this community. The shrubs in this community are *Rhamnus prinoides, Clausena anisata, Maytenus gracilipes, Rubus steudneri, Aspilia mosambicensis* and *Combretum paniculatum.* The dominant climbers/lianas include *Cissus petiolata, Cyphostemma cyphopetalum, Gouania longispicata, Ipomoea involucrata, Jasminum abyssinicum* and *Oncinotis tenuiloba.*

In the herb layer, consists of *Acalypha racemosa, Achyranthes aspera, Desmodium repandum, Oplismenus compositus, Tragia brevipes, Triumfetta brachyceras, Piper capense,* and *Piper umbellatum* dominating the field layer.

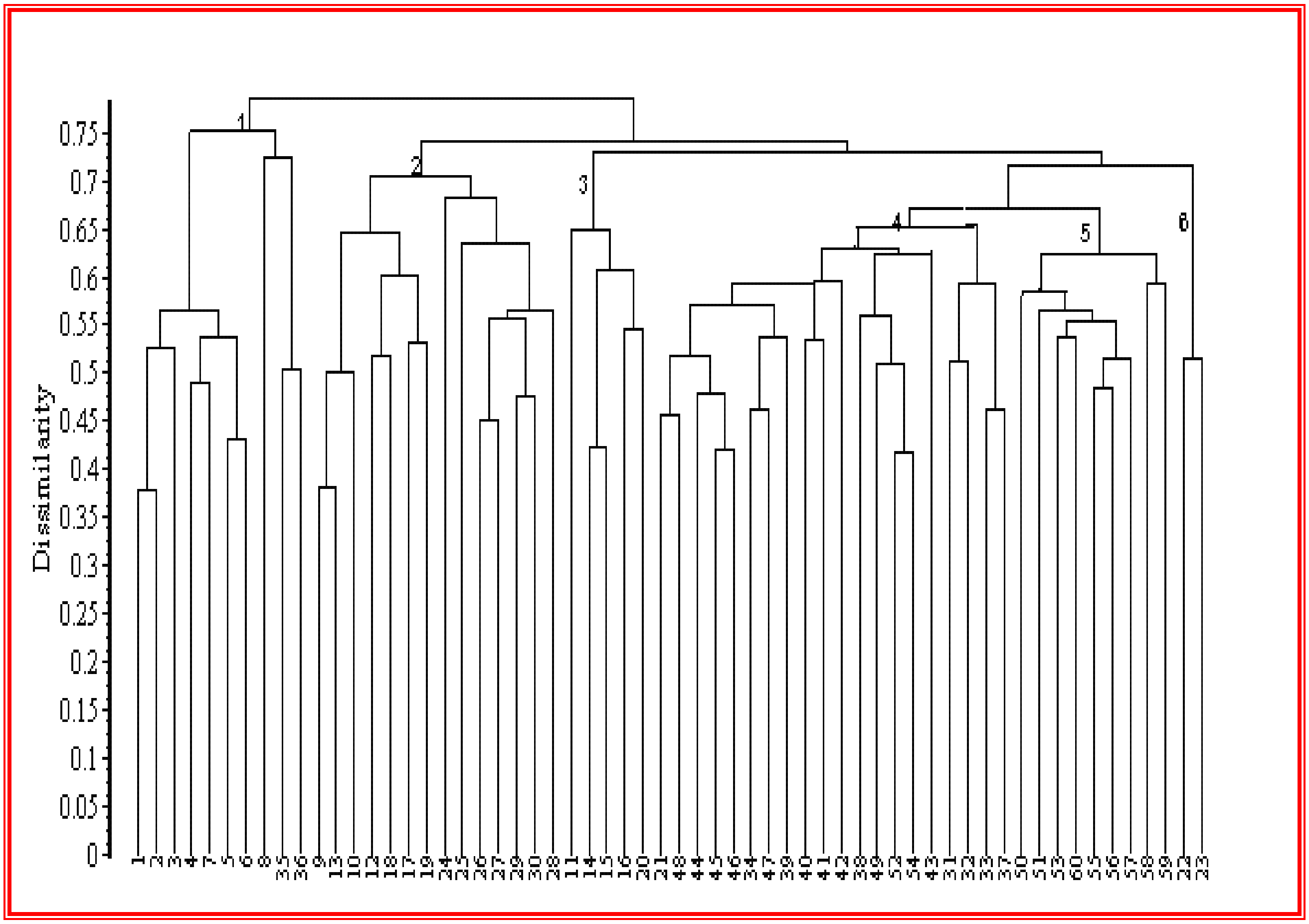


Fig. 3: Dendrogram showing plant community types of the study area

Table 2: Synoptic table

Species		**Community**				
	I	**II**	**III**	**IV**	**V**	**VI**
Acalypha racemosa	0.00	0.00	5.60	5.05	2.56	6.00
Achyranthes aspera	0.70	1.00	3.00	2.95	2.78	4.50
Allophylus abyssinicus	0.50	0.43	0.00	2.65	0.67	0.00
Asparagus racemosus	0.10	0.14	0.80	0.25	0.44	2.50
Aspilia mosambicensis	0.00	0.00	0.00	0.00	0.22	8.00
Asplenium dregeanum	2.20	1.00	1.60	3.00	4.78	0.00
Asplenium sandersonii	2.30	0.14	1.40	0.30	0.56	0.00
Asystasia gangetica	0.00	0.14	0.00	1.40	0.33	7.00
Basella alba	0.20	0.00	3.60	1.55	2.00	1.50
Celtis africana	0.60	2.36	0.00	0.00	0.00	0.50
Chionanthus mildbraedii	**4.20**	3.29	1.20	3.60	**4.67**	3.50
Cissus petiolata	1.10	4.29	2.40	4.45	4.22	5.00
Clausena anisata	**4.30**	3.36	2.20	3.30	1.56	3.00
Clematis hirsuta	0.20	1.71	0.00	3.10	1.67	2.50
Combretum paniculatum	1.40	3.64	4.10	**5.35**	3.67	**5.00**
Commelina diffusa	0.60	0.79	2.20	1.80	1.11	2.50
Cordia africana	0.00	2.50	1.00	**3.20**	1.33	3.00
Croton macrostachyus	2.20	1.50	3.40	2.35	1.88	**6.00**
Culcasia falcifolia	1.20	0.00	0.00	3.10	6.89	0.00
Cyphostemma cyphopetalum	2.00	0.86	4.40	3.30	2.78	3.00
Desmodium repandum	5.10	4.14	3.20	3.75	4.33	5.50
Dracaena afromontana	3.00	1.79	0.20	1.70	1.00	0.00
Dracaena steudneri	0.00	2.57	1.60	1.20	0.33	0.50
Ehretia cymosa	0.00	1.86	1.00	**3.30**	2.11	1.00
Embelia schimperi	0.00	0.93	0.00	0.75	3.33	1.00
Alangium chinense	0.50	2.21	2.00	2.85	1.22	2.00
Ficus sur	1.90	**3.71**	0.40	2.95	2.33	3.00
Ficus thonningii	0.00	2.36	0.00	0.25	2.00	0.00
Galinieria saxifraga	3.80	1.43	2.00	2.80	**4.11**	0.00
Govania longispicata	0.90	1.43	6.00	5.40	3.44	3.50
Hippocratea goetzei	3.80	3.07	0.00	3.15	4.00	0.00
Hymenodictyon floribundum	3.10	1.36	0.00	1.35	1.00	1.00
Ilex mitis	3.50	0.43	0.20	0.45	0.67	0.00
Ipomoea involucrata	1.30	0.57	3.20	5.80	1.44	5.00
Isoglossa somalensis	0.10	0.21	2.60	0.00	0.33	0.00
Isoglossa punctata	0.00	0.50	3.80	0.15	0.00	0.50
Jasminum abyssinicum	1.10	5.36	3.40	4.45	6.00	4.50
Justicia diclipteroides	0.00	0.00	0.00	1.95	2.67	0.00

Landolphia buchananii	5.40	4.93	1.60	4.20	4.56	1.50
Lepidotrichilia volkensii	2.80	**3.71**	2.40	1.40	2.44	2.50
?Harungana madagascariensis	2.30	2.64	0.20	2.05	0.22	0.00
Maytenus gracilipes	2.40	1.93	1.80	2.15	2.56	2.50
Millettia ferruginea	0.00	0.36	2.20	2.50	1.11	0.00
Momordica foetida	0.70	3.29	7.80	4.55	1.78	0.00
Olea welwitschii	**6.70**	**5.07**	0.40	1.35	0.44	0.00
Oncinotis tenuiloba	0.90	5.00	3.00	4.10	5.44	4.50
Oplismenus compositus	6.10	3.71	2.00	3.20	3.89	4.00
Oxyanthus speciosus	3.00	1.57	0.60	1.60	1.33	0.00
Peperomia abyssinica	0.00	0.71	0.00	1.40	4.33	0.00
Pergularia daemia	1.40	2.14	2.20	4.20	0.56	1.50
Phaulopsis imbricata	0.30	1.57	5.80	0.40	0.00	0.00
Pilea bambuseti	0.60	0.00	3.80	0.65	0.33	0.00
Piper capense	4.70	1.07	4.00	4.45	3.33	3.50
Polyscias fulva	1.50	3.64	2.40	**3.55**	1.89	2.50
Premna schimperi	0.00	0.07	0.00	0.00	0.00	2.50
Pteris pteridioides	1.20	1.21	1.20	4.10	6.11	0.0
Rhamnus prinoides	0.10	2.79	0.60	0.20	0.78	**7.50**
Rothmannia urcelliformis	0.20	2.93	0.80	**3.90**	3.00	1.00
Rubus steudneri	0.00	1.64	**5.80**	3.10	1.44	5.00
Rytigynia neglecta	0.90	2.07	1.00	2.15	0.56	2.00
Sanicula elata	3.40	3.00	0.80	2.45	4.00	0.50
Setaria megaphylla	0.00	0.64	3.20	3.65	2.89	4.00
Solanecio gigas	0.00	0.14	**4.20**	3.10	0.00	0.00
Tectaria gemmifera	1.80	2.71	4.80	1.20	2.33	1.00
Thelypteris longicaspis	1.50	1.14	1.60	4.45	4.67	2.50
Tiliacora troupinii	1.20	3.00	0.00	1.85	5.44	0.00
Tragia brevipes	0.00	0.00	0.20	1.85	0.00	5.50
Trichilia sp.	1.60	1.21	0.60	2.40	0.89	1.00
Triumfetta brachyceras	0.00	0.36	1.40	2.05	3.00	4.50
Urera hypselodendron	0.60	0.00	0.00	4.05	0.33	0.00
Vepris dainellii	4.10	3.33	1.00	3.15	**5.22**	0.00
Vernonia auriculifera	0.00	0.50	**4.40**	2.40	1.67	1.00

5.3 Species diversity, richness and equitability

From the computation of vegetation data from Bibita Forest (Gura Ferda) Shannon-Wiener diversity index showed the out put in Table 3.

Table 3: Shannon–Wiener Diversity Index

Community	Richness	Diversity index (H')	H'max	Evenness (H'/H'max)
1	81	3.98	4.39	0.91
2	112	4.25	4.72	0.90
3	79	4.05	4.37	0.93
4	125	4.44	4.83	0.92
5	108	4.30	4.68	0.92
6	58	3.82	4.06	0.94

Communities 2, 3, 4 and 5 have diversity index above 4.0. Community 4 is the most diversified one attaining a diversity index of 4.44. This community attained a species evenness index (J) of 0.92 showing the highest even distribution of species next to community 6 (J = 0.94) and 3 (J = 0.93). Community 1 (confined to the upper altitude) and 6 (with only two releves) got a diversity index of 3.98 and 3.82 respectively and are less diversified when compared to the others.

5.4 Vegetation structure

5.4.1 Tree density

The density of tree species with DBH greater than 2, 10, and 20 cm is shown in Table 4. The Density of trees with DBH greater than 2 cm in the study area is 777.2/ha. The number of stems with DBH >10 cm was found to be 501 and those with DBH >20 cm was 266. *Vepris dainellii* and *Chionanthus mildbraedii* alone contributed to 29.65% of the total density. Six other tree species namely *Rothmannia urcelliformis* (9.14%), *Allophylus abyssinicus* (5.58%), *Galinieria saxifraga* (5.63%), *Lepidotrichilia volkensii* (4.66%), *Ficus sur* (4.58%) and *Polyscias fulva* (3.91%) contributed to 33.5% of the total density. Regarding trees with DBH class >10 cm, *V. dainellii* contributed 13.32%, *C. mildbraedii* 10.66%, *R. urcelliformis* 7.08%, *P. fulva* 5.58%, *A. abyssinicus* 5%, *G. saxifraga* 5.83%, *L. volkensii* 3.83%, *F. sur* 5.69%. Concerning trees with

DBH > 20 cm, *P. fulva* contributed to 9.55%, *Olea welwitschii* 8.61%, *F. sur* 7.41%, *V. dainellii* 6.71%, *C. africana* 6.42%, *C. macrostachyu*s 6.13% *C. mildbraedii* 5.64%, *R. urcelliformis* 5.45% and *A. abyssinicus* 5.19%.

Table 4: Density of trees from Bibita Forest (Gura Ferda) with different DBH classes

No	Species	>2 cm	>10 cm	>20 cm
1	*Ilex mitis*	10.42	08.33	05.42
2	*Ocotea kenyensis*	03.33	02.08	02.08
3	*Croton macrostachyus*	22.92	20.80	16.30
4	*?Harungana madagascariensis*	20.00	13.80	06.25
5	*Chionanthus mildbraedii*	103.80	53.30	15.00
6	*Lepidotrichilia volkensii*	36.25	19.20	07.92
7	*Vepris dainellii*	126.70	66.70	17.90
8	*Albizia gummifera*	10.50	06.67	05.00
9	*Prunus africana*	20.50	02.50	01.67
10	*Olea welwitschii*	29.99	26.24	22.91
11	*Pouteria adolfi-friederci*	10.00	02.92	01.25
12	*Galinieria saxifraga*	43.75	32.20	06.25
13	*Pittosporum viridiflorum*	05.00	02.50	0.00
14	*Macaranga capensis*	11.25	09.17	05.42
15	*Trichilia sp.*	25.83	13.30	05.41
16	*Alangium chinense*	20.83	15.80	10.71
17	*Rothmannia urcelliformis*	71.67	35.40	14.60
18	*Dombeya torrida*	06.25	04.58	02.92
19	*Syzygium guineense*	11.25	09.17	05.83
20	*Polyscias fulva*	30.42	27.90	25.40
21	*Ficus sur*	35.56	28.50	19.70
22	*Cordia africana*	24.58	21.25	17.08
23	*Diospyros abyssinica*	02.50	01.25	01.25
24	*Millettia ferruginea*	14.92	11.60	09.17
25	*Celtis africana*	09.58	06.67	03.75
26	*Trichilia emetica*	05.00	03.33	01.67
27	*Ficus thonningii*	04.58	04.58	03.75
28	*Allophylus abyssinicus*	43.33	25.00	13.80
29	*Antiaris toxicaria*	0.42	0.42	0.42
30	*Dracaena steudneri*	07.50	05.00	02.92
31	*Trilepisium madagascariense*	01.67	01.67	0.83
32	*Mitragyna rubrostipulata.*	04.17	04.17	04.17
33	*Cassipourea malosana*	12.92	09.17	05.00
34	*Manilkara butugi*	04.16	03.33	0.83
35	*Schefflera abyssinica*	0.83	0.83	0.42
36	*Albizia grandibracteata*	02.92	0.42	0.42
Total		777.2	501	266

Tree densities with DBH greater than 10 and 20 cm in Bibita Forest (Gura Ferda) were compared with that of nine different forests in Ethiopia (Table 5). The ratio of tree densities with DBH >10 cm to tree densities > 20 cm is also included in the comparison.

Table 5: Comparison of tree densities with DBH >10 and 20 cm from Bibita Forest with other forests

Forest	DBH Class (cm)		Ratio
	DBH > 10 (A)	DBH > 20 (B)	A/B
Menagesha[1]	484.00	208.00	2.30
Chilimo[1]	638.00	250.00	2.60
Wof Washa[1]	329.00	215.00	1.50
Donkoro[2]	526.00	285.00	1.90
Masha Anderacha[3]	385.70	160.50	2.40
Dodola[4]	521.00	351.00	1.50
Dindin[5]	437.00	219.00	1.99
Magada[6]	608.00	332.00	1.80
Menna Angetu[7]	292.59	139.78	2.08
Bibita Forest	500.50	265.60	1.90

Source: [1]Tamrat Bekele (1993), [2]Abate Ayalew (2003), [3]Kumelachew Yeshitela and Taye Bekele (2003), [4]Kitessa Hundera (2003), [5]Simon Shibru and Girma Balcha (2004), [6]Genene Bekele (2005), [7] Ermias Lulekal (2005).

In this comparison, the ratio of tree densities with DBH >10 cm to density >20 cm in Bibita Forest (Gura Ferda) showed that there is close similarity with Donkoro and Dindin forests. The ratio A/B indicated that Bibita Forest has more trees in the lower DBH classes than in the higher classes when compared to Wof Washa, Dodolla and Magada. Four forest types in the comparison (Menagesha, Chilimo, Mena Angetu, and Masha Anderacha) have more A/B ratio values than Bibita Forest indicating that there is more predominance of trees in the lower DBH class in these forests than in Bibita Forest. Even though it is not as large as in the four forests with A/B ratio >2, the study shows that there is predominance of tree density in the lower DBH class.

5.4.2 Diameter at breast height (DBH)

The distribution of trees in different DBH classes is given in Fig. 4 The number of stems in DBH class less than 10 cm is 276.7/ha (35.6%). The distribution of tree species in different DBH classes is 234.9/ha (30.2%) in 10-20 cm, 196.418/ha (24.5%) in 20-50 cm and 47.915/ha (6.2%) in 50–80 cm, 12.917 (1.7%) in 80-110 cm, 4.168 (0.5%) in 110-140 cm and it was found to be 11.25 (1.4%) of the total in the DBH class >140 cm. The distribution of trees in DBH class from lower to higher showed a decreasing trend, but the percentage DBH of trees in DBH class >140 cm was contributed by *Olea welwitschii* and *Ficus sur* alone. The total DBH of trees in lower and higher DBH classes is lower when compared to the DBH of the intermediate ones. Bibita Forest, (Gura Ferda) is compared with other forests in Ethiopia regarding percentage distribution of tree species in different DBH Classes (Table 6).

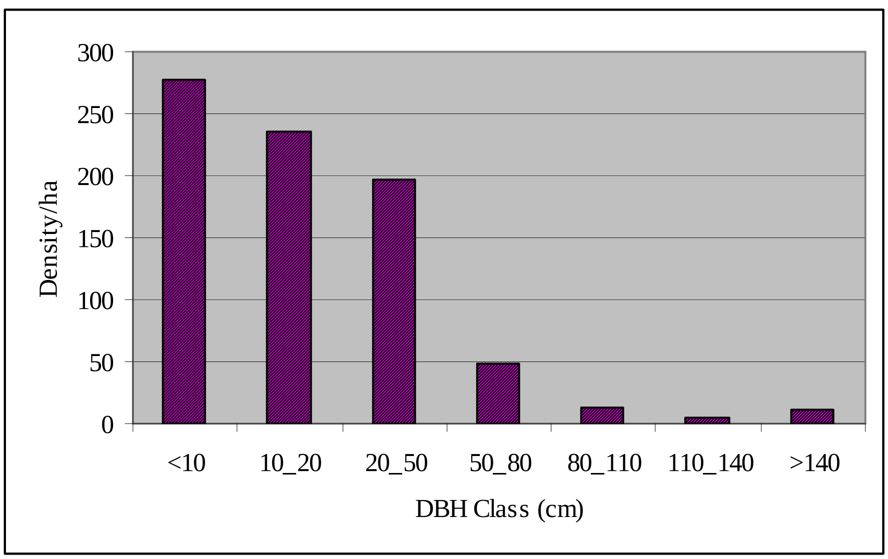


Fig. 4: DBH Class and Density of tree speciess

Table 6: The comparison of Bibita Forest (Gura Ferda) with other six forests in Ethiopia regarding percentage distribution of tree species in different DBH classes (I = 10-20, II = 20-50, III = 50-80, IV = 80-110, V = 110-140, VI = >140)

Forest	DBH Classes (cm)					
	I	II	III	IV	V	VI
Wof Washa[1]	32.6	31.7	14.6	17.7	0.0	0.0
Menagesha[1]	56.9	32.8	06.5	02.5	0.0	0.0
Chilimo[1]	60.8	36.5	02.6	0.00	0.0	0.0
Denkoro[2]	46.0	46.0	06.3	01.1	0.2	0.4
Menna Angetu[3]	32.8	25.5	08.9	02.4	0.7	1.1
Magada[4]	45.4	44.1	06.3	02.6	1.0	0.7
Bibita Forest	30.2	24.4	06.2	01.7	0.5	1.4

Source: [1] = Tamrat Bekele (1993), [2] = Abate Ayalew (2003), [3] = Ermias Lulekal (2005), [4] = Genene Bekele (2005).

Bibita Forest (Gura Ferda) is similar to Wof Washa and Menna Angetu in number of trees in the lower DBH class (I). The percent of trees in DBH class III in Bibita Forest is higher than that of Chilimo Forest but less than the others. The percent of trees in DBH class IV in Bibita Forest is higher than that of Donkoro and Chilimo (has no tree in this DBH class) but less than the others. The percent of trees in DBH class VI in Bibita Forest is greater than that of all the forests in the comparison. This shows that Bibita Forest, (Gura Ferda) is characterized by more matured trees than others.

5.4.3 Tree height

The trees in the study area could be convinently divided into seven height classes. The percent of trees decreased with increasing height classes (Table 7). The highest number of individual trees was found to be 262.916/ha representing the height class I. Trees in height class I and II, together make 63.74%/ha. Trees in the height classes III and IV together are found to be 24.63%. Height can be used as an indicator of age of the forest. The old trees are found in the height class above 26 m and their percentage distribution is 6.56. The trees representing the height class VII are *Olea welwitschii* (42.58%), *Polyscias fulva* (22.22%), *Albizia gummifera* (9.24%), *Croton macrostachyus* (7.42%), *Macaranga capensis* (7.42%), *Ficus sur* (5.56%) and ?*Harungana madagascariensis* (5.56%). The upper canopy is dominated by these seven tree species in the area. *Olea welwitschii* is the emergent tree and grows above all the canopy trees.

Table 7: The class distribution for trees higher than 6 m in Bibita Forest (Gura Ferda)

Height Class	Density/ha	%	Class
6 – 10	262.916	39.05	I
10 – 14	166.248	24.69	II
14 – 18	119.947	17.82	III
18 – 22	45.834	06.81	IV
22 – 26	34.168	05.07	V
26 - 30	21.666	03.22	VI
>30	22.500	03.34	VII
Total	673.279	100.00	

Vertical stratification

The vertical stratification of trees in the study area was examined using the IUFRO classification scheme (Lembandgut, 1958; cited in Lamprecht, 1989). According to this scheme, the top height is used for determining the vertical structure. Tree with >2/3 height of the top represents upper storey, trees with height between 1/3 and 2/3 of the top height represent the middle storey, and the lower storey is represented by trees with height < 1/3 of the top height.

Accordingly the species with highest height was *Olea welwitschii* with a height of 45 m. Based on this; the trees with height above 29 m represented the upper storey. These are *Albizia gummifera, Croton macrostchyus, Ficus sur, Macaranga capensis, ?Harungana madagascariensis, Olea welwitschii* and *Polyscias fulva*. These trees are found in all the three storeys except *Albizia gummifera*, which was not found in the lower storey. The trees, which belonged to all the three storeys, were found to cover 15.8% of the tree species in the height class. The trees in the height range of 15-29 m represented the middle layer (storey), and contributed to about 86.8% of the tree species in the height class. The species with height below 15 m represented the lower Storey. The trees found in this layer and absent in the middle as well as the upper storey were *Dracaena steudneri,* and *Galinieria saxifraga*. Eightyfour percent of the trees are found in both middle and lower storeys. In general, the percent of tree densities in lower, middle and upper storey was found to be 64/ha, 33/ha and 3/ha respectively (Fig. 5).

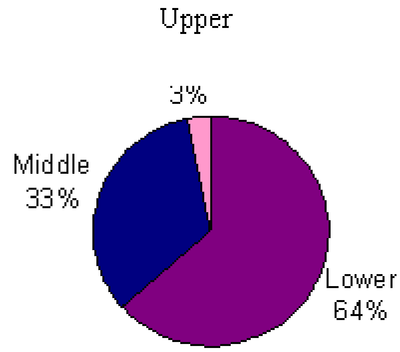


Fig. 5: % Density of trees in lower, middle and upper strata.

5.4.4 Basal area

The basal area of all tree species in Bibita Forest as calculated from DBH data is found to be 69.9 m^2/ha (Table 8). The normal basal area value for virgin tropical forests in Africa is 23– 37 m^2 /ha (Dawins, 1959; cited in Lamprecht, 1989). Thus the basal area value of Bibita Forest (Gura Ferda) is very high. *Olea welwitschii* took the biggest share in the percentage contribution of basal area (33.4%) of this forest. Other large trees in this forest such as *Ficus sur* (11.2%), ?*Harungana madagascariensis* (7%), *Trichilia emetica* (5.2%), *Cordia africana* (5%), *Polyscias fulva* (7%) and *Millettia ferruginea* (4.6%) together with *Olea welwitschii* contributed to 73.2% of the total basal area. The trees with highest densities such as *Vepris dainellii, Chionanthus mildbraedii* and *Rothmannia urcelliformis* with basal area values of 1.2, 1.0 and 1.2 each did not contribute much to the total basal area of this forest, because area depends on the size of the tree. The basal areas of *Olea welwitschii, Ficus sur, Polyscias fulva, ?Harungana madagascariensis*, *Trichilia emetica*, *Cordia africana*, and *Millettia ferruginea* are 23.3, 7.8, 4.9, 4.9, 3.6, 3.5, 3.2 m^2/ha respectively. *Olea welwitschii* is about 3 times more important than *Ficus sur,* and *Ficus sur* is about 1.5 times more important than *Harungana madagascariensis* and *Trichilia emetica*. The above seven tree species produced the highest basal area, but less density. The basal area of this forest is compared with the basal area of other 10 afromontane forests in Ethiopia (Table 9).

Table 8: Basal area (BA) of all tree species in Bibita Forest, (Gura Ferda)

No	Species	BA/ha	Relative BA
1	*Albizia grandibracteata*	0.1	0.1
2	*Albizia gummifera*	1.4	2.0
3	*Allophylus abyssinicus*	1.0	1.4
4	*Pouteria adolfi-friedercii*	0.2	0.3
5	*Antiaris toxicaria*	0.1	0.1
6	*Cassipourea malosana*	0.2	0.3
7	*Celtis africana*	0.3	0.4
8	*Chionanthus mildbraedii*	1.0	1.4
9	*Cordia africana*	3.5	5.0
10	*Croton macrostachyus*	2.3	3.3
11	*Diospyros abyssinica*	0.2	0.3
12	*Dombeya torrida*	0.1	0.1
13	*Dracaena steudneri*	0.8	1.2
14	*Alangium chinense*	0.9	1.3
15	*Ficus sur*	7.8	11.2
16	*Ficus thonningii*	1.4	2.0
17	*Galinieria saxifraga*	0.6	0.9
18	*Ilex mitis*	0.4	0.6
19	*Lepidotrichilia volkensii*	0.6	0.9
20	*Macaranga capensis*	0.6	0.9
21	*?Harungana madagascariensis*	4.9	7.0
22	*Manilkara butugi*	0.1	0.1
23	*Millettia ferruginea*	3.2	4.6
24	*Mitragyna rubrostipulata*	0.8	1.2
25	*Ocotea kenyensis*	0.2	0.3
26	*Olea welwitschii*	23.3	33.4
27	*Pittosporum viridiflorum*	0.1	0.1
28	*Polyscias fulva*	5.9	8.4
29	*Prunus africana*	0.7	1.0
30	*Rothmannia urcelliformis*	1.2	1.7
31	*Schefflera abyssinica*	0.1	0.1
32	*Syzygium guineense*	0.9	1.3
33	*Trichilia emetica*	3.6	5.2
34	*Trichilia sp.*	0.1	0.1
35	*Trilepisium madagascariense*	0.1	0.1
36	*Vepris dainiellii*	1.2	1.7
Total		69.9	100

Table 9: Comparison of Bibita Forest, (Gura Ferda), with other 10 afromontane forests in Ethiopia with respect to basal area (Note: BF= Bibita Forest (Gura Ferda), MA = Menna Angetu, MG = Magada, DN = Dindin, MAN = Masha Anderacha, DK = Donkoro, MN = Menagesha, CH = Chilimo, JB = Jibbat, WW = Wof Washa, DD = Dodolla)

Forest	GFBS	MA[1]	MG[2]	DN[3]	MAN[4]	DK[5]	MN[6]	CH[6]	JB[7]	WW[6]	DD[8]
Basal area (m^2)	69.90	94.22	68.52	49.00	81.90	45.00	36.10	30.10	47.50	101.80	129.00

Source: [1] = Ermias Lulekal (2005), [2] = Genene Bekele (2005), [3] = Simon Shibru and Girma Balcha (2004), [4] = Kumilachew Yeshitela and Taye Bekele (2003), [5] = Abate Ayalew (2003), [8] = Kitessa Hundera (2003) 6 = Tamrat Bekele (1993), [7] = Tamrat Bekele, (1994).

Magada and Bibita Forest have almost the same Basal area. Some forests such as DD, WW, MA and MAN have higher basal area while CH, MN, DK, DN and JB have much less basal area than GFBS. When compared to Menna Angetu, Wof washa and Dodolla forests, Bibita Forest is much lower in its basal area. There is close relationship between basal area and DBH because basal area is calculated from the DBH value.The basal area and density of 10 tree species with their respective percentage contribution is given in Table 10.

Table 10: Basal area, density, and percentage contribution of ten (10) tree species in Bibita Forest (Gura Ferda)

Species	Basal area (m2/ha)	%	Density	%
Olea welwitschii	23.3	33.4	29.99	03.86
Ficus sur	07.8	11.2	35.56	04.50
Polyscias fulva	04.9	07.0	30.42	03.91
?Harungana madagascariensis	04.9	07.0	20.00	02.57
Trichilia emetica	03.6	05.2	5.001	0.64
Cordia africana	03.5	05.0	24.58	03.16
Vepris dainellii	01.2	01.7	126.67	16.30
Chionanthus mildbraedii	01.0	01.4	103.75	13.33
Rothmannia urcelliformis	01.2	01.7	21.66	09.22
Allophylus abyssinicus	01.0	01.4	43.33	05.58

5.4.5 Frequency

Frequency is the number of relevés in which a given species occurred in the study area. The frequency of all the tree species in this forest is given in Table 11. Two tree species were most frequently occurred (in 54 quadrats out of 60). These are *Chionanthus mildbraedii* (90%), and *Vepris dainellii* (90%). The trees with more than 50% distribution were *Ficus sur* (58%), *Galinieria saxifraga* (63%), *Lepidotrichilia volkensii* (58%), *Polyscias fulva* (55%), *Rothmannia urcelliformis* (72%) and *Trichilia sp*. (63%). The trees with the least occurrence are *Albizia grandibracteata*, *Antiaris toxicaria*, *Mitragyna rubrostipulata*, and *Trilepisium madagascariense* contributing 1.7% each.

5.4.6 Importance Value Index (IVI)

Importance value index combines data for three parameters (relative frequency, relative density and relative abundance). 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). The importance value index for tree species in Bibita Forest is shown in Table 12. *Vepris dainellii* (40.1), *Chionanthus mildbraedii* (34.2), *Rothmannia urcelliformis* (24.4) and *Ficus sur* (14.1), *Lepidotrichilia vlkensii* (14.2), *Allophylus abyssinicus* (14), *Polyscias fulva* (12.4), *Trichilia sp*. (11.9), *Galinieria saxifraga* (11.2) *and Olea welwitschii* (11.8), all got IVI value above 10. They all summed up to give 188.3 IVI value (63.92%).

The reason why *V. dainellii* produced the highest IVI value is that it has the highest relative density, relative frequency and relative abundance. The same is true for *Chionanthus mildbraedii, Rothmannia urcelliformis* and others. High IVI value indicates that the species sociological structure in the community is high.

Table 11: Frequency distribution of tree species in Bibita Forest, (Gura Ferda) (Freq = frequency, %FR = % frequency, RFR = relative frequency).

No	Species	Freq.	% FR	RFR
1	*Albizia grandibracteata*	1	1.7	0.1
2	*Albizia gummifera*	24	40	3.4
3	*Allophylus abyssinicus*	20	33	2.8
4	*Pouteria adolfi-friederci*	18	30	2.5
5	*Antiaris toxicaria*	1	1.7	0.1
6	*Cassipourea malosana*	10	17	1.4
7	*Celtis africana*	10	17	1.4
8	*Chionanthus mildbraedii*	54	90	7.5
9	*Cordia africana*	22	36.7	3.1
10	*Croton macrostachyus*	27	45	3.8
11	*Diospyros abyssinica*	3	5	0.4
12	*Dombeya torrida*	6	10	0.8
13	*Dracaena steudneri*	24	40	3.4
14	*Alangium chinense*	28	47	3.9
15	*Ficus sur*	35	58	4.9
16	*Ficus thonningii*	12	20	1.7
17	*Galinieria saxifraga*	38	63	5.3
18	*Ilex mitis*	13	22	1.8
19	*Lepidotrichilia volkensii*	35	58	4.9
20	*Macaranga capensis*	8	13	1.1
21	*?Harungana madagascariensis*	24	40	3.4
22	*Manilkara butugi*	2	3.3	0.3
23	*Millettia ferruginea*	15	25	2.1
24	*Mitragyna rubrostipulata*	1	1.7	0.1
25	*Ocotea kenyensis*	17	28	2.4
26	*Olea welwitschii*	29	48	4.1
27	*Pittosporium viridiflorum*	16	27	2.2
28	*Polyscias fulva*	33	55	4.6
29	*Prunus africana*	3	5	0.4
30	*Rothmannia urcelliformis*	43	72	6
31	*Schefflera abyssinica*	2	3.3	0.3
32	*Syzygium guineense*	14	23	2
33	*Trichilia emetica*	3	5	0.4
34	*Trichilia sp.*	38	63	5.3
35	*Trilepisium madagascariense*	1	1.7	0.1
36	*Vepris dainellii*	54	90	7.5
Total		684	1139.1	100

Table 12: The importance value index of tree species in Bibita Forest (Gura Ferda)

(RF = Relative frequency, RD = Relative density, RB = Relative abundance, IVI = Importance value index)

No	Species	**RF**	**RD**	**RB**	**IVI**
1	*Albizia grandibracteata*	0.10	0.38	0.37	0.85
2	*Albizia gummifera*	3.40	0.97	0.96	5.33
3	*Allophylus abyssinicus*	2.80	5.58	5.57	14.00
4	*Pouteria adolfi-friedercii*	2.50	1.29	1.29	5.08
5	*Antiaris toxicaria*	0.10	0.05	0.05	0.20
6	*Cassipourea malosana*	1.40	1.66	1.66	4.72
7	*Celtis africana*	1.40	1.23	1.23	3.86
8	*Chionanthus mildbraedii*	7.50	13.34	13.34	34.20
9	*Cordia africana*	3.10	3.16	3.16	9.42
10	*Croton macrostachyus*	3.80	2.94	2.90	9.64
11	*Diospyros abyssinica*	0.40	0.32	0.32	1.04
12	*Dombeya torrida*	0.80	0.80	0.80	2.40
13	*Dracaena steudneri*	3.40	0.97	0.96	5.33
14	*Alangium chinense*	3.90	2.68	2.68	9.26
15	*Ficus sur*	4.90	4.58	4.57	14.10
16	*Ficus thonningii*	1.70	0.59	0.57	2.57
17	*Galinieria saxifraga*	5.30	5.63	0.25	11.20
18	*Ilex mitis*	1.80	1.34	1.34	4.48
19	*Lepidotrichilia volkensii*	4.90	4.66	4.66	14.20
20	*Macaranga capensis*	1.10	1.45	1.45	4.00
21	*?Harungana madagascariensis*	3.40	2.57	2.57	8.54
22	*Manilkara butugi*	0.30	0.54	0.54	1.38
23	*Millettia ferruginea*	2.10	1.92	1.92	5.94
24	*Mitragyna rubrostipulata*	0.10	0.54	0.54	1.18
25	*Ocotea kenyensis*	2.40	0.43	0.43	3.26
26	*Olea welwitschii*	4.10	3.86	3.86	11.80
27	*Pittosporum viridiflorum*	2.20	0.64	0.64	3.48
28	*Polyscias fulva*	4.60	3.91	3.91	12.40
29	*Prunus africana*	0.40	0.32	0.32	1.04
30	*Rothmannia urcelliformis*	6.00	9.22	9.21	24.40
31	*Schefflera abyssinica*	0.30	0.11	0.11	0.52
32	*Syzygium guineense*	2.00	1.45	1.45	4.90
33	*Trichilia emetica*	0.40	0.64	0.64	1.68
34	*Trichilia sp.*	5.30	3.32	3.32	11.90
35	*Trilepisium madagascariense*	0.10	0.21	0.21	0.52
36	*Vepris dainellii*	7.50	16.29	16.28	40.10

5.5 Tree species population structure

The analysis of population structure of all tree species in Bibita Forest, (Gura Ferda), resulted in six different patterns (Fig. 7a-f). The entire tree species in this study area were distributed in these six patterns except *Antiaris toxicaria*, which occurred singly, only in one plot.

The first pattern is represented by *Chionanthus mildbraedii* (Fig.6a). Species in this group all have high density in the lower DBH class and gradually decreases with increasing DBH (positively skewed). The study in Masha Anderacha Forest (Kumelachew Yeshitela and Taye Bekele, 2003) showed a similar pattern. They show inverted "J" curve pattern. All species in this pattern show good reproduction and recruitment. Species included in this group are *Albizia grandibracteata*, *Allophylus abyssinicus, Pouteria adolfi-friederci*, *Dombeya torrida, Dracaena steudneri*, *Lepidotrichilia volkensi*, *Rothmannia urcelliformis*, *Trichilia emetica*, *Trichilia sp*. and *Vepris dainellii.*

The second pattern is represented by *Ilex mitis (*Fig.6b). Species included in this group are *Cassipourea malosana*, *Celtis africana, Ficus thonningii*, *Albizia gummifera*, and *Mitragyna rubrostipulata show* a "J" curved shape and are in the second pattern. The number of individual trees in each species increases with increasing DBH class.

The third pattern is represented by *Manilkara butugi* (Fig.6c). The density of all species in this group increases with increasing DBH up to some points and then decreases with increasing DBH after wards. This pattern shows Gaussean curve. The tree species in this group are *Cordia africana, Croton macrostchyus, Alangium chinense, Galinieria saxifraga, Macaranga capensis, ?Harungana madagascariensis* and *Polyscias fulva*. Some of the trees dominating the upper canopy in this forest are found in this group.

The fourth pattern is represented by *Olea welwitschii* (Fig. 6d). The species included in this group are *Millettia ferruginea* and *Syzygium guineense.* They show decreasing pattern at the beginning and then increase up to some limits and then decrease up to some points and finally increase. This indicates irregular or Zigzag pattern as DBH increases.

The fifth pattern is represented by *Diospyros abyssinica* (Fig. 6e). The species included in this group are *Ocotea kenyensis*, *Schefflera abyssinica* and *Prunus africana*. These species occur in the lower DBH class 2-10 cm and 20-40 cm, but absent in the rest.

The sixth pattern is represented by *Pittosporum viridiflorum* (Fig. 6f). This group is present only in the first and second DBH classes (2–10 and 10–20 cm). There may be selective cutting of the trees in the middle and higher DBH classes for domestic use.

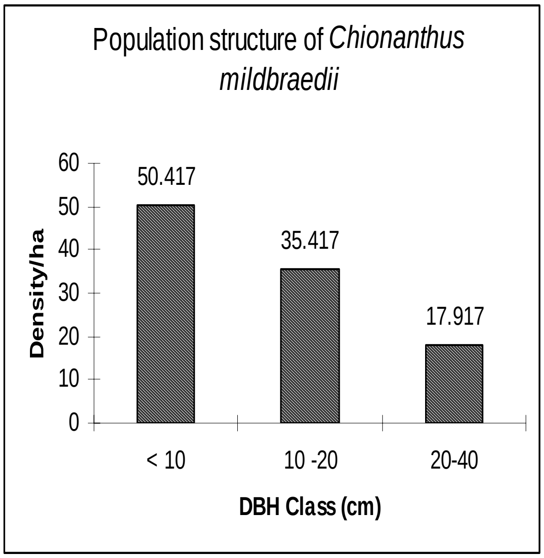


Fig. 6a

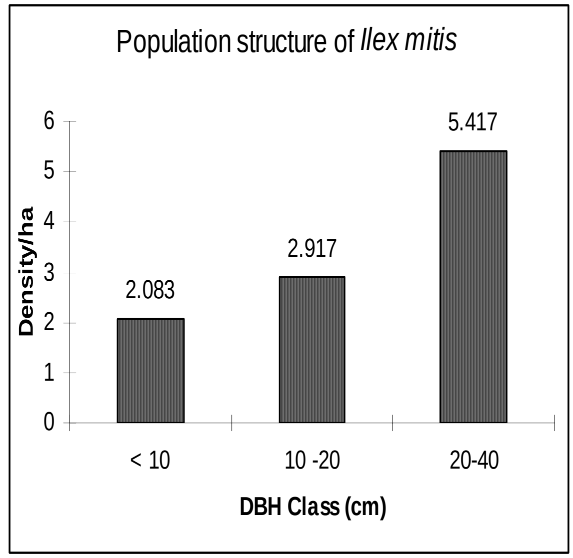


Fig. 6b

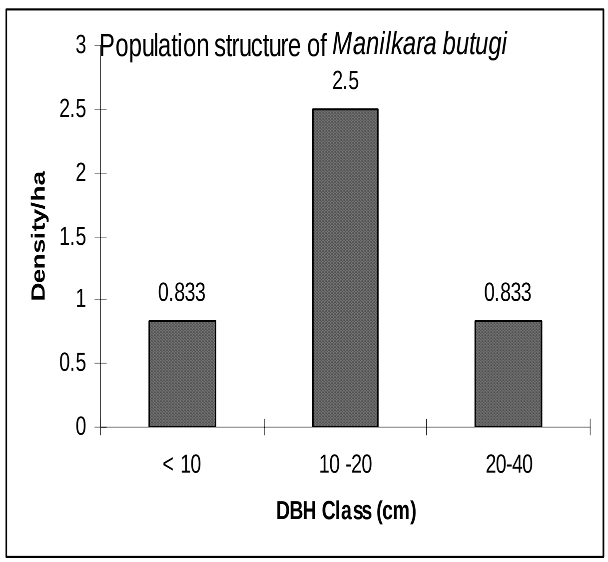


Fig. 6c

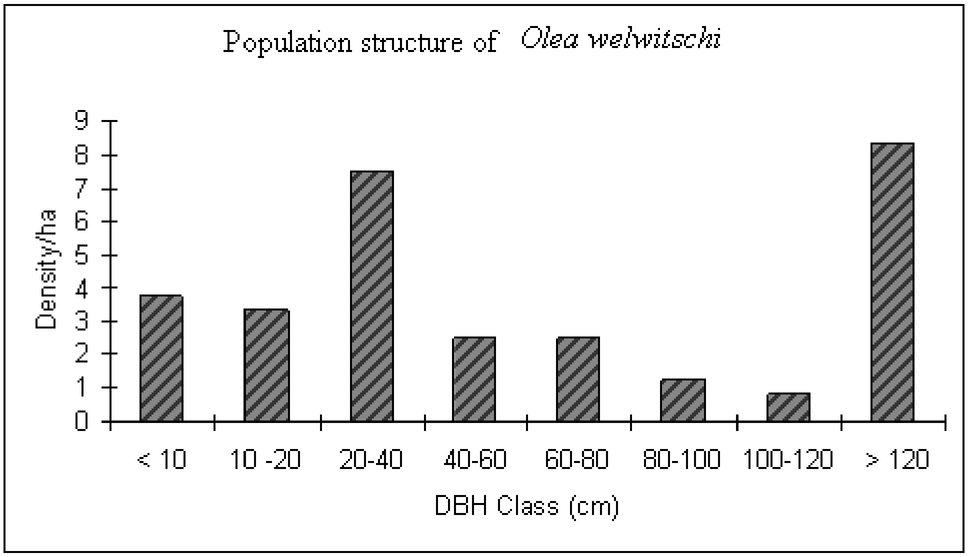
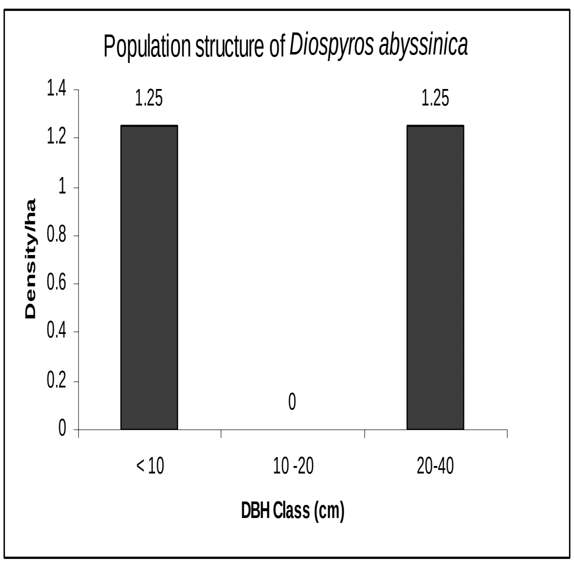


Fig. 6d



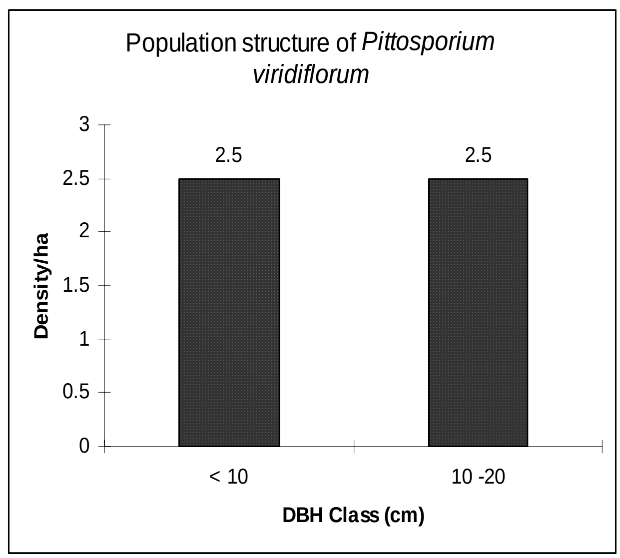


Fig. 6e

Fig. 6f

Fig. 6a-f: Population structure of tree species in Bibita Forest (Gura Ferda).

5.6 Regeneration status of Bibita Forest (Gura Ferda)

The composition and density of seedlings and saplings of tree species in Bibita Forest were included in this study. The number and type of seedlings and saplings in any forest shows the regeneration status of that forest. The tree species in the study area were categorized into two groups based on the number of seedlings and saplings encountered during the study (Table 13).

Group "A" = species with ≥1 seedlings
Group "B" = species with no seedling at all

From this study, 1498.1 seedlings and 1057.1 saplings/ha were recorded from 34 tree species (Annex 6). These tree species contributed to 17.9% of the total floristic composition of the study area. Eight species contributed to 67.3% and 70.8% of the total seedling and sapling count respectively. These are *Chionanthus mildbraedii*, *Lepidotrichilia volkensii*, *Albizia gummifera*, *Vepris dainellii*, *Galinieria saxifrage*, *Rothmannia urcelliformis,* and *Coffea arabica*. *Apodytes dimidiata* and *Phoenix reclinata* occur only in the seedling stratum. *Antiaris toxicaria, Trichilia sp, Trichilia emetica*, *Diospyros abyssinica* and *Mitragyna rubrostipulata* have no seedlings as well as saplings in the study area. All the rest occur as matured tree species as well. The ratio of parent plant to seedling was 1:2.2 and that of sapling was 1:1.6. The composition, distribution and density of seedlings and saplings indicate the future status of the forest. Coming to the conservation priorities, the tree species in "B" category should be given priority for conservation.

Table 13: The regeneration status of different tree species in Bibita Forest, (Gura Ferda)

N0	**"A"**	**"B"**
1	*Ficus thonningii*	*Trichilia sp.*
2	*Syzygium guineense*	*Diospyros abyssinica*
3	*Polyscias fulva*	*Antiaris toxicaria*
4	*Ocotea kenyensis*	*Mitragyna rubrostipulata*
5	*Phoenix reclinata*	*Trichilia emetica*
6	*?Harungana madagascariensis*	
7	*Prunus africana*	
8	*Apodytes dimidiata*	
9	*Pittosporum viridiflorum*	
10	*Olea welwitschii*	
11	*Ficus sur*	
12	*Dombeya torrida*	
13	*Alangium chinense*	
14	*Celtis africana*	
15	*Cassipourea malosana*	
16	*Manilkara butugi*	
17	*Cordia africana*	
18	*Millettia ferruginea*	
19	*Dracaena steudneri*	
20	*Croton macrostachyus*	
21	*Pouteria adolfi-friederci*	
22	*Allophylus abyssinicus*	
23	*Albizia grandibracteata*	
24	*Macaranga capensis*	
25	*Schefflera abyssinica*	
26	*Trilepisium madagascariense*	
27	*Ilex mitis*	
28	*Chionanthus mildbraedii*	
29	*Lepidotrichilia volkenssii*	

30	*Albizia gummifera*
31	*Vepris dainellii*
32	*Galinieria saxifraga*
33	*Rothmannia urcelliformis*
34	*Coffea Arabica*

5.7 Phytogeographical comparison

Bibita Forest is characterized by moist afromontane forest type vegetation. The most characteristic tree species of afromontane rainforest (Linda and Morison 1974; Friis *et al.*, 1982) are found in this study site. These are *Pouteria adolfi-friedercii, Diospyros abyssinica, Mitragyna rubrostipulata, Olea welwitschii, Prunus africana and Sysygium guineense* subsp. *afromontanum*. The altitude range of afromontane rainforest is mostly between 1200–2500 m, the mean annual rainfall lies between 1250 and 2500 mm (Friis *et al.*, 1982; White, 1983). The study site ranges from 1650–2055 m at the tip of Camti Mountain near Bibita village and is in the range of afromontane rainforest vegetation type.

Bibita Forest (Gura Ferda) is compared with five other afromontane forests in Ethiopia. These included Masha Anderacha, Harenna, Jibbat, Jemjem and Menagesha Suba.

Masha Anderacha is a moist afromontane forest located in southwest Ethiopia, about 650 km from Addis Ababa. It is located between $07^{0}30^{'}$–$08^{0}00^{'}$N and $35^{0}30^{'}$–$36^{0}00^{'}$E and lies between 1250 m and 2700 m a.s.l. (Kumelachew Yeshitela and Taye Bekele, 2003). Jibbat forest is a transitional forest between dry evergreen afromontane and moist evergreen afromontane forest. It is found in western Shewa (Central Ethiopia) about 200 km from Addis Ababa. It extends from 2000 m to 3000 m altitude a.s.l. (Tamrat Bekele, 1994). Harenna Forest is located in the Bale Mountain National Park in southern Ethiopia. It is an example of transitional forest between dry evergreen afromontane and moist evergreen afromontane forests. Its altitude ranges from 1510–3250 m (Zerihun Woldu *et al.*, 1989). Jemjem Forest is a dry evergreen afromontane forest and is located in Southern Ethiopia within a geographical location of $38^{0}5'$ and $39^{0}29'$–$5^{0}32'$ and $5^{0}33'$ N, and lies between 1570 m and 1940 m a.s.l. (Hailu Sharew, 1982). Menagesha Suba is well-protected state forest located about 30 m southwest of Addis Ababa. It is a dry evergreen afromontane forest and located between $38^{0}32'$ and $38^{0}34'$ E – $8^{0}56'$ and $9^{0}00'$ N. Its northern and southern peaks are 3350 m and 3300 m respectively (Sebsebe Demisew, 1980).

These forests were compared with Bibita Forest (Gura Ferda) based on similarities in species distribution. Tree and shrub species were used in this similarity analysis. The similarity index used to evaluate the similarity of Bibita Forest with these forests is Sorensen's similarity index. Table 14 shows the floristic distribution similarity between Bibita Forest (Gura Ferda) and the other five-afromontane forests in Ethiopia.

a = common to Bibita and the forest in comparison,

b = found only in Bibita Forest,

c = found only in the forest in comparison with Bibita,

Sc = Sorensen`s similarity coefficient,

Ds = Dissimilarity.

Table14: Comparison of Bibita Forest (Gura Ferda) with other 5 forests in Ethiopia based on their similarities/differences

Forest	a	b	c	Sc	Ds
Masha Anderacha	52	35	41	0.58	0.42
Harenna	44	43	40	0.51	0.49
Jibbat	25	62	23	0.37	0.63
Jemjem	27	60	39	0.35	0.65
Menagesha Suba	15	72	25	0.24	0.76

Bibita Forest, (Gura Ferda) showed the highest floristic similarity (0.58) with Masha Anderacha Forest. Both its range of altitude and geographical location are very similar to Bibita Forest (Gura Ferda). Both are among the moist montane forests in southwest Ethiopia. These common characteristics of the two forests contributed to their similarity in their vegetation.

Harenna Forest in south Ethiopia showed close similarity with Bibita Forest following Masha Anderacha. The intermediate position that the forest occupied between dry and moist evergreen montane forests might contribute to this high similarity. The altitudinal range of the study site at Bibita (1650-2055 m) is all in all within the altitudinal range (1510-3250 m) of Harenna Forest.

Even though it is a transitional forest between dry evergreen and moist evergreen afromontane forests, the floristic similarity of Jibbat Forest with Bibita Forest (Gura Ferda) was found to be less than that with Harenna Forest. Variation in altitude may be the most probable factor that contributed to this result.The altitudinal range shared by Bibita Forest and Jibbat is only from 2000 m to 2055 m, which might not contribute much to the similarity in their vegetation composition.

The floristic similarity of the two dry evergreen afromontane forests with Bibita Forest is much less than the similarities Bibita Forest shared with moist and transitional afromontane forests. From the two dry evergreen afromontane forests the phytosociology of Menagesha Suba was the least. Jemjem Forest with similarity index of 0.35 shared a wide range of altitude with Bibita Forest while the altitude of Menagesha Suba is very different from that of Bibita Forest. This may be a reason for the variation in phytosociological association of the two dry evergreen afromontane forests with Bibita Forest (Gura Ferda).

5.8 Soil Environmental factors

The result of environmental factors for all communities in Bibita Forest (Gura Ferda) is shown in Table 15a and b. It is also graphically represented in Fig. 7a and b. The relationship of different environmental factors with each other is shown in Table 16a and b. Annex 7 and 8 show soil environmental parameters for each relevé.

Table 15a: Mean values of soil environmental variables (topsoil) and community types. (n = 2-20 relevés, mean ± sd.)

Community	PH	EC (ms/cm)	% Sand	% Silt	% Clay
1	5.67 ± 0.23	0.46 ± 0.10	62 ± 15.03	20 ± 4.94	18±11.03
2	6.09 ± 0.28	0.38 ± 0.16	53 ± 11.65	24 ± 5.08	23 ± 8.17
3	6.34 ± 0.19	0.49 ± 0.10	61 ± 7.99	23 ± 5.76	16 ± 4.67
4	6.22 ± 0.36	0.40 ± 0.15	53 ± 8.82	24 ± 4.65	23 ± 6.75
5	6.06 ± 0.21	0.37 ± 0.10	60 ± 12.27	21 ± 6.78	19 ± 8.53
6	6.33 ± 0.92	0.47 ± 0.02	53 ± 12.02	24 ± 5.66	23 ± 6.36

Table 15b: Mean values of soil environmental variables (subsoil) and community types. (n = 2-20 relevés, mean ± sd.).

Community	pH	EC	% Sand	% Silt	% Clay
1	5.20 ± 0.27	0.88 ± 0.58	39.2 ± 14.82	28.00 ±5.0	32.00 ±11.62
2	5.87 ± 0.39	0.18 ± 0.13	44.43 ±18.22	26.57± 7.25	29 ± 13.36
3	6.34 ± 0.27	0.23 ± 0.05	44.60 ± 8.71	28.80 ± 5.01	26.60 ± 8.65
4	5.98 ± 0.55	0.18 ± 0.13	43.80 ± 17.11	29.05 ± 7.35	27.15 ±15.01
5	5.68 ± 0.27	0.12 ± 0.04	35.00 ± 6.71	29.33 ± 2.65	35.67 ± 7.75
6	5.43 ± 0.19	0.13 ± 0.004	51.00 ± 29.70	24.00 ± 8.49	25.00 ±21.21

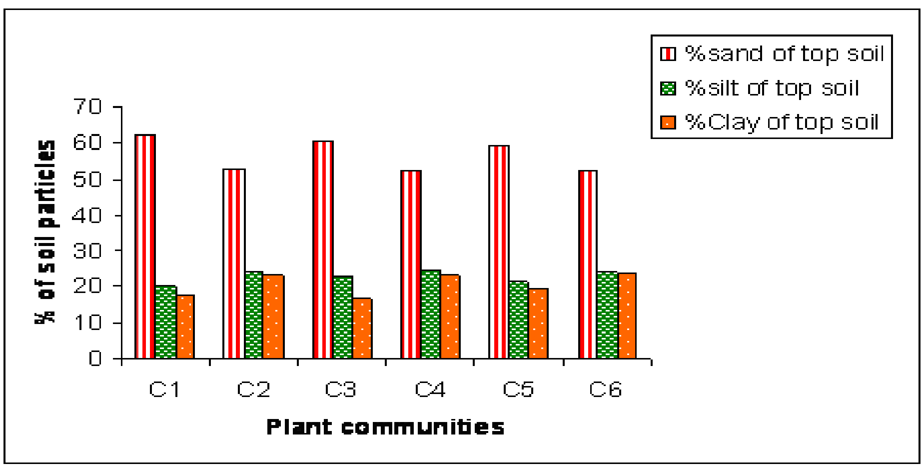


Fig. 7a: Soil texture (topsoil) in relation to plant communities

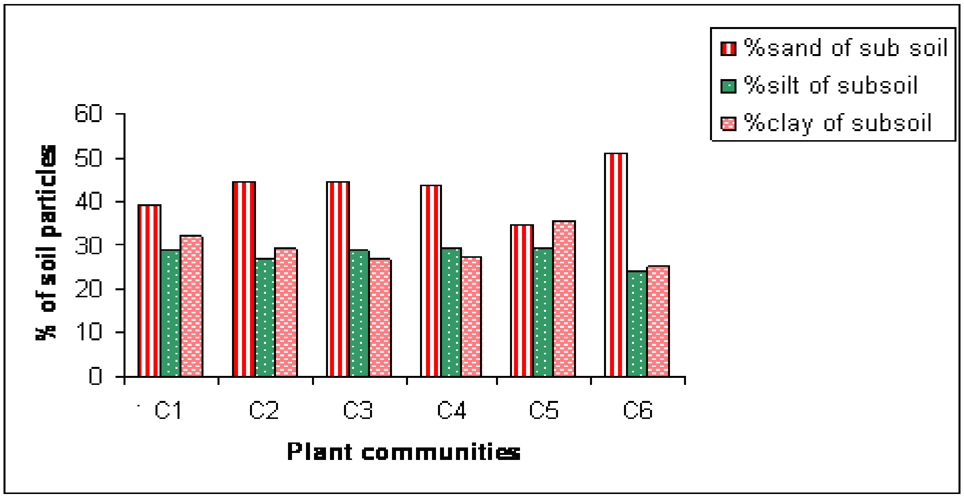


Fig. 7b: Soil texture (subsoil) in relation to plant communities

Table 16a: Pearson's Correlation coefficient for soil parameters (topsoil) and altitude (a = Correlation is significant at the 0.05 level, b = Correlation is significant at the 0.01 level)

Parameters	pH	EC	% Sand	% Silt	% Clay	Altitude
pH	-					
EC	0.330(a)	-				
% sand	-0.067	0.253	-			
% Silt	0.013	-0.107	-0.774(b)	-		
% Clayl	0.086	-0.288(a)	-0.912(b)	0.447(b)	-	
Altitude	-0.392(b)	0.153	0.120	0.019	-0.183	-

Table 16b: Pearson's Correlation coefficient for soil parameters (subsoil) and altitude (a = Correlation is significant at the 0.05 level, b = Correlation is significant at the 0.01 level)

Parameters	pH	EC	% Sand	% Silt	% Clay	Altitude
pH	-					
EC	0.619(b)	-				
%Sand	0.164	0.191	-			
% Silt	0.121	0.045	-0.605(b)	-		
%Clay	-0.259(a)	-0.254(a)	-0.922(b)	0.251	-	
Altitude	-0.269(a)	-0.111	0.044	0.025	-0.066	-

The minimum and maximum pH of topsoil in all the six communities is 5.67 and 6.34 respectively. The communities at higher altitude are relatively acidic when compared to the others, which are found in the lower altitude. The pH of subsoil ranges from 5.1 to 6.34. The pH of soil for communities in the higher altitude is also more acidic in case of subsoil too. Electrical conductivity values range from 0.37 to 0.49 for topsoil and 0.09 to 0.23 for subsoil.

Topsoil and subsoil pH values are significantly negatively correlated with altitude ($P < 0.01$, 0.05 respectively). The pH of topsoil is positively correlated ($r = 0.33$) with electrical conductivity of topsoil and this is statistically significant ($P < 0.05$). The pH of topsoil in communities 2, 3, 4, 5, and 6 were above 6.0 showing slight acidity and that of community 1 was found to be between 5.0 and 6.0 showing relatively more acidity than 2, 3, 4, 5, and 6 communities.

The pH of subsoil for community 3 was above 6.0, while those of the subsoil in communities 1, 2, 4, 5 and 6 were found to be between 5 and 6. The pH values of subsoil for all communities were found to be more acidic than that of topsoil except that of community 3.

Sand particles (% sand) of both top and subsoil were positively correlated with altitude but the correlation in the subsoil was not significant ($P < 0.05$). Sand particle is strongly negatively correlated with both silt and clay particles.Analysis of Variance (ANOVA) for different environmental factors for both topsoil and subsoil is given in Table 17a and b.

Table 17a: Summary of ANOVA for properties of topsoil

Treatment	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups Within Groups Total	2.499 4.454 6.953	5 54 59	0.500 0.082	6.060	0.000
EC	Between Groups Within Groups Total	0.085 1.108 1.193	5 54 59	0.017 0.021	0.827	0.536
% sand	Between Groups Within Groups Total	1010.163 6876.687 7886.850	5 54 59	202.033 127.346	1.586	0.180
% Silt	Between Groups Within Groups Total	153.333 1498.600 1651.933	5 54 59	30.667 27.752	1.105	0.369
% Clay	Between Groups Within Groups Total	416.563 3536.020 3952.583	5 54 59	83.313 65.482	1.272	.289

Table 17b: Summary of ANOVA for properties of subsoil

Treatment	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
PH	Between Groups Within Groups Total	6.188 9.213 15.401	5 54 59	1.238 0.171	7.254	0.000
EC	Between Groups Within Groups Total	0.101 0.608 0.709	5 54 59	0.020 0.011	1.795	0.129
%sand	Between Groups Within Groups Total	860.905 13403.429 14264.333	5 54 59	172.181 248.212	0.694	0.630
% Silt	Between Groups Within Groups Total	103.405 2164.779 2268.183	5 54 59	20.681 40.088	0.516	0.763
%Clay	Between Groups Within Groups Total	601.100 9047.750 9648.850	5 54 59	120.220 167.551	0.718	0.613

Analysis of Variance (ANOVA) showed that there was statistically significant difference in altitude (F = 14.506), pH of topsoil (F = 6.06) and pH of subsoil (F = 7.254) among all the communities.

5.8.1 Environmental factors and species diversity and richness

Environmental factors such as altitude, pH, soil texture etc affect species diversity and richness. The output of pearson`s correlation coefficient showed the effect of environmental factors with species diversity and richness (Table 18a). The analysis of variance for species diversity, richness and alttitude is also shown in Table 18b).

Table 18a: Pearson's correlation coefficient showing the relationship of species diversity and richness with the environmental factors (pHt = pH of topsoil, ECt = electrical conductivity of topsoil, %st = % sand of topsoil, %ct = % clay of topsoil, %slt = % silt of topsoil, pHs = pH of subsoil, ECs = EC of subsoil, %ss = % sand of subsoil, %cs = % clay of subsoil, %sls = % silt of subsoil, Sr = species richness, Sd = species diversity, al = altitude, a = Correlation is significant at the 0.05 level, b = Correlation is significant at the 0.01 level)

	pHt	ECt	%st	%ct	%slt	pHs	ECs	%ss	%cs	%sls	Sr	Sd	al
pHt	-												
ECt	.33a	-											
%st	-.07	.25	-										
%ct	.01	-.11	-.77b	-									
%slt	.07	-.29a	-.91b	.45b	-								
pHs	.56b	.13	.04	.06	-.10	-							
ECs	.18	-.09	-.06	.08	.04	.62b	-						
%ss	.10	.04	-.23	.18	.20	.16	.19	-					
%cs	-.004	.06	.29a	-.22	-.27a	.12	.05	-.61b	-				
%sls	-.12	-.07	.13	-.11	-.12	-.26a	-.26a	-.92b	.25	-			
Sr	.26a	-.17	-.23	.27a	.15	.22	.09	.06	-.04	-.06	-		
Sd	.26a	-.13	-.30a	.30a	.23	.17	.93	.12	-.13	-.08	.74b	-	
Al	-.39b	.15	.12	.02	-.18	-.27a	-.11	.04	.03	-.07	-.56b	-.48b	-

Table 18b: Sumary of ANOVA for species richness, diversity and altitude

Treatments	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Species richness	Between Groups	2735.849206	5	547.1698413	14.44084	.000
	Within Groups	2046.084127	54	37.8904468		
	Total	4781.933333	59			
Species diversity	Between Groups	2.203582083	5	0.440716417	5.94679	0.0001889
	Within Groups	4.0019381	54	0.074109965		
	Total	6.205520183	59			
Altitude	Between Groups	385834.9159	5	77166.98317	14.50557	.000
	Within Groups	287270.0675	54	5319.816064		
	Total	673104.9833	59			

Pearson's product–moment correlation coefficient matrix between species diversity and environmental factors showed that heterogeneity (H') has significant negative correlation (r = - 0.48) with altitude and %sand of topsoil (r = - 0.30) (at P < 0.01 level) and positive correlation with pH of topsoil (r = 0.26) (P <0.05) and % clay of topsoil (r = 0.30) (P < 0.05) and % silt of topsoil was not significant (r = 0.23). The eclectrical conductivity of top and subsoil, pH of subsoil, and the three soil particles of subsoil have no significant correlation with species diversity.

Species richness has significant negative correlation (r = -0.56) with altitude at P < 0.01 levels. It also showed significant positive correlations (r = 0.26) at P < 0.05 level with pH of topsoil and % clay of topsoil (r = 0.27) (p < 0.05).

The analysis of variance also showed significant difference among the communities at (F = 14.441) in relation to species richness and at (F=5.947) in species diversity (p < 0.05 significance level).

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 altitude and as a result the soil acidity increases with rising altitude and this could affect the chemical reaction between plant roots and nutrients, the availability of nutrients in the soil for plant use, and microbial activity. These could be the possible reasons for declining of species richness and diversity with altitude. The communities with more acidic characteristics than others are found at the top of the mountain.

6 CONCLUSIONS

From the study of floristic composition of Bibita Forest, (Gura Ferda), 192 species of plants belonging to 170 genera and 74 families were identified. Rubiaceae had the highest number of species. Out of 192 species 12 were endemic to Ethiopia.

Vegetation of Bibita Forest (Gura Ferda) is grouped into six community types. The communities at the bottom and middle of the altitudinal gradient were found to be rich in species composition while the community restricted to the top (above 2000 m) was poor in species composition. Lianas are mostly restricted to the communities below 2000 m.

pH of both top and subsoils were negatively correlated with altitude. Acidity increases with altitude.

The density of tree species in Bibita Forest (Gura Ferda) decreases with increasing DBH and Height classes. The forest is characterized by high density of trees in the lower class than in the higher. Thus, the forest is in good state of recruitment.

Three layers were identified from the study of vertical stratification of Bibita Forest (Gura Ferda) - the tree layer, the shrub layer, and the field (herb) layer. The tree layer is further divided in to three tree layers (the upper, the middle and the lower storey). The trees in the upper layers were *Albizia gummifera, Croton macrostachyus, Ficus sur, Macaranga capensis, ?Harungana madagascariensis, Olea welwitschii* and *Polyscias fulva.*The presence of three tree layers is a characteristic of rainforest. *Olea welwitschii* is the emergent tree of Bibita Forest.

The tree species population structure showed different dynamics. Most species have high population in the lower DBH and Height classes. Few species occur in all DBH and Height classes showing variation in population size.

The regeneration status of Bibita Forest (Gura Ferda) was studied by taking tree species alone. This study showed that Bibita Forest, (Gura Ferda) is in a good state of regeneration.

7 RECOMMENDATIONS

Bibita Forest (Gura Ferda) is one of the remnant forests in Ethiopia. To conserve this forest appropriate management strategy is vital.

This study is only on one site of Gura Ferda Forest. Because of the limited resources available it had not been possible to cover the whole forest in this study. The study of the whole Gura Ferda Forest is recommended to know the current status of the entire forest.

The presence of *Ipomoea involucrata and ?Harungana madagascariensis*(new records for Ethiopia) is an indication of the potential of the area for the presence of more species which have not been recorded in the flora area so far. Thus, further study on the whole Gura Ferda forest is recommended to bring many unknown species into sight.

Nine plant species and three subspecies were found to be endemic to Ethiopia. This shows that the area has a potential for the presence of more endemic species. Thus, further study on the whole Gura Ferda Forest is recommended.

One of the threats to the forest vegetation of Bibita Forest (Gura Ferda) is the settlement program being carried out in the area. There is an urgent need for an open discussion between the communities, political and administrative bodies to come up with concrete alternative plan that would help the people without destroying all the forest.

Shekos (the Indigenous people) use *Cordia africana* (one of the indigenous species) for making beehives. This has affected the population structure of *Cordia africana* in this forest. Introducing the local people to modern beehives and bee keeping techniques would save this tree species from its elimination from the forest.

The living style of Sheko people has been responsible for the existence of this forest so far. The local knowledge of these people concerning vegetation conservation should be studied.

Even though it is not included in this study, Sheko people use forest plants for different purposes. Thus, detailed ethno-botanical study on Bibita Forest (Gura Ferda) is highly recommended.

Bibita Forest (Gura Ferda) has been out of sight of the scientific community so far. This may be because of its remoteness and lack of infrastructure. The concerned bodies should give due attention to solve the infrastructure problems and the scientific community should devote more time to look at this poorly known forest.

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APPENDICES

Annex1: Species list collected from Bibita Forest (Gura Ferda). (Ha = habit, T = tree, S = shrub, H = herb, T/S = tree/shrub, C = climber, Scs = scandent shrub, CH = climbing herb, E = epiphyte, F = fern, V.N = Vernacular name)

No	*Species*	Family	Sheko language	Ha	Coll. No
1	*Abutilon ramosum* Guill. & Perr.	Malvaceae		H	D91
2	*Acalypha racemosa* Baill.	Euphorbiaceae	Shotti	H	D81
3	*Acanthus eminens* C.B.Clarke	Acanthaceae	Oso	S	D102
4	*Achyranthes aspera* L.	Amaranthaceae	Zada	H	D52
5	*Achyrospermum schimperi* (Hochst. ex Briq.) Perkins	Lamiaceae		H	D151
6	*Adenostemma perottettii* DC.	Asteraceae	Xianqubay	H	D118
7	*Aerangis brachycarpa* (A. Rich.) Th. Dur. & Schinz.	Orchidaceae		E	D167
8	*Aframomum latifolium* K.Schum.	Zingberaceae		H	D77
9	*Albizia grandibracteata* Taub.	Fabaceae	Zina	T	D144
10	*Albizia gummifera* (J.F. Gmel.) C.A. Sm.	Fabaceae		T	D11
11	*Alchemilla fischeri* Engl.	Rosaceae		H	D180
12	*Allophylus abyssinicus* (Hochst.) Radlk.	Sapindaceae		T	D188
13	*Allophylus macrobotrys* Gilg.	Sapindaceae		S	D189
14	*Amorphophallus gallaensis* (Engl.) N.E. Br.	Araceae	Wumu	H	D113
15	*Pouteria adolfi-friedercii* (Engl.) Baehni	Sapotaceae	Gomu	T	D191
16	*Antiaris toxicaria* Lesch	Moraceae	Fana	T	D161
17	*Apodytes dimidiata* E. Mey. ex Arn.	Icacinaceae	Okam	T	D30
18	*Ardisiandra sibthorpioides* Hook.f.	Primulaceae	Goshcaru	H	D73
19	*Arisaema schimperianum* Schott	Araceae	Humu	H	D47
20	*Artabotrys monteiroae* Oliv.	Anonaceae	Caxu	S	D110
21	*Arthropteris monocarpa* (Cordem.) C. Chr.	Oleandraceae		F	D93
22	*Asparagus racemosus* Willd.	Asparagaceae	Daro	S	D41
23	*Aspilia mosambicensis* (Oliv.) Wild.	Asteraceae	Kirshu	S	D119
24	*Asplenium dregeanum* Kunze.	Aspleniaceae	Cencu	F	D20
25	*Asplenium sandersonii* Hook.	Aspleniaceae	Cencu	F	D21
26	*Asystasia gangetica* (L.) T. Anders. subsp *micrantha* (Nees) Ensermu	Acanthaceae		H	D103
27	*Basananthe hanningtoniana* (Mast.) de Wilde	Passifloraceae		H	D169
28	*Basella alba* L.	Baselaceae	Amu	C	D99
29	*Bersama abyssinica* Fresen.	Melianthaceae	Toshka	S	D10
30	*Bothriocline schimperi* Oliv. & Hiern ex Benth.	Asteraceae		S	D120
31	*Brachiaria lata* (Schumach.) C. E. Hubb.	Poaceae		H	D174
32	*Bridelia micrantha* (Hochst.) Baill.	Euphorbiaceae	Ucham	S	D139
33	*Brillantaisia grotanellii* Pichi- Serm.	Acanthaceae		H	D104
34	*Carissa spinarum* L.	Apocynaceae		S	D111
35	*Cassipourea malosana* (Baker.) Alston	Rhizophoraceae	Gusha	T	D88
36	*Celtis africana* Burm.f.	Ulmaceae	Dira	T	D86
37	*Chionanthus mildbraedii* (Gilg & Schellenb.) Stearn	Oleaceae	Merqu	T	D5
38	*Chloachne oplismenoides* (Hack.) Robyns	Poaceae		H	D175
39	*Chlorophytum comosum* (Thunb.) Jacq.	Araceae	Wonu	H	D85
40	*Christella dentata* (Forsk.) Holtt.	Thelypteridaceae	Susa	F	D67
41	*Cissampelos mucronata* A. Rich.	Menispermaceae		C	D160

42	*Cissus petiolata* Hook.f.	Vitaceae	Asqusa	C	D39
43	*Clausena anisata* (Willd.) Benth.	Rutaceae	Durbay	S	D12
44	*Clematis hirsuta* Perr. & Guill.	Ranunculaceae	Urnus	C	D40
45	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	Di'i	S	D56
46	*Coccinia schliebenii* Harms	Cucurbitaceae		Ch	D131
47	*Coffea arabica* L.	Rubiaceae	Genu	T/S	D59
48	*Combretum paniculatum* Vent.	Combretaceae	Nocho	S	D37
49	*Commelina diffusa* Burman	Commelinaceae	Zobi	H	D31
50	*Commelina imberbis* Ehrenb. ex Hassk	Commelinaceae	Zobi	H	D33
51	*Cordia africana* Lam.	Boraginaceae	Giqa	T	D63
52	*Crassocephalum crepidioides* (Benth.) S. Moore	Asteraceae	Tunqush	H	D89
53	*Crotalaria petitiana* (A. Rich.) Walp.	Fabaceae	Xopharo	H	D145
54	*Croton macrostachyus Del.*	Euphorbiaceae	Woshu	T	D3
55	*Culcasia falcifolia* Engl.	Araceae		C	D114
56	*Cyphostemma cyphopetalum* (Fresen.) Descoings ex Wild & Drummond.	Vitaceae	Xiaru	C	D57
57	*Dalbergia lactea* Vatke	Fabaceae		S	D146
58	*Desmodium repandum* (Vahl) DC.	Fabaceae	Soqusoski	H	D17
59	*Didymochlaena truncatula* (SW.) J. Sm.	Dryopteridaceae	Ziqu	F	D138
60	*Dioscorea schimperiana* Hochst. ex A.Rich.	Dioscoriaceae	Berkamu	C	D137
61	*Diospyros abyssinica* (Hiern) F. White	Ebenaceae	Kuri	T	D65
62	*Diplocyclos palmatus (*L.) C.Jeffrey	Cucurbitaceae		H	D132
63	*Dombeya torrida* (J. F. Gmel.) P. Bamps.	Sterculiaceae	Bobco	T	D46
64	*Dorstenia barnimiana* Schweinf.	Moraceae		H	D162
65	*Dorstenia brownii* Rendle	Moraceae	Ferenjqumci	H	D19
66	*Dracaena afromontana* Mildbr.	Dracaenaceae	Gorcha	S	D25
67	*Dracaena fragrans* (L.) Ker Gawl.	Dracaenaceae	Gorcha	S	D70
68	*Dracaena steudneri* Engl.	Dracaenaceae	Osto	T	D100
69	*Droguetia iners* (Forssk.) Schweinf.	Urticaceae		H	D74
70	*Drymaria cordata* (L.) Schultes in Roem. Schultes	Caryophyllaceae		H	D128
71	*Drynaria volkensii* Hiern.	Polypodiaceae		E	D178
72	*Ehretia cymosa* Thonn.	Boraginaceae	Derma	T/S	D90
73	*Elatostema monticolum* Hook.f.	Urticaceae		H	D66
74	*Embelia schimperi* Vatke	Myrsinaceae		C	D165
75	*Ensete ventricosum* (Welw.) Cheesman	Musaceae	Geiba	H	D24
76	*Erythrococca trichogyne* (Muell.Arg.) Prain	Euphorbiaceae	Cicqa	S	D96
77	*Euphorbia schimperiana* Scheele	Euphorbiaceae		H	D140
78	*Alangium chinense* (Lour.) Harms	Alangiaceae	Hora	T	D44
79	*Ficus sur* Forssk.	Moraceae	Shamu	T	D53
80	*Ficus thonningii* Blume	Moraceae	Situ	T	D163
81	*Flacourtia indica* (Burm. f.) Merr.	Flacourtiaceae		S	D149
82	*Galinieria saxifraga* (Hochst.) Bridson	Rubiaceae	Tsinda	T	D9
83	*Girardinia diversifolia* (Lisk) Friis	Urticaceae	Dubo	H	D97
84	*Gloriosa superba* L.	Colchicaceae	Qabtsu baykachi	H	D130
85	*Glycine wightii* (Wight & Arn.) Verdc. subsp. *wightii* var. *longicauda* (Schweinf.) Verdc.	Fabaceae	Doru xorsi	C	D147
86	*Gouania longispicata* Engl.	Rhamnaceae	Pucu	C	D98
87	*Grewia ferruginea* Hochst. ex A. Rich.	Tiliaceae		S	D198
88	*Habenaria malacophylla* Rchb.f.	Orchidaceae		H	D168

Annex 1 continued

89	*?Harungana madagascariensis* Lam.ex Poir.	Clusiaceae	Ashu	T	D4
90	*Hibiscus macranthus* Hochst. ex A. Rich	Malvaceae	Suska	H	D156
91	*Hibiscus physaloides* Guill & Perr.	Malvaceae		H	D157
92	*Hippocratea africana* (Willd.) Loes.	Celastraceae	Esuku	C	D129
93	*Hippocratea goetzei* Loes.	Celastraceae	Zurga	C	D14
94	*Hymenodictyon floribundum* (Hochst. & Steud.) Robinson	Rubiaceae	Haygeni	S	D42
95	*Hyparrhenia rufa* (Nees) Stapf	Poaceae	Fasha	H	D176
96	*Ilex mitis* (L.) Radlk.	Aquifoliaceae	Disha	T	D2
97	*Impatiens aethiopica* Grey- Wilson.	Balsaminaceae	Kata	H	D48
98	*Ipomoea involucrate* Beauv.	Convolvulaceae	Shirtu	C	D49
99	*Isodon ramosissimus* (Hook. f.) Codd.	Lamiaceae		H	D152
100	*Isoglossa punctata* (Vahl) Brummitt. & Wood	Acanthaceae		H	D106
101	*Isoglossa somalensis* Lindau	Acanthaceae		S	D105
102	*Jasminum abyssinicum* Hochst. ex DC.	Oleaceae	Compay	C	D62
103	*Justicia diclipteroides* Lindau subsp. *aethiopica* Hedren	Acanthaceae	Qumbay	H	D107
104	*Keetia gueinzii* (Sond.) Bridson	Rubiaceae	Shikara	S	D181
105	*Kyllinga bulbosa* P. Beauv.	Cyperaceae	Bider	H	D134
106	*Lagenaria abyssinica* (Hook.f.) C. Jeffrey.	Cucurbitaceae		Ch	D92
107	*Landolphia buchananii* (Hall.f.) Stapf.	Apocynaceae	Yerimbay	C	D13
108	*Lepidotrichilia volkensii* (Gurke) Leroy	Meliaceae	Shahu	T	D6
109	*Ludwigia abyssinica* A. Rich.	Onagraceae		H	D166
110	*Lycopersicon esculentum* Mill.	Solanaceae		H	D195
111	*Macaranga capensis* (Baill.) Sim.	Euphorbiaceae	Jaro	T	D35
112	*Maesa lanceolata* Forssk.	Myrsinaceae	Tura	T/S	D79
113	*Manilkara butugi* Chiov.	Sapotaceae	Gosha	T	D192
114	*Mariscus sieberianus* Nees	Cyperaceae	Eja	H	D135
115	*Maytenus gracilipes* (Welw. ex Oliv.) Exell.subsp. arguta (Loes.) Sebsebe.	Celastraceae	Shiqu	S	D28
116	*Micractis bojeri* DC.	Asteraceae		H	D121
117	*Microglossa pyrifolia* (Lam.) Kuntze.	Asteraceae		S	D122
118	*Mikaniopsis clematoides* Sch. Bip.ex A.Rich Milne-Redh.	Asteraceae		H	D123
119	*Millettia ferruginea* (Hochst.) Bak.	Fabaceae	Ziagu	T	D101
120	*Mitragyna rubrostipulata* (K. Schum.) Havil.	Rubiaceae	Opho	T	D182
121	*Momordica foetida* Schumach.	Cucurbitaceae	Shishu	Ch	D69
122	*Ocimum lamiifolium* Hochst. ex Benth.	Lamiaceae		S	D153
123	*Ocotea kenyensis* (Chiov.) Robyns & Wilczek.	Lauraceae	Hujuri	T	D1
124	*Olea welwitschii* (Knobl.) Gilg & Schellenb.	Oleaceae	Zemu	T	D27
125	*Oncinotis tenuiloba* Stapf.	Apocynaceae		C	D112
126	*Oncoba routledgei* Sprague	Flacourtiaceae	Shareboko	S	D150
127	*Oplismenus compositus* (L.) P. Beauv	Poaceae	Bongu	H	D16
128	*Oxyanthus lepidus* S. Moore. var. *lepidus*	Rubiaceae		S	D183
129	*Oxyanthus speciosus* DC. subsp. *gerardii* (Sond.) Bridson	Rubiaceae	Goragoit	T/S	D7
130	*Paullinia pinnata* L.	Sapindaceae		C	D190
131	*Pavetta abyssinica* Fresen. var. *abyssinica*	Rubiaceae	Nophay	S	D87
132	*Pavonia urens* Cav.	Malvaceae		S	D158
133	*Pennisetum squamulatum* Fresen.	Poaceae	Gelda	H	D177
134	*Pentarrhinum abyssinicum* Decne	Asclepiadiaceae		C	D36
135	*Pentas lanceolata* (Forssk.) Deflers	Rubiaceae		H	D184

Annex 1 continued

136	*Pentas tenuis* Verdc.	Rubiaceae	Shinta	H	D50
137	*Peperomia abyssinica* Miq.	Piperaceae		H	D171
138	*Peperomia tetraphylla* (Forster.) Hook. & Arn.	Piperaceae		E	D172
139	*Peponium vogelii (*Hook.f.) Engl.	Cucurbitaceae	Berktiamu	Ch	D61
140	*Pergularia daemia* (Forssk.) Chiov.	Asclepiadiaceae	Debeden	C	D116
141	*Oenanthe palustris* (Chiov.) Norman	Apiaceae		H	D18
142	*Phaulopsis imbricata* (Forssk.) Sweet	Acanthaceae	Qumbay	H	D108
143	*Phoenix reclinata* Jacq.	Arecaceae	Anco	T	D58
144	*Phyllanthus limmuensis* Cufod.	Euphorbiaceae	Merimesi	Scs	D141
145	*Phyllanthus mooneyi* M.Gilbert	Euphorbiaceae		H	D142
146	*Phytolacca dodecandra* L ' H'erit.	Phytolacaeae		S	D170
147	*Pilea bambuseti* Engl. subsp. *aethiopica* Friis	Urticaceae		H	D95
148	*Pilea rivularis* Wedd.	Urticaceae		H	D75
149	*Piper capense* L.f.	Piperaceae	Qetsu	H	D15
150	*Piper umbellatum* L.	Piperaceae	Qetsu	H	D173
151	*Pittosporium viridiflorum* Sims	Pittosporaceae	Deduninxi	T	D34
152	*Plectranthus assurgens* (Baker.) J. K. Morton	Lamiaceae		H	D154
153	*Polyscias fulva* (Hiern) Harms	Araliaceae	Bata	T	D55
154	*Premna schimperi* Engl.	Lamiaceae		S	D76
155	*Prunus africana* (Hook.f.) Kalkm	Rosaceae	Ota	T	D26
156	*Psydrax schimperiana* (A. Rich.) Bridson	Rubiaceae	Qarcu	S	D71
157	*Pteris atrovirens* Wild	Pteridaceae	Susa	F	D179
158	*Pteris pteridioides* (Hook.) Balland	Pteridaceae	Susa	F	D23
159	*Rhamnus prinoides* L'Herit.	Rhamnaceae	Bonku	S	D60
160	*Rothmannia urcelliformis* (Hiern) Robyns	Rubiaceae	Boko	T	D45
161	-	Rubiaceae	Nopha	T	D185
162	*Rubus steudneri* Schweinf.	Rosaceae	Tsunxubay	Scs	D64
163	*Rytigynia neglecta* (Hiern) Robyns	Rubiaceae	Mera	S	D38
164	*Sanicula elata Buch.*-Ham. ex D. Don	Apiaceae	Gaycaru	H	D29
165	*Schefflera abyssinica* (Hochst. ex A. Rich.) Harms	Araliaceae	Kabu	T	D115
166	*Scleria racemosa* Poir.	Cyperaceae		H	D136
167	*Senna obtusifolia* (L.) Irwin & Barneby.	Fabaceae		S	D148
168	*Setaria megaphylla* (Steud.) Th. Dur. & Schinz	Poaceae	Bosho	H	D82
169	*Smilax anceps* Willd.	Smilicaceae	Zuru shosh	C	D193
170	*Smilax aspera* L.	Smilicaceae	Zuru shosh	C	D194
171	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Deda	S	D124
172	*Solanum anguivi* Lam.	Solanaceae		S	D196
173	*Solanum capsicoides* Allioni	Solanaceae		S	D197
174	*Stachys aculeolata* Hook. f.	Lamiaceae		H	D155
175	*Stephania abyssinica* (Dill. & A. Rich.) Walp.	Menispermaceae	Gaybacaru	H	D84
176	*Syzygium guineense* (Willd.) DC subsp. *afromontanum* F. White.	Myrtaceae	Mutku	T	D51
177	*Teclea nobilis* Del.	Rutaceae	Gemu	S	D187
178	*Tectaria gemmifera* (Fee) Alston	Aspidiaceae	Susa	F	D22
179	*Thalictrum rhynchocarpum* Dill. & A. Rich.	Rhamnaceae		H	D94
180	*Thelypteris longicaspis* (Bak.) Schelpe	Thelypteridaceae	Susa	F	D68
181	*Thunbergia alata* Boj.ex Sims	Acanthaceae		C	D109

Annex 1 continued

182	*Tiliacora troupinii* Cuf.	Menispermaceae	Jexi	C	D54
183	*Tragia brevipes* Pax	Euphorbiaceae	Shishtu	H	D143
184	*Trichilia emetica* Vahl	Meliaceae	Dapi	T	D159
185	*Trichilia sp.*	Meliaceae	Chotto	T	D43
186	*Trilepisium madagascariense* DC.	Moraceae	Guita	T	D164
187	*Triumfetta brachyceras* K. Schum.	Tiliaceae	Kaya	H	D83
188	*Tylophoropsis sp.*	Asclepiadiaceae	Ebucaru	C	D117
189	*Urera hypselodendron (*A.Rich.) Wedd.	Urticaceae	Shibba	C	D32
190	*Vepris dainellii* (Pichi Serm.) Kokwaro	Rutaceae	Kaja	T	D8
191	*Vernonia amygdalina Del.*	Asteraceae	Baka	S	D125
192	*Vernonia auriculifera* Hiern.	Asteraceae	Buzu	S	D72
193	*Vernonia hochstetteri* Sch. Bip.ex Walp.	Asteraceae	Baytashu	S	D126
194	*Vernonia sp.*	Asteraceae	Gashtubori	S	D80
195	*Vernonia urticifolia* A. Rich.	Asteraceae		S	D127
196	*Zehneria scabra* (Linn.f.) Sond.	Cucurbitaceae		Ch	D133

Annex 2a*: Ipomoea involucrata Beauv.*

Type: Nigeria, Oware, Beauvous (G.hojo)

SYN: *Convolvulus perfoliatus* Schumach & Jhonn; Beskr. Guin, pl.:89(1827)

Type: Ghana, Thonning

Source: B. Verdcourt (1963)

An exceedingly variable annual or perennial; stems slender, twining, glabrescent to villose, up to 8 m long; leaf blade ovate to cordate, 9 (-11.5) –7 cm, acute or acuminate at the apex, hairy to villous on both surfaces; petiole 1.3–8 cm long. Inflorescence a dense head enclosed in a large foliceous boat–shaped involucre; peduncle 1–16 cm long; flowers few to many, very shortly pedicellate; bract 2.7–6.5 x 0.8–1.5 cm, ± pubescent; inner bracts small, obovate to linear–oblong, acute to aristate. Sepals 6–15 x 1.5–4 mm, glabrescent to hairy, margins setose; the outer lanceolate, the inner shorter and more ovate. Corolla purple, funnel shaped, 2–5.5cm long, 2–5cm wide at the upper part.

Plate 2: *Ipomoea involucrata* (a new record for Ethiopia)

Distribution and habitat in Ethiopia

Ipomoea involucrata is distributed throughout all the communities in Bibita Forest, (Gura Ferda) from 1735–2040 m a.s.l. It occurs mostly in open canopies.

Distribution and habitat outside Ethiopia

Distributed throughout tropical Africa from West Africa to Angola and Northern Transvaal (Verdcourt, 1963), in grassland, forest, woodland and abandoned cultivated lands.

Annex 2b: *? Harungana madagascariensis* Lam. ex Poir.

Type : Madagascar, Commerson and Martin
Source : E. Milne-Redhead (1953), eds. W.B. Turril., and E. Milne-Redhead, M.A.F.L.S

Shrub or tree upto 12 m (exceptionally 27 m) high, much branched, evergreen, with scaly bark and orange or blood-red sap. Young stems densely covered with rusty stellate or dendroid hairs. Leaves petiolate, upto 27 m long, blades laceolate to ovate, ranging from 6.5 x 4.5 cm and 8.5 x 3.5 cm to 20 x 10 cm, shortly acumnate, rounded (rarely broadly cunate, truncate or cordate) at the base, with about 14 parallel lateral veins on each side of the mid rib, glabrescent and dark glossy green above, pallid below with short glandular or rust stillate indumentum, young leaves densely rusty on both surfaces. Inflorescence a large many-flowered corymbose-cymose panicle, flowers sweet-scented. Sepals ovate-elliptic, upto 3 mm long, with a few longitudinal linear gland dots near the apex, white. Stamens 3-4 per bundle, filaments glabrous. Drupe spherical, about 4 mm diameter ; pericarp crustaceous, yellow or orange ; pyrenes each 0-2 seeded. Seeds about 2 mm long.

Plate: Harungana madagascariensis (a new record for Ethiopia)

Habitat and distribution in Ethiopia

Harungana madagascariensis Lam. ex Poir. is distributed throughout all the communities in Bibita Forest, (Gura Ferda) except in Community 5. It is found in altitudinal range between 1650 – 2050 m a.s.l. It is among the trees forming the upper canopy in the study area.

Distribution outside Ethiopia

It is distributed in Northeast Tropical Africa (Sudan); East Tropical Africa (Tanzania Kenya and Uganda); West-Central Tropical Africa (Burundi, Cameroon, Equatorial Guinea – Bioko, Rwanda, Sao Tome and Principe and Zaire); West Tropical Africa (Cote d'Ivoire, Gambia, Ghana, Guinea, Liberia, Mali, Nigeria, Senegal, and Sierra Leone); South Tropical Africa (Angola, Malawi, Mozambique, Zambia, and Zimbabwe) and Western Indian Ocean (Madagascar; Mauritius).

Annex 3: Relevés and their characteristics

Releve	altitude (m)	No of species	Latitude	Longitude
1	2054	27	06 48.120	035 06.391
2	2047	24	06 47.582	035 06.896
3	2029	28	06 48.158	035 06.410
4	2022	35	06 47.685	035 06.851
5	2004	30	06 48.170	035 06.430
6	1997	30	06 47.838	035 06.765
7	1979	34	06 48.377	035 06.461
8	1972	34	06 47.831	035 06.771
9	1954	37	06 48.361	035 06.469
10	1947	37	06 47.983	035 06.887
11	1929	43	06 48.406	035 06.483
12	1922	48	06 48.012	035 06.850
13	1904	38	06 48.432	035 06.464
14	1897	46	06 48.125	035 06.874
15	1879	40	06 48.494	035 06 561
16	1872	48	06 48.155	035 06.847
17	1854	38	06 48.532	035 06.518
18	1847	33	06 48.216	035 06.843
19	1829	42	06 48.592	035 06.536
20	1822	44	06 48.302	035 06.805
21	1804	59	06 48.622	035 06.650
22	1797	44	06 48.392	035 06.762
23	1779	51	06 48.656	035 06.568
24	1772	46	06 48.454	035 06.771
25	1754	32	06 48.700	035 06.585
26	1747	40	06 48.552	035 06.840
27	1729	41	06 48.741	035 06.605
28	1722	51	06 48.632	035 06.786
29	1704	48	06 48.776	035 06.843
30	1679	56	06 48.781	035 06.669
31	2015	45	06 48.658	035 05.930
32	1999	54	06 49.196	035 05.477
33	1990	64	06 48.650	035 05.948
34	1974	41	06 49.143	035 05.528
35	1965	45	06 48.673	035 06.007

Annex 3 continued

36	1949	36	06 49.131	035 05.634
37	1940	53	06 48.710	035 06.022
38	1924	46	06 49.178	035 05.673
39	1915	53	06 48.772	035 06.036
40	1899	55	06 49.198	035 05.612
41	1890	45	06 48.801	035 06.081
42	1874	51	06 49.254	035 05.707
43	1865	52	06 48.820	035 06.097
44	1849	41	06 49.178	035 05.740
45	1840	51	06 48.856	035 06.140
46	1824	54	06 49.226	035 05.824
47	1815	38	06 48.876	035 06.165
48	1799	50	06 49.215	035 05.892
49	1790	52	06 48.877	035 06.245
50	1774	45	06 49.187	035 05.998
51	1765	44	06 48.895	035 06.308
52	1749	51	06 49.145	035 06.126
53	1740	47	06 48.888	035 06.359
54	1724	51	06 49.117	035 06.180
55	1715	50	06 48.889	035 06.380
56	1699	53	06 49.053	035 06.169
57	1690	64	06 48.893	035 06.409
58	1674	54	06 49.022	035 06.282
59	1665	54	06 48.888	935 06.471
60	1649	55	06 48.897	035 06.494

Annex 4: Communities and the number of relevés they contained.

Community	Releves it contained	Altitude
1	1,2,3,4,5,6,7,8,35,36	1950-2055
2	9,10,12,13,17,18,19,24,25,26,27,28,29,30	1680-1955
3	11,14,15,16,20	1820-1930
4	21,31,32,33,34,37,38,39,40,41,42,43,44,45,46,47,48,49,52,54	1725-2015
5	50,51,53,55,56,57,58,59,60	1650-1775
6	22,23	1780-1800

Annex 5: Some causes of canopy gap formation in Bibita Forest, (Gura Ferda).
In some of the sample plots canopy gaps were formed due to wind throws (plates 6 and 7); branch breaks, dead standing trees and other related biotic factors (plates 8 and 9).

Plate 4: wind throws

plate 5: Wind throw

Plate 6: dead standing tree (biotic)

plate 7: effect of climbers (biotic)

Annex 6: The regeneration status of Bibita Forest (the number of seedlings and saplings per hectare of each tree species)

No	Species	Seedling count/ha	Sapling count/ha
1	*Ilex mitis*	10.4	10.0
2	*Ocotea kenyensis*	20.4	0.0
3	*Croton macrostachyus*	15.6	10.0
4	*?Harungana madagascariensis*	08.3	07.0
5	*Chionanthus mildbraedii*	180.0	120.0
6	*Lepidotrichilia volkensii*	130.0	80.0
7	*Vepris dainellii*	170.0	153.0
8	*Albizia gummifera*	180.0	110.0
9	*Prunus africana*	12.9	03.0
10	*Apodytes dimidiata*	09.6	0.0
11	*Olea welwitschii*	30.8	35.0
12	*Pouteria adolfi-friederci*	15.6	12.0
13	*Galinieria saxifraga*	70.1	75.0
14	*Pittosporum viridiflorum*	17.9	06.0
15	*Macaranga capensis*	10.4	08.0
16	*Trichilia sp.*	0.0	0.0
17	*Alangium chinense*	21.3	18.0
18	*Rothmannia urcelliformis*	173.0	115.1
19	*Dombeya torrida*	16.3	12.0
20	*Syzygium guineense*	20.4	20.0
21	*Polyscias fulva*	39.2	08.0
22	*Ficus sur*	22.1	20.0
23	*Cordia africana*	33.3	12.0
24	*Diospyros abyssinica*	0.0	0.0
25	*Millettia ferruginea*	29.2	20.0
26	*Celtis africana*	17.7	10.0
27	*Coffea arabica*	105.0	80.0
28	*Phoenix reclinata*	15.6	10.0

Annex 6 continued

29	*Trichilia emetica*	0.0	0.0
30	*Ficus thonningii*	12.1	08.0
31	*Allophylus abyssinicus*	17.1	16.0
32	*Antiaris toxicaria*	0.0	0.0
33	*Dracaena steudneri*	29.2	22.0
34	*Trilepisium madagascariense*	17.5	10.0
35	*Mitragyna rubrostipulata.*	0.0	0.0
36	*Cassipourea malosana*	18.8	08.0
37	*Manilkara butugi*	17.5	08.0
38	*Schefflera abyssinica*	11.3	08.0
39	*Albizia grandibracteata*	9.2	05.0
Total		1498.1	1057.1

Annex 7: Soil environmental parameters for topsoil (EC = electrical conductivity, S = sand, Si = silt, C = Clay, STC = soil textural class)

Field No	Depth (cm)	PH	EC (ds/m)	S (%)	Si (%)	C (%)	Class
P 1/10	0-10	5.63	0.288	74	14	12	Sandy Loam
P 2/10	0-10	5.56	0.554	61	22	17	Sandy Loam
P 3/10	0-10	5.71	0.433	76	16	8	Sandy Loam
P 4/10	0-10	5.48	0.343	76	16	8	Sandy Loam
P 5/10	0-10	5.66	0.493	30	28	42	Clay
P 6/10	0-10	5.3	0.458	78	16	6	Loamy Sand
P 7/10	0-10	5.86	0.485	56	20	24	Sandy clay loam
P 8 /10	0-10	6.14	0.596	66	22	12	Sandy Loam
P 9/10	0-10	6.22	0.514	58	24	18	Sandy Loam
P 10/10	0-10	6.2	0.608	78	16	6	Loamy Sand
P 11/10	0-10	6.22	0.584	66	22	12	Sandy Loam
P 12/10	0-10	5.88	0.413	64	22	14	Sandy Loam
P 13/10	0-10	6.23	0.348	43	34	23	Loam
P 14/10	0-10	6.48	0.342	48	28	24	Loam
P 15 /10	0-10	6.08	0.574	58	28	14	Sandy Loam
P 16/10	0-10	6.36	0.510	63	22	15	Sandy Loam
P 17/10	0-10	5.78	0.310	58	20	22	Sandy clay loam
P 18/10	0-10	6.19	0.112	50	22	28	Sandy clay loam
P 19/10	0-10	6.47	0.437	58	20	22	Sandy clay loam
P 20/10	0-10	6.54	0.437	68	14	18	Sandy Loam
P 21/10	0-10	6.2	0.160	40	26	34	Clay loam
P 22/10	0-10	6.26	0.492	61	20	19	Sandy Loam
P 23/10	0-10	6.39	0.457	44	28	28	Clay loam
P 24/10	0-10	5.94	0.328	48	28	24	Loam
P 25/10	0-10	5.98	0.320	59	18	23	Sandy clay loam
P 26/10	0-10	6.1	0.283	52	22	26	Sandy clay loam
P 27/10	0-10	5.99	0.280	32	30	38	Clay loam
P 28/10	0-10	6.67	0.870	58	26	16	Sandy Loam
P 29/10	0-10	5.59	0.304	38	30	32	Clay loam
P 30/10	0-10	5.95	0.230	44	24	32	Clay loam
P 31/10	0-10	5.77	0.344	66	22	12	Sandy Loam

Annex 7 continued

P 32/10	0-10	5.65	0.220	49	24	27	Sandy clay loam
P 33/10	0-10	5.72	0.464	36	32	32	Clay loam
P 34/10	0-10	6.57	0.650	47	26	27	Sandy clay loam
P 35/10	0-10	5.79	0.564	52	28	20	Sandy Loam
P 36/10	0-10	5.57	0.352	54	20	26	Sandy clay loam
P 37/10	0-10	5.98	0.496	52	30	18	Sandy Loam
P 38/10	0-10	6.41	0.631	56	24	20	Sandy Loam
P 39/10	0-10	5.99	0.333	50	28	22	Loam
P 40/10	0-10	6.11	0.390	52	24	24	Sandy clay loam
P 41/10	0-10	6.85	0.433	58	22	20	Sandy Loam
P 42/10	0-10	6.16	0.284	46	28	26	Loam
P 43/10	0-10	6.41	0.496	56	30	14	Sandy Loam
P 44/10	0-10	6.45	0.600	68	18	14	Sandy Loam
P 45/10	0-10	6.75	0.225	48	26	26	Sandy clay loam
P 46/10	0-10	5.78	0.168	48	24	28	Sandy clay loam
P 47/10	0-10	5.86	0.253	50	26	24	Sandy clay loam
P 48/10	0-10	6.29	0.435	51	22	27	Sandy clay loam
P 49/10	0-10	6.68	0.622	58	12	30	Sandy clay loam
P 50/10	0-10	6.04	0.355	58	28	14	Sandy Loam
P 51/10	0-10	5.77	0.260	54	24	22	Sandy clay loam
P 52/10	0-10	6.55	0.377	48	24	28	Sandy clay loam
P 53/10	0-10	6.16	0.550	49	22	29	Sandy clay loam
P 54/10	0-10	6.13	0.468	72	18	10	Sandy Loam
P 55/10	0-10	5.89	0.413	43	26	31	Clay loam
P 56/10	0-10	5.92	0.340	68	20	12	Sandy Loam
P 57/10	0-10	6.15	0.296	58	28	14	Sandy Loam
P 58/10	0-10	5.98	0.276	68	20	12	Sandy Loam
P 59/10	0-10	6.5	0.471	53	18	29	Sandy clay loam
P 60/10	0-10	6.12	0.401	84	6	10	Loamy Sand

Annex 8: Soil environmental parameters for subsoil (EC = electrical conductivity, S = sand,
Si = silt, C = clay, STC = soil textural class)

Field No	Depth (cm)	PH	EC (ds/m)	S (%)	Si (%) %	C (%) %	STC
P 1/50	30-50	5.07	0.061	16	30	54	Clay
P 2/50	30-50	5.04	0.053	30	32	38	Clay loam
P 3/50	30-50	5.14	0.074	34	30	36	Clay loam
P 4/50	30-50	5.47	0.069	32	30	38	Clay loam
P 5/50	30-50	4.78	0.027	42	30	28	Clay loam
P 6 /50	30-50	4.97	0.045	42	30	28	Clay loam
P 7 /50	30-50	5.34	0.102	36	30	34	Clay loam
P 8 /50	30-50	5.1	0.081	36	36	28	Clay loam
P 9 /50	30-50	6.55	0.571	48	30	22	Loam
P 10/50	30-50	6.43	0.164	34	38	28	Clay loam
P 11/50	30-50	6.01	0.164	38	36	26	Loam
P 12/50	30-50	5.86	0.132	28	34	38	Clay loam
P 13 /50	30-50	6.27	0.137	52	26	22	Sandy clay loam
P 14 /50	30-50	6.75	0.255	44	32	24	Loam
P 15 /50	30-50	6.28	0.272	58	26	16	Sandy Loam
P 16/50	30-50	6.23	0.178	36	24	40	Clay
P 17/50	30-50	5.65	0.371	36	34	30	Clay loam
P 18/50	30-50	5.72	0.112	28	30	42	Clay
P 19 /50	30-50	6	0.187	76	16	8	Sandy Loam
P 20/50	30-50	6.42	0.261	47	26	27	Sandy clay loam
P 21/50	30-50	5.89	0.130	28	32	40	Clay
P 22/50	30-50	5.29	0.122	30	30	40	Clay
P 23/50	30-50	5.56	0.129	72	18	10	Sandy Loam
P 24/50	30-50	5.27	0.072	32	26	42	Clay
P 25/50	30-50	6.19	0.151	72	18	10	Sandy Loam
P 26/50	30-50	5.7	0.097	19	36	45	Clay
P 27/50	30-50	5.77	0.122	52	22	26	Sandy clay loam
P 28/50	30-50	5.86	0.122	33	20	47	Clay
P 29/50	30-50	5.6	0.125	40	24	36	Clay loam
P 30/50	30-50	5.25	0.127	72	18	10	Sandy Loam
P 31/50	30-50	5.54	0.090	30	34	36	Clay loam

Annex 8 continued

P 32/50	30-50	4.9	0.079	76	16	8	Sandy Loam
P 33/50	30-50	4.93	0.096	27	20	53	Clay
P 34/50	30-50	6.21	0.139	68	22	10	Sandy Loam
P 35/50	30-50	5.35	0.131	72	20	8	Sandy Loam
P 36/50	30-50	5.69	0.230	52	20	28	Sandy clay loam
P 37/50	30-50	6.21	0.178	66	26	8	Sandy Loam
P 38/50	30-50	6.01	0.145	42	34	24	Loam
P 39/50	30-50	5.7	0.142	53	24	23	Sandy clay loam
P 40/50	30-50	6.62	0.170	37	34	29	Clay loam
P 41/50	30-50	6.32	0.120	75	21	4	
P 42/50	30-50	6.03	0.120	34	30	36	Clay loam
P 43/50	30-50	6.53	0.120	33	30	37	Clay loam
P 44/50	30-50	6.72	0.291	43	30	27	Loam
P 45/50	30-50	6.61	0.401	38	32	30	Clay loam
P 46/50	30-50	5.86	0.317	58	30	12	Sandy Loam
P 47/50	30-50	5.89	0.122	34	52	14	Silt Loam
P 48/50	30-50	6.12	0.120	28	28	44	Clay
P 49/50	30-50	6.66	0.607	50	30	20	Loam
P 50/50	30-50	5.74	0.114	38	34	28	Clay loam
P 51/50	30-50	5.6	0.198	28	26	46	Clay
P 52/50	30-50	5.28	0.077	40	28	32	Clay loam
P 53/50	30-50	5.71	0.157	36	30	34	Clay loam
P 54/50	30-50	5.47	0.141	16	28	56	Clay
P 55/50	30-50	5.74	0.133	46	28	26	Loam
P 56/50	30-50	6.15	0.150	32	26	42	Clay
P 57/50	30-50	5.19	0.107	34	28	38	Clay loam
P 58/50	30-50	5.65	0.080	24	30	46	Clay
P 59/50	30-50	5.44	0.079	42	30	28	Clay loam
P 60/50	30-50	5.87	0.098	35	32	33	Clay loam

Declaration

I, the undersigned, declare that this thesis is my work and all that sources of materials used for the thesis have been dully acknowledged.

Name Signature