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Feyera Senbeta Wakjira

Biodiversity and ecology of Afromontane rainforests with wild *Coffea arabica* L. populations in Ethiopia

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ABSTRACT

Wild *Coffea arabica* occurs as undergrowth in the Afromontane rainforests of southwest and southeast Ethiopia. Ethiopia is the center of origin and diversity of *Coffea arabica*. In spite of their importance, the conservation of Afromontane rainforests with their genetic resources of wild *Coffea arabica* has been neglected in the past although these forests are under continuous threat. The present study was conducted in five forest regions, namely Harenna (southeast), Bonga, Maji and Berhane-Kontir and Yayu (southwest). Floristic analyses reveal 651 species and 118 families. About 5% of the species are endemic to Ethiopia and about 50% of the species occur in only one of the forests. Alpha diversity is high in the Bonga forest, whereas beta and gamma diversity are high in the Berhane-Kontir forest. A cluster analysis reveals five plant communities: *Chionanthus mildbraedii-Psychotria orophila*, *Afrocarpus falcatus*, *Trilepisium madagascariense-Dracaena fragrans*, *Whitfieldia elongata-Zanha golungensis* and *Coffea arabica*. Four plant communities follow the four forest regions, while the *Coffea arabica* community represents plots at all sites where wild coffee occurs abundantly. The studied rainforests are floristically different, while wild coffee populations and physiognomic similarity are the common features of the geographically separated forests. The plant communities of the Yayu and Berhane-Kontir forests are linked to Guineo-Congolian floral elements and can be considered as “transitional rainforests.”

Wild populations of *Coffea arabica* are widely distributed over SE and SW Ethiopia, but are patchy locally. The wide geographical distribution of wild coffee reflects the capability of the species to exist over different environmental gradients. Locally, the patchy distribution of wild coffee populations is related to major spatial discontinuities due to different edaphic, biotic and topographic features within the forests. Wild coffee populations occur between 1000 and 2000 m a.s.l., but the critical altitude is between 1300 m and 1600 m. Coffee abundance is negatively correlated with an increase in slope angle. Slight forest disturbance was found to favor coffee recruitment and establishment; however, serious disturbances in forest areas, such as use as pasture, may limit the regeneration capacity of the coffee plants.

The conversion of a forest coffee system into a semi-forest coffee system affects the floristic composition and diversity of the forest. A comparison of semi-forest coffee and forest coffee systems in two rainforests, i.e., Harenna and Berhane-Kontir, reveals a reduction of up to 50% in the number of species of lianas, small trees and shrubs in the semi-forest coffee system. Furthermore, the families dominating in the semi-forest coffee system are different to those dominating in the forest system. Continuous management of the wild coffee in the semi-forest coffee system suppresses woody plant regeneration, reduces tree density and eventually leads to the disappearance of the forest species and finally the forest, while temporarily benefiting the coffee plants.

The maintenance of wild coffee populations in the Afromontane rainforests of Ethiopia is highly dependent on the extent to which the rainforest fragments are maintained, and conservation of these rainforests is therefore urgently required. In this study, conservation measures are recommended for future management.

KURZFASSUNG

Wilder *Coffea arabica* kommt im Unterwuchs der afromontanen Regenwälder im Südwesten und Südosten Äthiopiens vor. Das Land ist das Mannigfaltigkeitszentrum von *Coffea arabica*. Trotz ihrer Bedeutung ist die Erhaltung der afromontanen Regenwälder einschließlich der genetischen Ressourcen von wildem *Coffea arabica* in der Vergangenheit vernachlässigt worden, obwohl diese stark bedroht sind. Die vorliegende Studie wurde in fünf Waldregionen, namentlich in Harenna (Südost-Äthiopien), Bonga, Maji, Berhane-Kontir und Yayu (Südwest-Äthiopien) durchgeführt. Die floristischen Analysen ergaben 651 Arten und 118 Familien. Ungefähr 5% dieser Arten sind endemisch und ca. 50% der Arten kommen in nur einem der untersuchten Wälder vor. Im Bonga Wald ist die Alphadiversität hoch, während im Berhane-Kontir Wald die Beta- und Gammadiversität hoch sind. Eine Clusteranalyse ergab fünf Pflanzengemeinschaften: *Chionanthus mildbraedii-Psychotria orophila, Afrocarpus falcatus, Trilepisium madagascariense-Dracaena fragrans, Whitfieldia elongata-Zanha golungensis* und *Coffea arabica*. Die ersten vier Gemeinschaften entsprechen den vier Waldregionen, während die *Coffea-arabica*-Gemeinschaften Flächen mit einem hohen Vorkommen des wilden Kaffees an allen Standorten repräsentiert. Die untersuchten Regenwälder weisen floristische Unterschiede auf, haben jedoch die wilden Kaffeepopulationen und eine physiognomische Ähnlichkeit als gemeinsame Eigenschaft. Die Pflanzengemeinschaften der Yayu und Berhane-Kontir Wälder beherbergen Elemente der guineo-congolischen Flora und können als "Übergangsregenwälder" betrachtet werden.

Wilde Populationen von *Coffea arabica* haben eine weite Verbreitung in Südost- und Südwestäthiopien, ihr lokales Vorkommen ist aber lückenhaft. Die breite geographische Verteilung von wildem Kaffee spiegelt die Fähigkeit der Art wieder, über verschiedene Umweltgradienten zu bestehen. Lokal hängt die unregelmäßige Verteilung der Populationen mit deutlichen Unterschieden in den edaphischen, biotischen und topografischen Bedingungen innerhalb der Wälder zusammen. Wilder Kaffee kommt zwischen 1000 und 2000 m NN vor, die kritische Höhe ist jedoch zwischen 1300 m und 1600 m. Die Häufigkeit von Kaffee ist negativ mit zunehmender Hangneigung korreliert. Geringe Störungen im Wald zeigten sich als vorteilhaft für die Regeneration und Etablierung des Kaffees; starke Störungen in Wäldern, die als Waldweide genutzt werden, können die Regenerationsfähigkeit der Kaffeepflanzen einschränken.

Die Umwandlung von einem Waldkaffeesystem in ein Semi-Waldkaffeesystem beeinflusst die floristische Zusammensetzung und Diversität des Waldes. Ein Vergleich von Semi-Waldkaffee- und Waldkaffeesystemen in den Regenwaldgebieten Harenna und Berhane-Kontir zeigt eine bis zu 50%ige Reduktion in der Artenanzahl von Lianen, kleinen Bäumen und Sträuchern im Semi-Waldkaffeesystem. Außerdem dominierten andere Pflanzenfamilien im Waldkaffeesystem als im Semi-Waldkaffeesystem. Das regelmäßige Management des wilden Kaffees im Semi-Waldkaffeesystem unterdrückt die Regeneration der holzigen Pflanzen, reduziert die Baumdichte und führt schließlich zum Verschwinden des Waldes und der Waldarten, während die Kaffeepflanzen vorübergehend gefördert werden.

Die Erhaltung der wilden Kaffeepopulationen in den afromontanen Regenwäldern von Äthiopien hängt stark davon ab, ob die Regenwaldfragmente erhalten werden. Der Schutz von Regenwäldern mit wilden Kaffeepopulationen ist daher dringend notwendig. Die vorliegende Arbeit enthält Vorschläge für Schutzmaßnahmen.

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ACKNOWLEDGEMENTS

1 GENERAL INTRODUCTION

1.1 Background

The term biodiversity is used to convey the total number, variety and variability of living organisms and the ecological complexes in which they occur (Wilson 1988; CBD 1992; Rosenzweig 1995). The concept of biological diversity can be applied to a wide range of spatial and organization scales, including genetics, species, community, and landscape scales (Noss 1990; Austin et al. 1996; Tuomisto et al. 2003). It is becoming increasingly apparent that knowledge of the role of patterns and processes that determine diversity at different scales is at the very heart of an understanding of variation in biodiversity. Processes influencing diversity operate at different spatial and temporal scales (Rosenzweig 1995; Gaston 2000). A variety of environmental events and processes, including past evolutionary development, biogeographic processes, extinctions, and current influences govern the biodiversity of a particular site (Brown and Lomolino 1998; Gaston 2000; Ricklefs and Miller 2000).

Biodiversity is valued and has been studied largely because it is used, and could be used better, to sustain and improve human well-being (WWF 1993; WCMC 1994). However, there has been a rapid decline in the biodiversity of the world during the past two to three decades (Wilson 1988; Whitmore and Sayer 1992; Lugo et al. 1993; Whitmore 1997). Recently, conserving biodiversity in a wide variety of ecosystems has become a major environmental and natural resources management issue of national and international importance (Salwasser 1991; Angermeier and Karr 1994; Lovett et al. 2000). It is consequently essential to study not only diversity in perfect environments but also the impact of alternative uses and management practices on biodiversity to conserve as much as possible where disturbance and deforestation cannot be prevented and, where possible, to improve the conservation value of areas already overexploited.

Ethiopia, located in the Horn of Africa, is a country with greatly varying landscapes ranging from high and rugged mountains, flat-topped plateaus, deep gorges, and incised rivers to valleys and rolling plains. These diverse physiographic features have contributed to the formation of diverse ecosystems characterized by a great species diversity. According to WCMC (1994), Ethiopia is one of the top 25 biodiversity rich countries of the World. The flora of Ethiopia, for instance, is estimated to comprise between 6,000 and 7,000 higher plant species (Cufodontis' 1953-1972; Gebre-Egziabher 1991) and about 10 –12% of these are estimated to be endemic to Ethiopia (Brenan 1978; Thulin 1983; Gebre-Egziabher 1991). In general, the forest areas of Ethiopia have a high biodiversity and are of considerable economic and ecological importance to the nation.

In Ethiopia, high forests were once much more extensive (around 40 % of the total area of the country), but this cover declined to less than 3% by the late 1980s or early 1990s (Rogers 1992; EFAP 1994; McCann 1995). The extent to which the highlands of Ethiopia were formerly covered by forest is evidenced by the presence of mosaic landscapes made up of patches of primary and secondary forests, scrublands and isolated trees. Various human-induced pressures such as agriculture, overgrazing, fire and settlements have contributed to the reduction of forest covers (Logan, 1946; von Breitenbach 1963; Bonnefille and Hamilton 1986; EMA 1988; EFAP 1994, McCann 1997; Reusing 1998; Senbeta and Tefera 2002; Darbyshire et al. 2003). The concerted action of these factors has accelerated the decline of forest resources and led to environmental degradation such as soil erosion, loss of biodiversity and impoverishment of ecosystems. The ever-increasing demands for forest products and forestland together with the increase in human population is putting intolerable pressure on the remaining forest fragments (Teketay 1992; Teketay 1996; Senbeta and Teketay 2001; Senbeta 2004; Senbeta et al. 2005).

Today, Afromontane rainforest is the major remnant forest in the country. Different authors have named this forest vegetation differently: (Afro) montane rainforest (Friis 1992), moist montane forest or moist montane evergreen forest (Friis 1986a; Demissew et al. 1996; Zerihun 1999). Hereafter, the name "Afromontane rainforest" is adopted throughout this thesis.

A segment of Afromontane rainforest has long been recognized as the center of origin and diversity of wild *Coffea arabica* (Strenge 1956; Meyer 1965; Gebre-Egziabher 1990; Tesfaye et al. 2005). Currently, wild populations of *Coffea arabica* occur in many Afromontane rainforest fragments, which are geographically separated and isolated from each other due to settlements and farmland. Like other forests, these forest fragments are under continuous threat due to the expansion of agriculture and commercial plantations (e.g., tea, coffee) and also to modifications of the forest coffee due to the use of wild coffee (Teketay 1999; Woldemariam et al. 2002; Senbeta 2004; Senbeta in press). Whatever the causes of deforestation might be, the bottom line is that conservation efforts are mandatory in order to maintain the remaining Afromontane rainforests. A diverse range of social, economic and ecological information about the forest is necessary to design suitable conservation and sustainable use approaches.

In fact, only limited ecological information is available concerning the floristic composition, diversity, distribution, and abundance, and the anthropogenic influences in the Afromontane rainforests of Ethiopia (Tadesse and Nigatu 1996; Woldemariam 2003). Several ecological studies have been conducted in the Ethiopian forests (Gebre-Egziabher 1978, 1986; Demissew 1980; Friis 1992; Bekele 1994; Teketay 1996; Teketay 1997; Tadesse and Nigatu 1996), but most of these studies focused on the dry Afromontane forests. The common feature of the geographically separated Afromontane rainforests is the occurrence of wild coffee populations. In view of that, comparative biodiversity and ecological studies are very important for defining conservation priorities among the different Afromontane rainforest areas. As humans are part of the systems, sustainable use and management can only be based on the understanding of how such forests actually work ecologically and interact with human uses. Rural communities have been using the forest traditionally for a long time, and hence they must have played an important role in influencing forest structure and diversity.

This study assesses how the Afromontane rainforest regions with wild coffee populations are similar or differ. The study was carried out in five Afromontane rainforests of Ethiopia, namely Harenna, Maji, Bonga, Berhane-Kontir, and Yayu. The study is part of a joint research project of the Center for Development Research (ZEF), University of Bonn and the Ethiopian Agricultural Research Organization (EARO), which focuses on “Conservation and use of the wild populations of *Coffea arabica* in the montane rainforests of Ethiopia.”

1.2 Objectives of the study

The general objective of the present study is to make a comparative inter-regional species diversity analysis of geographically separated Afromontane rainforests and to generate information for management decision-making regarding *in-situ* conservation of the genetic resources in the forests with wild coffee populations. The specific objectives of the study are:

1. To examine the vegetation structure, composition and plant species diversity in five Afromontane rainforests with wild coffee populations (Chapter 4 and 5);
2. To assess the importance of regional variables such as rainfall and altitude as well as local variables (e.g., soil characteristics, slope and canopy cover) on coffee distribution and abundance in the rainforests (Chapter 6);
3. To evaluate the influence of wild coffee management on floristic composition, diversity and vegetation structure (Chapter 7);
4. To contribute toward the development of conservation and use concepts for the Afromontane rainforests as well as for forest coffee ecosystems (Chapter 4-8).

2 STATE-OF-THE-ART OF AFROMONTANE RAINFORESTS, ECOLOGY OF WILD *C. ARABICA* AND BIODIVERSITY CONSERVATION

2.1 Forest vegetation of Ethiopia

Several attempts have been made to classify the vegetation of Ethiopia. Previous descriptions of vegetation types include those by Logan (1946), Pichi-Sermolli (1957), von Breitenbach (1963), White (1983), Friis (1986a), Friis (1992), Demissew et al. (1996), and Friis and Demissew (2001). Most classifications are based on climate and physiognomy, with some account of species composition. For an example, Demissew et al. (1996) broadly categorized the vegetation of Ethiopia into nine major groups. These include Afroalpine and Subafroalpine vegetation, dry evergreen montane forest, moist evergreen montane forest, wetlands, evergreen scrub, *Combretum-Terminalia* woodland, *Acacia-Commiphora* woodland, lowland dry forest, and lowland semi-desert and desert areas. These attempts have all contributed considerably towards the understanding of the vegetation types of Ethiopia. However, these classifications are still unsatisfactory owing to partly their terminological incompatibilities or inconsistencies concerning concepts such as forest, woodland, bush land and to the complexity of the vegetation (Woldu 1999). The complexity arises from the great variations in altitude implying equally great spatial differences in moisture regimes as well as temperatures within very short horizontal distances.

Similar to the general vegetation classification, many scholars have attempted to categorize the forest vegetation of Ethiopia (Logan 1946; Chaffey 1979; Friis 1986a; Friis 1992). The classification by Friis (1992) is commonly employed for the description of the forest vegetation of Ethiopia and comprises seven forest types. These include lowland dry peripheral semi-deciduous Guineo-Congolian forest, transitional rainforest, Afromontane rainforest, undifferentiated Afromontane forest, dry single-dominant Afromontane forest of the Ethiopian Highlands, dry single-dominant Afromontane forest of the escarpments, and riverine forest. A detailed account of each forest can be seen in Friis (1992). Out of these aforementioned forest types, Afromontane rainforest and transitional rainforest are known to support wild populations of *Coffea arabica*, and hence they are the subject of the present study.

However, the lowland Guineo-Congolian forest is floristically apparently very similar to transitional forest, and hence this forest is described here. The following descriptions of each forest type are based on the information from Friis (1986a) and Friis (1992).

1. **Lowland dry peripheral semi-deciduous Guineo-Congolian forest**

   The dry peripheral semi-deciduous Guineo-Congolian forests are restricted to the Baro lowlands of Gambella, western Ethiopia. The forest occurs within the altitudinal range of 450-600 m a.s.l. and is characterized by a mean annual temperature of maximum 35°C, and minimum 19°C and an annual rainfall ranging from 1300 to 1800 mm. The forest occurs mainly on sandy soils, which are well drained, and is semi-deciduous, with a 15-20 m tall continuous canopy of *Baphia abyssinica* (endemic to SW Ethiopia and adjacent areas of the Sudan). Major forest tree species are *Baphia abyssinica*, *Celtis toka*, *Diospyros abyssinica*, *Lecaniodiscus fraxinifolius*, *Pouteria alnifolia*, *Zanha golungensis*, *Alstonia boonei*, *Antiaris toxicaria*, *Melicia excelsa*, *Celtis gomphophylla*, and *Zanthoxylum leprieurii*. The shrub layer is sometimes dense and includes *Alchornea laxiflora*, *Argomuellera marcophylla*, *Oxyanthus specisous*, *Rinorea ilicifolia and Whitfieldia elongata. Capparis erythrocarpos, Paullinia pinnata, and Hippocratea africana* are commonly the dominating climbing plant species. Epiphytes are rare in this forest. A thick layer of litter mostly covers the ground, and only very, few plant species, one being common is Streptogyma crinita.

2. **Transitional rainforest**

   The transitional rainforests are known from the southwestern escarpments of Wallega, Illubabour and Keffa, Ethiopia. They occur between 500 and 1500 m a.s.l., with mean annual temperatures ranging from 20 to 25°C and an annual rainfall of about 2000 mm in some places. Rainfall occurs all year round (Eklundh 1996; EMSA 1996; Asres 1996). The transitional rainforest is similar in physiognomy and composition to the Afromontane rainforest described below, with additional species from the lowland Guineo-Congolian forest described above. Characteristic tree species include *Pouteria atissima, Anthocleista schweinfurthii, Celtis philippensis, C. zenkeri*, *Eugenia bukobensis*, *Garcinia huillensis*, *Manilkara butugi*, *Morus mesozygia*, *Strychnos mitis*, *Trichilia dregeana*, and *Trilepisium madascariense*. Many of these species are a common association in Guineo-Congolian forests.

3. Afromontane rainforest

The Afromontane rainforests occur in the southwest of the NW and SE highlands at altitudes between 1500 and 2600 m. Mean annual temperatures range from 15-20^{0}C and annual rainfall from 700 to 2500 mm. The tree canopies are characteristically made up of a mixture of *Afrocarpus* and broad-leaved species. Noteworthy is that *Afrocarpus* is predominant in the southeast and gradually becomes rare towards the southwest, while *Pouteria adolfi-friederici* becomes more prominent there. The characteristic canopy species include *Croton macrostachyus*, *Ilex mitis*, *Olea welwitschii*, *Afrocarpus falcatus*, *Pouteria adolfi-friederici*, and *Schefflera abyssinica.* Natural coffee is one of the characteristic species in the understory. Shrubs and lianas are very common and include *Landolphia buchananii*, *Jasminium abyssinicum, Hippocratea goetzei*, *Oxyanthus speciosus*, *Oncinotis tenuiloba*, *Tiliacora troupinii*, and *Hippocratea africana.* Epiphytes are very common and include *Peperomia tetraphylla*, *Asplenium sandersonii*, *Loxogramme lanceolata*, *Aerangis luteoalba*, *Arthropteris monocarpa*, and *Asplenium aethiopicum*. The Harenna forest, SE Highlands, is floristically closely related to the southwest forest except for a few forest trees not known in other parts of Ethiopia, e.g., *Filicium decipiens* and *Warburgia ugandensis*.

2.2 Phytogeographical description

The phytogeographical analysis of Africa and Ethiopia has long attracted the attention of botanists and biogeographers, both in the regionalization of floristic units and in the classification of floristic elements (e.g., White 1979, 1983; Friis 1986b, 1992 and references therein). White (1983) categorized the phytogeographical regions of Africa in nine regional centers of endemism and in nine regional transition zones between these centers of endemism. A detailed account is given in White (1978, 1983). One of these regional centers of endemism is the Afromontane region.

The Afromontane region is an archipelago-like centre of endemism, which extends from the Loma Mountains and the Tingi Hills in Sierra Leone in the west to the Ahl Mescat Mountains in Somalia in the east, and from the Red Sea Hills in the Sudan Republic in the north to the Cape Peninsula in the south (White 1983). In addition to the large number of species common to most of these mountains, the Afromontane region also varies in floristic composition, physiognomy and ecology and shows varying relationships with other phytogeographic regions (Coetzee 1978). Most Afromontane communities are found above 2000 m, but they can occur as low as 1200 a.s.l. in some places (White 1983). The Afromontane region contains about 4000 plant species, and about 75% of these are endemic or near endemic to the region. Very recently, this region was designated as the “Eastern Afromontane Hotspot,” which is one of the 34 regions globally important for biodiversity conservation (Conservation International 2005).

The Ethiopian highlands form the largest mountain complex in Africa and comprise over 50% of the African land area covered by Afromontane vegetation (Tamrat, 1994). A phytogeographical analysis of forest vegetation of Ethiopia by Friis (1992) recognized six local phytochoria (centers of endemism), mainly based on the presence of particular forest types. These phytochoria are:

1. The lowland dry peripheral Guineo-Congolian forest area, which includes the exclave of lowland dry peripheral semi-deciduous Guineo-Congolian forest vegetation on the Nile valley plains in the Baro Lowlands.
2. The transitional area between lowland Guineo-Congolian and Afromontane vegetation on the slopes of the SW escarpment of the NW highlands.
3. The humid Afromontane forest area, which largely agrees with the low-ranking center of endemism as well as with the Afromontane rainforest type.
4. The widespread Afromontane forest area, which largely agrees with the low ranking centre of endemism as well as with the undifferentiated Afromontane forest and dry single-dominant Afromontane forest type.
5. The transitional area between Afromontane and Somalia-Masai vegetation.
6. The riverine forest area.

This study focuses on the humid Afromontane forest, and the transitional forest between lowland Guineo-Congolian and Afromontane forest centers of endemism, as they are the major regions with wild populations of *Coffea arabica*.

2.3 Occurrence and use of wild *Coffea arabica*

2.3.1 Distribution of wild coffee

Coffea arabica or Arabica coffee is the only coffee species that occurs naturally in Ethiopia. Geographically, *C. arabica* is isolated from all other coffee species occurring in the Ethiopian plateaus. It is the only self-compatible species of the genus *Coffea* (Monaco 1968). This mean that *C. arabica* flowers can be fertilized by their own pollens, while others have to be fertilized by pollen from flowers on others shrubs. It follows one of the typical patterns of distribution of polyploids, i.e., expansion outside the range of distribution of the diploid species of the genus (Monaco 1968). Self-compatibility could have provided the opportunity for quick occupation of new regions away from the original range of distribution. Outside Ethiopia, small populations of Arabica coffee were reported to occur in southeast Sudan and northern Kenya (Monaco 1968; Friis 1992; Woldu 1999).

Arabica coffee occurs abundantly in the Afromontane rainforests of Ethiopia within an altitudinal range of 1000 and 2000 m a.s.l. It occurs within the annual rainfall range of 1000 to 2400 mm and grows on a wide range of soil types, i.e., acidic to slightly acidic with low availability of phosphorus (Purseglove 1968; Dubale and Shimber 2000). Topographic factors such as slope and exposition are said to govern the occurrence of coffee (Willson 1985; Dubale 1996; Teketay 1999). The natural dispersion of coffee seems to be accomplished with the help of many dispersal agents such baboons, birds and monkey.

2.3.2 Coffee production systems

Ethiopia’s economy is predominately dependent on agriculture, and this agriculture-based economy is highly dependent on coffee production, as it contributes more than 67% to the total exchange earnings and over 6% to the gross national product (Wondimu 1998). Despite its economic importance, however, smallholder farmers dominate the production of coffee. It can be noted that around 25% of the Ethiopian population is engaged in coffee production, processing and marketing services, and derives its livelihood from the coffee industry. In addition, coffee is of enormous cultural, social and economic importance to the nation.

Generally, four types of coffee production systems can be recognized in Ethiopia (Woldetsadik and Kebede 2000). These include forest coffee, semi-forest coffee, garden coffee and plantation coffee. Forest coffee is a production system where coffee berries are simply picked from naturally growing coffee. In this system, there is no management to improve coffee production. It is estimated to cover about 10% of the total coffee production in the country (Teketay et al. 1998). In the semi-forest coffee system, coffee berries are also collected from naturally grown coffee. Here, however, in order to improve the productivity of wild coffee, competing understory trees and shrubs are regularly removed from the system. This system accounts for about 35% of the total coffee production in the country. In the garden coffee system, coffee is planted and managed in the area surrounding the farmer’s home. It accounts for about 35% of the total coffee production in the country (Teketay et al. 1998; Woldetsadik and Kebede 2000). Plantation coffee is grown on a large scale by private coffee farmers (investors) or the government. It is usually well managed and accounts for about 15% of the total coffee production (Teketay et al. 1998; Woldetsadik and Kebede 2000).

2.4 Biodiversity conservation

2.4.1 Why conserve?

Many people in the tropical countries are dependent on biodiversity for their subsistence livelihoods (WWF 1993). However, there has been a rapid decline in the biodiversity of this region of the world, more particularly during the past two to three decades (Wilson 1988; Whitmore and Sayer 1992; Lugo et al. 1993; Whitmore 1997). Such losses occur due to habitat destruction, overharvesting, pollution, inappropriate and often accidental introduction of exotic plants and animals, etc. (Whitmore and Sayer 1992). Strategies to overcome such losses must therefore be sought in the larger policy framework of development.

In Ethiopia, particularly in the Afromontane rainforests (with wild coffee populations), habitat destruction and degradation due to anthropogenic activities are reducing the forest cover and the associated biodiversity (Woldemariam and Teketay 2001; Yeshitela 2001). The changes in the forest cover are becoming increasing significantly and impairing the function and services of the forest ecosystems.

In view of the growing threat to biodiversity, the time has come to appreciate the Earth’s biological resources as assets to be conserved and managed for all humanity. Conservation and sustainable use of biological resources can prolong the services and functions they provide to human beings. According to Kumar (1999), there are three global objectives of biodiversity conservation. These are: (1) to maintain essential ecological processes and life-support systems, (2) to preserve genetic diversity, and (3) to ensure the sustainable utilization of species and ecosystems. It addition, biodiversity needs to be conserved as a matter of principle, as a matter of survival and as a matter of economic benefit.

2.4.2 Conservation approaches

The design and effectiveness of various conservation strategies depend on our understanding of the environmental features supporting biodiversity as well as on the motivation and ability of institutions to implement strategies once they are developed. Two fundamental conservation approaches are recognized: *in-situ* and *ex-situ. Ex-situ* conservation refers to the conservation outside the natural habitat, while *in-situ* conservation refers to the conservation of biological resources in their natural habitats. As the limitation of *ex-situ* genetic conservation has become more apparent, renewed attention is being given to *in-situ* conservation strategies. *Ex-situ* conservation can never take over the function of *in-situ* conservation as a means of storing the world’s genetic diversity of crop plants or their wild relatives with a potential use and vice versa. In practice, no single conservation technique can effectively conserve the full range of genetic diversity of target species (Falk 1990), but the two strategies can be complementary.

In the *in-situ* conservation method, biosphere reserves have come up in designing conservation sites (Kumar 1999). Biosphere reserves have concentric areas zoned (i.e., core, buffer and transition zones) for different uses. The ‘core zone’ is devoted to preserving biodiversity with no human interference. Around this core is a ‘buffer zone’ in which some settlement and resource use is allowed, surrounded in turn by an indefinite ‘transition area’ where sustainable development activities are permitted.

A frequently suggested alternative to conservation options is sustainable use of biodiversity, which is hoped to provide for a balanced utilization and conservation of biodiversity. As economics vary according to the climate, soil conditions, topography, infrastructure (Pearce and Moran, 1994), and the biological component harbored in the area, no universal criteria are available for sustainable use of biodiversity.

3 THE STUDY AREA AND SAMPLING METHODS

3.1 Study sites

3.1.1 General: study area

The Ethiopian Rift Valley system runs from northeast to southwest and divides the country into the northwestern and southeastern highlands. The highlands give way to extensive semi-arid lowlands to the east, south and west of the country. Afromontane rainforests occur in the southwest part of the NW and SE Highlands (Figure 3.1). The present study was conducted in five Afromontane rainforests, namely Bonga, Berhane-Kontir, Maji, Harenna, and Yayu (Figure 3.1). A fifth site, i.e., Yayu, relevant data were obtained from Woldemariam (2003). The Harenna and Yayu forests are located in the Oromia National Regional State, while the other forests are situated in the Southern Nation, Nationalities, Peoples' Regional State (SNNPRS) of Ethiopia, all in Table 3.1 and Figure 3.1.

Table 3.1 Location and some characteristics of the five studied Afromontane rainforests in Ethiopia

Regions	Site Code	Area (ha)	No. plots	Elevation (m)	Lat. (N)	Long. (E)	TRF (mm)	MT (^{0}C)	Cons
Bonga	BO	5000	28	1700-2200	7^0 08´	$35^0$53´	1700	18	Dg
Berhane-Kontir	BK	10000	55	950-1800	$7^0$00'	$35^0$00'	2200	22	Dg
Maji	MA	2000	13	1600-1750	$6^0$00'	$36^0$00'	1600	20	No
Harenna	HA	15000	59	1300-2000	$6^0$00'	$39^0$00'	1000	18	Dg
Yayu	YA	10000	48[1]	1200-2150	8^0 05'	35^0 06´	1800	21	Dg

[1]Source: Woldemariam (2003); TRF-total annual rainfall; MT - mean annual temperature; Cons - conservation status (Dg – designated; No – no conservation measure).

Except for Harenna, which is located in the SE highlands, all other are located in the NW highlands. They are separated from each other by agricultural and/or settlement landscapes.

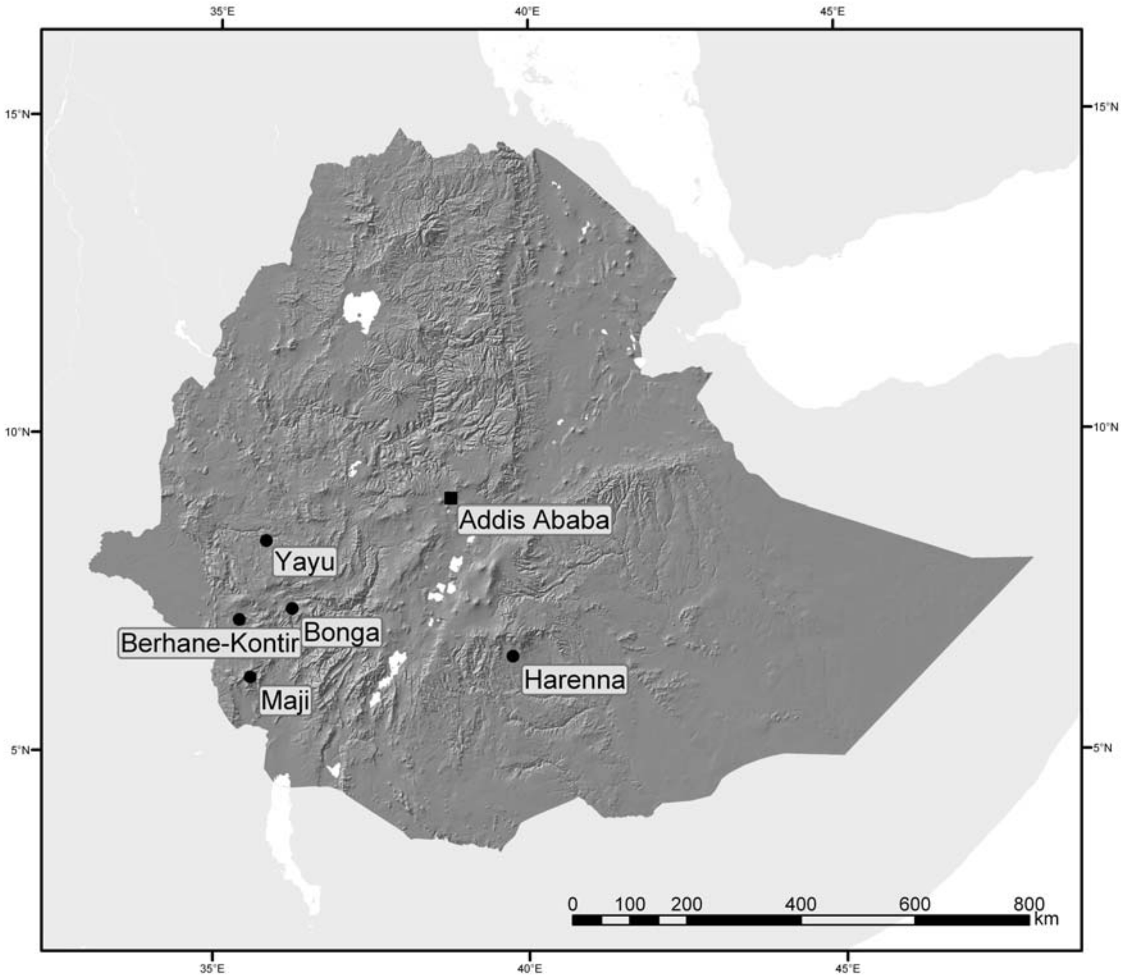

Figure 3.1 Map of Ethiopia showing the location of the study areas (Bonga,Yayu, Berhane-Kontir, Maji and Harenna)

The rainfall and temperature patterns of some of the study sites are shown in Figure 3.2. Table 3.2 presents climatic data from the meteorological stations close to the study sites. Annual rainfall ranges from 1000 mm to over 2200 mm.

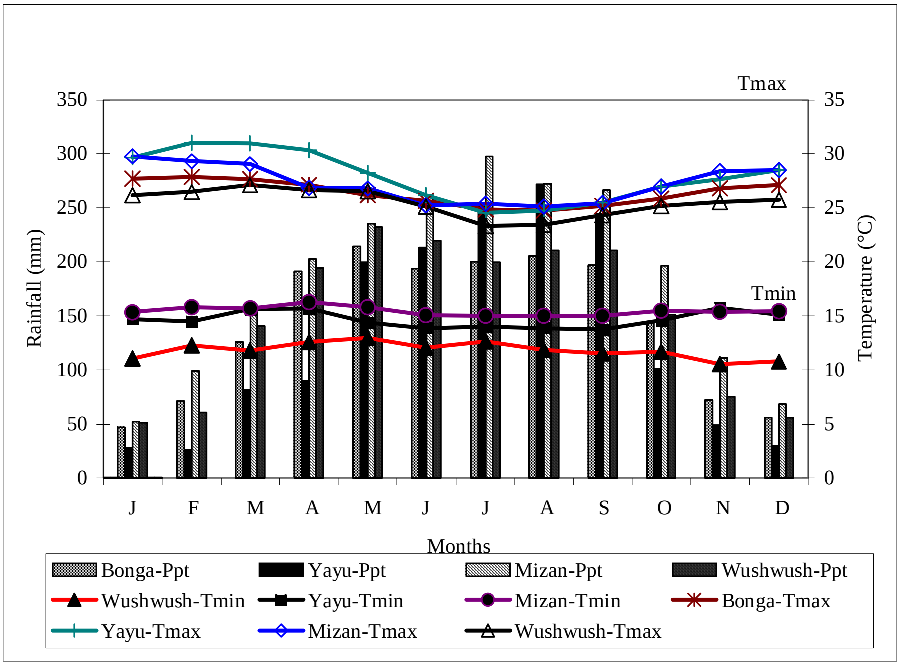

Figure 3.2 Annual rainfall and temperature distribution patterns at four meteorological stations near the Bonga, Berhane-Kontir and Yayu forests of Ethiopia (Ppt = Mean monthly precipitation; Tmax = Mean monthly maximum temperature; Tmin = Mean monthly minimum temperature)

Table 3.2 Climatic data for meteorological stations closest to study sites in the rainforests of Ethiopia

Station	Alt. (m)	Lat. (N)	Long. (E)	Years of observation	P	Tmax	Tmin	RH
Bebeka[1]	1100	6^{0}53´	35^{0}26´	34	1914	29	15	66
Tepi[1]	1200	7^{0}05´	35^{0}15´	7	-	29	19	54
Mizan Teferi[1]	1370	6^{0}58´	35^{0}36´	48	2216	27	15	-
Yayu[2]	1630	8^{0}22´	35^{0}50´	20	1786	28	13	-
Metu[2]	1680	8^{0}19´	35^{0}35´	36	1792	27	12	-
Gore[2]	2025	8^{0}10´	35^{0}33´	26	1937	23	13	64
Bonga[3]	1725	7^{0}13´	36^{0}17´	49	1718	26	12	-
Wushwush[3]	1950	7^{0}16´	36^{0}11´	48	1794	25	11	91
Maji	2310	6^{0}12´	35^{0}36´	23	1638	-	-	-
Harenna	1400	6^{0}00’	40^{0}00’	-	1000	34	10	61

[1] Berahne-Kontir, [2] Yayu, [3] Bonga; Alt = Altitude, P = Mean annual rainfall (mm), Tmax = Maximum annual mean temperature (°C), Tmin = Minimum annual mean temperature (°C), RH = Relative humidity at 12:00 Am.);(Source: EMSA 2002)

3.1.2 The Bonga Forest

The Bonga forest is located in the Gimbo Wereda of the Kafa Zone of SNNPRS (Figure 3.1 and Table 3.1) on the steep north and northwestern facing slope of a mountain range. The soils of the area like those of other southwestern highland plateaus are characterized by red to reddish-brown colors and have limited available phosphorus (Murphy 1968). The soils are made up of different taxonomic groups (e.g., Nitosols, Regosols, and Cambisols). Meteorological data from Wushwush village at 1725 m a.s.l. ($7^0 13'$ N, $36^0 17'$E) indicate that the annual rainfall is around 1800 mm, the wettest months being May and June; mean average temperature is around 19^0C.

The Kaficho is the dominant ethnic group in the area. Over 90% of the population in the area is engaged in subsistence agriculture. Like in other areas, activities related to coffee production provide the largest income and employment opportunities for the local communities. Apiculture and spices also play an important role in the households' economy. The major land-use types in the area are (1) forest, (2) agriculture, (3) tea plantation (4) grazing land, (5) wetland, and (6) settlements. Although designated as a National Forest Priority Area around mid 1980s, the conservation efforts made so far are not encouraging. The adjacent communities appear to have unrestricted access to the forest. As a result, the forest is subjected to agricultural expansion and selective cutting. Only very recently, FARM-Africa initiated the Participatory Forest Management approach and the implementation process has been ongoing since 1996.

3.1.3 The Berhane-Kontir Forest

The Berhane-Kontir forest is located in the Sheko Wereda of the Bench-Maji Zone of SNNPRS (Figure 3.1 and Table 3.1). The forest occurs on undulating to steep slopes. Rocks of Precambrian origin dominate the geological formation of the area (Hagmann 1991; Asres 1996). The soils are moderately acidic with a high cation exchange capacity (Murphy 1968). During fieldwork, Acrisols, Regosols and Nitosols were observed. This forest represents the transition rainforest between the Afromontane rainforest and the lowland forest. The annual rainfall is around 2200 mm and mean annual temperature around 22^0C (EMSA 1996; Teketay et al. 1998).

The Sheko, Bench, Amhara, Kaffa, Mejenger and Menit are the major ethnic groups in the area. Over 90% of the population in the area is engaged in subsistence agriculture. Traditionally, the forest forms the major livelihood basis for the native Majenger people as a source of non-timber forest products (local information). In the recent past, however, with the arrival of new settlers from other parts of the country, conversion of the forest into agriculture and the expansion of the semi-forest coffee system through removal of trees and undergrowth have greatly reduced the forest cover. It appears that, besides honey, coffee production and processing provide significant income and employment opportunities to the local people. The major land-use types in the study area are forest, agriculture, grazing land, and settlement. Although the forest was identified and designated as a National Forest Priority Area in the early 1980s and as a Forest Coffee Conservation Site in 2000, it does not appear to have received much conservation interest until very recently.

3.1.4 The Maji Forest

The Maji forest is located in the Bench-Maji Zone of SNNPRS (Figure 3.1 and Table 3.1). It is one of the most southern forests with wild coffee populations in Ethiopia; it is separated from other forest coffee regions by lowland vegetation and savanna. According to the data from National Meteorological Services Agency (EMSA), the annual rainfall of the area is around 1600 mm and the mean annual temperature around 20^0C. Soil and geological data are similar to those of the other southwestern sites (Murphy 1968; Hagmann 1991; Asres 1996). The present study was carried out at the site called “Kassi-Bero” forest, which is one of the few remaining patches of coffee forest in the region. Population pressure has influenced the forest for many years. According to local evidences, shifting cultivation started in the area at the beginning of the 20th century. In the mid 1950s, many people entered the area from other parts of the country for hunting big game animals. Some settled and started slash-and-burn cultivation. They founded the village of “Jabba” in the center of the forest.

The two indigenous ethnic groups in the study area are the Surma and Dizi. The Dizi are somewhat sedentary and dependent on subsistence agriculture, whereas the Surmas are Nomadic and dependent on livestock. The major economic activities for many households are agriculture and livestock. In addition, honey, coffee, and gold mining are commonly practiced by many households.

3.1.5 The Harenna Forest

The Harenna forest is located in the Bale Zone of the Oromia State (Figure 3.1 and Table 3.1). It is the most eastern Afromontane rainforest and constitutes the largest sub-section of the Bale Mountains National Park. The Bale Mountains are formed from lava outpourings in the Miocene and Oligocene geological periods (Mohr 1965). This trap lava covered all previous rock formations and was formed prior to the formation of the Rift Valley, probably about 40-25 million years ago (Mohr 1965; Mohr 1971; Umer and Bonnefille 1998). The Harenna forest lies between 1300 and over 3000 m a.s.l However, forest coffee only occurs in the lower lying areas of the forest between 1300 and 1850 m a.s.l. The soil in the Harenna forest has been characterized and described by Nigatu (1987), and Tadesse and Nigatu (1996). Accordingly, the soil of Harenna forest is noted as dark reddish-brown silt-clay rich in basic exchangeable cations. The soil in the coffee zone is acidic to slightly acidic with a pH between 5.3 and 6.6. The rainfall pattern in the area is the bi-modal type, i.e., March through April (short rain season) and August through October (long rain season). Annual rainfall is about 1000 mm and the mean annual temperature is 18 ^{0}C.

The Oromo is the dominant ethnic group in the area. Livestock and subsistence agriculture form the major livelihoods of the rural communities. Coffee and honey also play a significant role. The major land-use categories in the area are (1) forest, (2) agriculture, (3) grazing land, (4) wetland, and (5) settlement. Although the Harenna forest is demarcated and considered as a National Forest Priority Area partly located in the Bale Mountains National Park, there have been only few conservation efforts. The forest cover is shrinking due to the continuous human activities.

3.2 Methods

3.2.1 Vegetation sampling

A systematic sampling design was used to collect vegetation and environmental data (Mueller-Dombois and Ellenberg 1974; Kent and Coker 1992; McCune and Grace, 2002). Vegetation data were collected in each forest using quadrats of 20 m x 20 m that distributed along transects. Many researchers have used similar sample sizes and shapes in the different Afromontane forests in Ethiopia (Bekele 1994; Tadesse and Nigatu 1996; Teketay 1996; Yeshitela 1997; Senbeta and Teketay 2003; Woldemariam 2003). The first plot was located randomly, then the plots were established at 300-m intervals along transects. Transects were spaced one kilometer or more apart depending on the size of the forest. In all, 203 plots were set up. The total number and distribution of sample plots for each forest varied with the size of the forest (Table 3.1). All data for the Yayu forest are taken from Woldemariam (2003). In each plot, all plant species with diameter at breast height (dbh; 1.30 m above ground) $\geq$ 2 cm and height $\geq$ 0. 5 m were identified and counted. The height was measured using a Suunto clinometer and diameter at breast height using a caliper. The presence of epiphytes, herbs, grasses, sedges and ferns were recorded. Species occurring outside the plots were recorded for floristic completion. Plant identification was done both in the field and in the herbarium, and voucher specimens were collected and placed in the National Herbarium, Addis Ababa University. Additionally, The Royal Botanic Gardens in Kew was visited for specimen identification.

Frequency and abundance of trees, shrubs and lianas were summarized on a plot basis. Frequency is expressed as either an absolute (number of plots in which the respective species occurs) or a relative number (the ratio of absolute frequency of a species to the total number of plots multiplied by 100). Abundance is the number of individual plants per plot. The cross-sectional area of tree stems at diameter at breast height (at 1.3 m above ground) is usually expressed as basal area (BA). It is generally a measure of dominance and is calculated using the formula $BA = \frac{dbh^2}{4}\Pi$.

Additionally, species were classified in one of four vertical strata: forest floor (maximum height < 0.5 m); shrub layer (maximum height 0.5 – 5 m); small tree layer (maximum height 5 – 15 m); tree layer (maximum height > 15 m) and their percentage canopy cover estimated.

Nomenclature followed the publications of the Flora of Ethiopia and Eritrea (Hedberg and Edwards 1989; Hedberg and Edwards 1995; Edwards et al. 1995; Edwards et al. 1997; Edwards et al. 2000; Hedberg et al. 2003).

3.2.2 Environmental data

The following environmental parameters were measured in each plot: slope (using clinometer), altitude (using pocket altimeter and Garmin GPS-72), exposition (using Silva compass), soil, coordinates (using GPS-72) and disturbance factor. As a certain level of anthropogenic disturbance exists in all forest vegetation of Ethiopia (Bonnefille and Hamilton 1986), the type and extent of disturbance were evaluated for each plot on ordinal scales from 0 to 3 (where 0 represents the absence of the influence and 3 the highest influence). Disturbance scores were based on visible signs of coffee harvesting, honey production, grazing and tree cutting. The visible indicators of coffee production are the presence of twisted branches/stems and broken branches, and for honey production the presence of beehives on the tree. Grazing is noted by the occurrence of cropped vegetation and trampled seedlings. The presence of stumps and branch debris on the ground confirmed the presence of cutting in the forest. Overall, the combined impact of these variables could result in higher impacts than the individual effects.

For pedological analysis, soil profiles were described from soil pits and supplemented with profiles taken with a pedological auger. Soil pits were systematically distributed in each forest. A total of 12 soil pits from three forests, i.e., Bonga (6), Berhane-Kontir (3) and Maji (3) were considered. Soil data for the Harenna and Yayu areas are taken from Taddesse and Nigatu (1996) and Woldemarima (2003), respectively. The pits reached a depth of 50 cm to over 2 m or to the rock basement. The description of the soil profiles follows the FAO guideline (1977). The soils encountered in the study area are classified according UNESCO/FAO (1988). Each horizon is described using depth, Munsell color sheets, field methods for texture, and structure analysis. Soil samples from each soil horizon were collected for chemical analysis. A senior soil expert assisted during the (field) soil classification.

For the climatic characterization of the sites, meteorological data (1954-2001) were obtained from the nearest meteorological stations according to the database provided by the Ethiopian Metrological Service Agency (EMSA). However, the period of data set differs among the meteorology stations, from 10 to 48 years.

3.2.3 Soil analysis

Soil analyses were carried out at the Soil Laboratory of the International Livestock Research Institute (ILRI), Addis Ababa. The samples were analyzed for pH-H_2O, % organic matter, % carbon (C), % total nitrogen (N), available phosphorus (P) (ppm), and exchangeable potassium (K) (meq/100g). Soil pH was determined in 1:2.5 pH-H_2O using the Beckman Zeromatic-II pH meter. Total organic carbon was determined by oxidation with acid dichromate and spontaneous heating by dilution of sulfuric acid according to Walkley and Black (1934). Exchangeable K was extracted with 1N ammonium acetate adjusted to pH 7.0 and the amounts determined with an atomic absorption spectrophotometer (Juo 1978). Available P was determined by the method of Bray and Kurtz (1945). Total N was determined with the macro-Kjeldahl method (Jackson 1958).

3.2.4 Data analysis

The data analysis methods are described in each relevant chapter to avoid redundancy.

4 BIODIVERSITY OF VASCULAR PLANT SPECIES IN THE AFROMONTANE RAINFORESTS OF ETHIOPIA

4.1 Introduction

Plant diversity is heterogeneously distributed across the earth (Gentry 1982; Wilson 1988; Barthlott et al. 1996; Gaston 2000; Tuomisto et al. 2003). Ultimately, understanding the variation in plant diversity patterns at different scales is an important topic of concern both for ecological explanations and for effective conservation design (Whittaker and Niering 1965; Lima and Zollner 1996; Austin et al. 1996; Urban et al. 2000; Balvanera et al. 2002). Patterns of plant species diversity have often been noted for prioritizing conservation activities because they reflect the underlying ecological processes that are important for management (Lovett et al. 2000).

In Ethiopia, plant diversity has rarely been studied and this is especially true for the Afromontane rainforests. Previous works (e.g., Friis et al. 1982; Friis 1992; Tadesse and Nigatu 1996) have documented a very limited extent of species diversity in the Afromontane rainforests. Given this lack of information, studies that provide information for conservation priorities between the different rainforest areas have become important. Additionally, the occurrences of wild Arabica coffee populations in the rainforests emphasize the need for study in order to design conservation measures (Strenge 1956; Meyer 1965; Teketay 1999; Tadesse and Nigatu 1996; Woldemariam 2003).

In the present study, a comparative analysis of the diversity of vascular plant species is carried out in four forest regions in SW and SE Ethiopia. The objectives of the study are to assess i) the magnitude of floristic composition and diversity of the forests with a wide geographical area (alpha and gamma diversity), ii) the patterns of species turnover within and between geographically separated rainforests (beta diversity), iii) the floristic similarity and dissimilarity among the forests, and iv) the phytogeographical affinities and endemicity of plant species in the Afromontane rainforests.

4.2 Material and methods

4.2.1 Study sites

The study was conducted in the Berhane-Kontir, Bonga, Maji, and Harenna Afromontane rainforests located in SE and SW Ethiopia (Figure 3.1). In addition to these sites, the Yayu forest was included in the analysis using the data source of Woldemariam (2003). Most of these forests have been declared conservation areas and are some of the largest remaining patches of Afromontane rainforests.

4.2.2 Vegetation sampling

For the present analysis, 147 plots from the undisturbed parts of the forests were considered. Of these, 24 plots are from Harenna, 37 from Berhane-Kontir, 28 from Bonga, 10 from Maji, and 48 plots from Yayu. The sampling methods are described in detail in Chapter 3.2 of this thesis.

4.2.3 Diversity analysis

Species richness is a biologically appropriate measure of alpha (α) diversity and is usually expressed as number of species per sample unit (Whittaker 1972). The Shannon diversity ($H^{'}$) and evenness ($E^{'}$) indices are calculated as a measure to incorporate both species richness and species evenness (Magurran 1988). The Shannon diversity index (H') is calculated from the equation:

$$H^{'} = -\sum_{i=1}^{s} p_i \ln p_i \qquad (4.1)$$

where p_i, is the proportion of individuals found in the i^{th} species. The values of Shannon diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 (Magurran 1988 and references therein). Evenness ($E^{'}$) was calculated from the ratio of observed diversity to maximum diversity using the equation:

$$E' = \frac{H}{H\max} = \frac{H}{\ln s} \qquad (4.2)$$

where H_{max} is the maximum level of diversity possible within a given population, which equals ln (number of species). E' is normal between 0 and 1, and with 1 representing a situation in which all species are equally abundant.

In addition, the Fisher's α, which is often known as log-series distribution, was used to describe the relationship between the number of species and abundance (Magurran 1988; Rosenzweig 1995). The advantage of Fisher's α index is that it is not influenced by sample size, unlike the other indices (Rosenzweig 1995). If abundances fit log-series distribution, then the number of observed species will follow this equation (Magurran 1988; Rosenzweig 1995):

$$S = -\alpha \ln(1 - x) \tag{4.3}$$

where α is a constant that depends on diversity alone, and x is a variable that depends on sample size. The variable x satisfies:

$$S/N = [(x-1)/x]\ln(1-x) \tag{4.4}$$

where S is the total number of species and N is the total number of individuals. The diversity index α can be obtained using the equation:

$$\alpha = \frac{N(1-x)}{x} \tag{4.5}$$

where N is the total number of individuals. Shannon diversity and evenness, and Fisher's α indices were calculated using the software BioDiversity Pro (McAleece 1997).

Beta (β) diversity is a measure used to characterize the patterns of species diversity across heterogeneous regions (Perlman and Adelson 1997). There are different beta (β) diversity measures which: (1) estimate richness and evenness differences over a range of habitats or sites, (2) indicate diversity changes along a gradient, or (3) compare the species composition of different communities (Wilson and Shimida 1984; Magurran 1988). Although there are different ways to calculate beta diversity, all methods determine species turnover (replace one another) between different sites or along environmental gradients (Perlman and Adelson 1997). In the present study, beta diversity was determined using the Whittaker (1972), and Wilson and Shmida (1984) methods.

The Whittaker (1972) method is:

$$\beta w = \frac{Sc}{S} - 1 \tag{4.6}$$

where βw is Whittaker beta diversity, Sc is the number of species in the composite sample (number of species in the whole data set), and S is the average species richness in the sample units. If βw is 0 then all sample units have the same species. βw <1 is rather low and βw >5 can be considered high (McCune and Grace 2002). The maximum value of βw is obtained when no species are shared among sample units. Species turnover (β_T) diversity between transects was determined as the gain and loss of species according to the formula proposed by Wilson and Shmida (1984):

$$\beta_T = \frac{g(H) + l(H)}{2\alpha} \tag{4.7}$$

where $g(H)$ and $l(H)$ are the number of species gained and lost along the transect respectively and α is the mean species richness of adjacent transects. A high β value indicates high species turnover and less similarity between the compared units (Porembski et al. 1996). A low β value indicates high habitat similarity between the compared units studied. Species richness over a range of habitats (landscape, geographical area) is called gamma (γ) diversity (Moreno and Halffter 2001; McCune and Grace 2002). It is the number of species in a region of study.

Species turnover analysis was complemented by calculating the floristic similarities between all pairs of sites using Sorensen’s similarity index (Magurran 1988), using:

$$Ss = \frac{2C}{(A+B)} \tag{4.8}$$

In this equation, *C* is the number of species common to both sites, *A* is the number of species present in one of the sites to be compared, and *B* is the number of species present in the other site.

4.2.4 Cluster analysis

Cluster analysis helps to group together a set of observations (here plots or vegetation samples) based on their attributes or floristic similarities (Kent and Coker 1992; McCune and Grace 2002). In the present analysis, a hierarchical cluster analysis was performed using PC-ORD for Windows Version 4.20 (McCune and Mefford 1999). The abundance data of a species were used for the analysis. The Relative Euclidean Distance (RED) measures using Ward’s method (linkage) was applied. The Euclidean Distance was used because it eliminates the differences in total abundance among sample units; Ward’s method was used because it minimizes the total within-group mean of squares or residual sum of squares (van Tongeren 1995; McCune and Grace 2002). The identified groups were tested for the hypothesis of no difference between the groups using the multi-response permutation procedure (MRPP).

In community analysis, a very common goal is to detect and describe the value of different species for indicating environmental conditions. If environmental differences are conceptualized as groups of sample unity, then Dufrêne and Legendre (1997) method of calculating species indicator values provides a good solution. An indicator of a particular group should be faithful to that group. The method combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a species in a particular group (McCune and Mefford 1999). It produces indicator values for each species in each group. Indicator values are tested for statistical significance using a Monte Carlo (randomization) test technique.

The indicator values range from zero (no indication) to 100 (perfect indication). Perfect indication means that presence of a species points to a particular group without error, at least with the data set in hand. In this analysis, data from the Maji forest (10 plots) was excluded as the dataset was incomplete.

4.2.5 Ordination

Ordination is a multivariate method that expresses the relationships between samples, species and environmental variables in a low-dimensional space using ordination diagrams (ter Braak 1995; McCune and Grace 2002). And there are different ordination techniques. In the present analysis, the Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used. All analyses were done with the computer program CANOCO version 4.5 (ter Braak 2003). The DCA is indirect unimodal ordination method with detrending and whereas CCA is a direct gradient analysis (for a detail see Jongman et al. 1987; ter Braak 1995; McCune and Grace 2002). The appropriate analysis depends on whether the species are responding linearly to gradients (linear response) or have the best performance around some environmental optima (unimodal response). A maximum gradient length exceeding 4 standard deviation (SD) implies a strong unimodal response between the species and environmental variables, and in this case, use of Canonical Correspondence Analysis is recommended (Jongman et al. 1987). If the relationship between vegetation response and environmental variables is likely to be linear (with gradient length less than 3 SD), use of Redundancy Analysis (RDA) is recommended. Environmental variables were tested for statistical significance using a Monte Carlo test technique and automatic forward selection of variables (ter Braak 2003). In the present analysis, 137 sample plots, 107 species and 4 environmental variables (slope, altitude, aspects and human disturbance) were included in the analysis. Only the datasets from Bonga, Yayu, Harenna, and Berhane-Kontir forests were used.

4.3 Results

4.3.1 Floristic composition

The floristic analyses of the five Afromontane rainforests altogether yielded 651 species and 118 families, including species recorded outside the sample plots (Table 4.1; for species lists see Appendix 1). This total includes 16 pteridophytes families, 2 gymnosperm families, 19 monocotyledon and 83 dicotyledon families. Of the total number of species, 50 pteridophytes, 599 angiosperms, and 2 gymnosperms are represented in the forests. The species-richest family is the Orchidaceae (19 genera, 40 species), followed by Rubiaceae (26 genera, 32 species), Fabaceae (21 genera, 31 species) and Asteraceae (17 genera, 30 species). However, the order of family dominance varies in each forest (Table 4.2). The 10 species-richest families contribute 37% of the total species, and the 20 species-richest families contribute 51% of the total species.

Table 4.1 Number of plant families, genera and species found in the studied Afromontane rainforests of Ethiopia (Abbreviations as in Table 3.1)

	BO	BK	YA	MA	HA
No. of families	91	91	69	57	87
No. of genera	213	256	163	124	212
No. of species	285	374	217	146	289
Genera/families	2.34	2.81	2.36	2.18	2.44
Species/genera	1.34	1.46	1.33	1.18	1.36

Out of the total 118 families recorded, 47 (40%) occurred in all five forests, 15 (13%) in four forests, 14 (12%) in three forests, 17 (14%) in 2 forests and 25 (21%) in one forest only. Of the families occurring in only one forest, 9 families are from Berhane-Kontir, 8 from Bonga, 5 from Harenna, 2 from Yayu and none from Maji forest. Families with discontinuous distributions are Dilleniaceae, Nyctaginaceae, Violaceae, Balanophoraceae and Marantaceae (Berhane-Kontir); Basellaceae, Marattiaceae, Melastomataceae, Thelypteridaceae and Vittariaceae (Bonga); Canellaceae and Erythroxylaceae (Harenna) and Taccaceae (Yayu).

Table 4.2 The 10 species-richest families in the Afromontane rainforests of Ethiopia and in each forest decreasing order (S= number of species; Abbreviations as in Table 1)

All regions		Forest region				
Family	S	BO	BK	YA	MA	HA
Orchidaceae	40	Fabacae	Orchidaceae	Euphorbiaceae	Rubiaceae	Fabacae
Rubiaceae	32	Asteraceae	Rubiaceae	Rubiaceae	Fabacae	Rubiaceae
Fabaceae	31	Orchidaceae	Euphorbiaceae	Orchidaceae	Euphorbiaceae	Orchidaceae
Asteraceae	30	Euphorbiaceae	Moraceae	Fabacae	Celastraceae	Euphorbiaceae
Euphorbiaceae	29	Aspleniaceae	Acanthaceae	Moraceae	Rutaceae	Asteraceae
Acanthaceae	25	Rubiaceae	Fabacae	Asteraceae	Aspleniaceae	Acanthaceae
Poaceae	24	Poaceae	Poaceae	Malvaceae	Sapindaceae	Celastraceae
Moraceae	19	Labiatae	Aspleniaceae	Acanthaceae	Moraceae	Rutaceae
Asclepiadaceae	15	Piperaceae	Amaranthaceae	Poaceae	Malvaceae	Aspleniaceae
Aspleniaceae	15	Celastraceae	Sapindaceae	Celastraceae	Asteraceae	Sapindaceae

Of the total 651 species recorded, 62 (10%) occurred in five forests, 47 (7%) in four forests, 63 (10%) in three forests, 133 (20%) in two forests and the largest proportion 346 (53%) in one of the forests. Most of theses species are rare and have a low frequency of occurrence. Of the total species occurring in only one forest, 133 were in Berhane-Kontir, 83 in Harenna, 78 in Bonga, 45 in Yayu and 7 in Maji forest. In contrast, about 50% of the woody species recorded in the present study have abundance values of less 20 individuals across all studied forests.

4.3.2 Alpha, beta and gamma diversity

At the 400 m^2 sample plot, species richness ranged from 37 (Maji) to 66 (Bonga) and the overall mean of all forest was 49 (Table 4.3). The Fisher's α, was highest in the Berhane-Kontir (24.4) and lowest in Yayu (9.9) forest (Table 4.3). On the other hand, Shannon diversity indices ranged from 1.54 to 3.17, with the highest value in Bonga and the lowest in Maji. Evenness was highest in the Bonga forest.

Table 4.3 Summary of the various diversity parameters calculated in the different Afromontane rainforests of Ethiopia (Abbreviation as in Table 1)

Characteristics*	BO	BK	HA	MA	YA
Species richness per plot	66	45	46	37	30
Fisher's α	15.4	24.4	19.7	15.1	9.9
Shannon diversity (H')	3.17	2.83	2.60	1.54	2.80
Evenness index (E')	0.67	0.54	0.51	0.31	0.63
Whittaker beta diversity (βw)	1.82	4.96	3.22	2.36	2.38
Species turnover (β_T)	1.86	6.48	3.27	2.22	2.65
Gamma (γ) diversity	285	374	289	146	217

** Woody species (including YA species richness) but species richness and gamma diversity refers to vascular plant species.*

The magnitude of beta diversity indicates the change in species composition between adjacent transects along the environmental gradient. In this case, the highest beta diversity was recorded in the Berhane-Kontir forest and the lowest in Bonga (Table 4.3). Overall, the two indices of beta diversity showed very close results for each site, and the values follows the order Berhane-Kontir>Harenna>Yayu>Maji> Bonga. On the other hand, observed regional (gamma) diversity, i.e., total number of species in each region, is likewise high in the Berhane-Kontir and Harenna forests, and low in the Maji forest.

4.3.3 Floristic similarities

Sorensen's similarity coefficient indicates the highest floristic similarity between Harenna and Bonga (0.50), the lowest between Yayu and Bonga/Harenna (0.42) (Table 4.4). Similarity coefficients of all forests lie between 0.42 and 0.50. The relationship between beta diversity and similarity coefficients is that they are inversely related. High beta diversity indicates low similarity coefficients (i.e., high species turnover between the communities) and vice versa. The fewer the species that the different communities or gradients positions share, the higher is beta diversity.

Table 4.4 Sorensen’s similarity coefficient in species composition between the studied Afromontane rainforests of Ethiopia

Site	BO	BK	YA	MA	HA
BO	-	0.43	0.42	0.47	0.50
BK		-	0.45	0.45	0.44
YA			-	0.48	0.42
MA				-	0.46
HA					-

4.3.4 Cluster analysis

Five community types are derived from the hierarchical cluster analysis (classification) (Figure 4.1). The analysis is based on the abundance data of the species. The data matrix contains 135 plots and 107 woody species. Two plots (19 and 39) were recognized as outliers and were not considered in the analysis. The decision on the number of groups was based on the MRPP technique (no-difference hypothesis) and the ecological interpretation of the groups. The test statistic ***T*** value for the five groups was -65.282 ($P < 0.001$) and the agreement statistic ***A*** was 0.300. The test statistic ***T*** describes the separation between the groups. The more negative ***T*** value, the stronger the separation. The agreement statistic ***A*** describes within group homogeneity, compared to the random expectation, and falls between 0 and 1. When all items within-groups are identical ***A*** = 1 and 0 if the groups are heterogeneous. In community ecology, ***A*** values are commonly below 0.1, and greater 0.3 is high (McCune and Grace, 2002). From the result, the null hypothesis of no difference among groups can be rejected. The five groups occupy different regions of species space, as shown by the strong chance correction within the group (***A***) and test statistic (***T***). From the present analysis, a 5 cluster solution (plant community) was considered optimal. The indicator species for each community is shown in Table 4.5. A species with a significant indicator value at $P < 0.05$ is considered as an indicator species of the group. The five communities obtained in this analysis were named after one or two of the dominant indicator species. The four communities identified follow the four forest regions that are considered for the study and hence the name of the forest is used exchangeable. The major characteristic of each community is summarized as follows:

C1. *Chionanthus mildbraedii-Psychotria orophila* community ("Bonga forest"): This community comprises 23 plots of which 21 plots are in Bonga and only one each in Harenna and Yayu, and they can thus be named as "Bonga Forest." This community has many indicator species with significant indicator values (Table 4.5). The common tree and shrub species of the community include *Chionanthus mildbraedii, Psychotria orophila, Dracaena afromontana, Phoenix reclinata, Deinbollia kilimandscharica, Galiniera saxifraga, Syzygium guineense, Allophylus abyssinicus, Elaeodendron buchananii, Rytigynia negelcta, Oxyanthus speciosus, Ilex mitis, Millettia ferruginea*, and *Macaranga capensis*. The lianas are dominated by *Jasminum abyssinicum, Embelia schimperi, Hippocratea africana, culcasia falcifolia* and *Dalbergia lactea.* The field layer is mostly patchy and composed of mainly *Oplismenus hirtellus, Oplismenus undulatifolius, Sanicula elata* and different ferns. Most species in this community are the Humid Afromontane forest (Afromontane rainforest) species, e.g., *Millettia ferruginea, Ilex mitis, Deinbollia kilimandscharica, Olea welwitschii,* and *Pouteria adolfi-friederici*. The community occurs on the higher elevations between 1800 and 2040 m. The terrain is mostly undulating and comprises different soils.

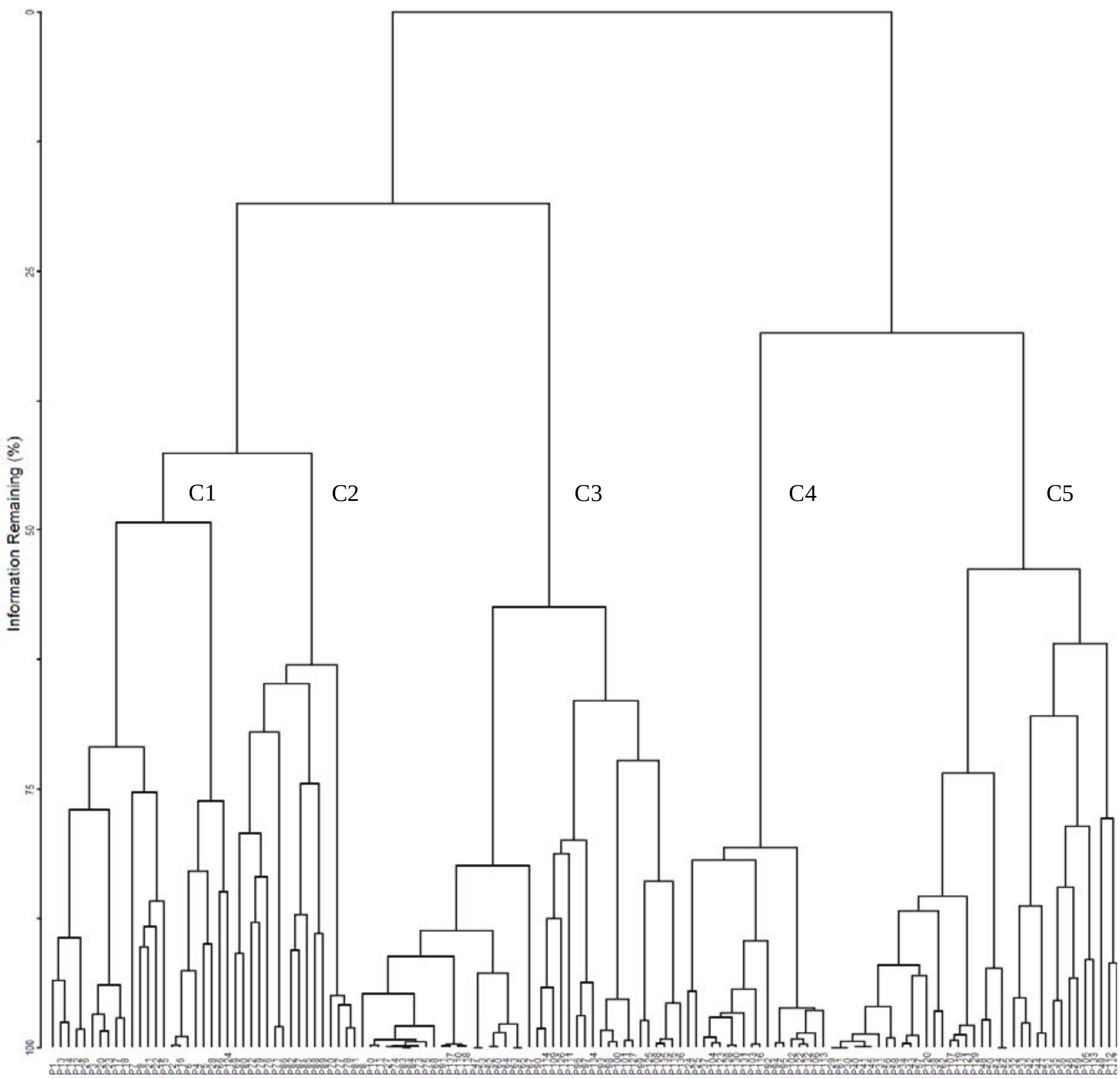

Figure 4.1 Dendrogram of the cluster analysis results of species abundance of 107 woody species found in 135 plots in four studied Afromontane rainforests of Ethiopia. The level of grouping was based on 55% information remaining. The plot code and the arrangement of the plots along the dendrogram from left to right are as follows: **C1**:1, 13, 14, 12, 26, 3, 20, 23, 17, 18, 7, 9, 21, 22, 15, 2, 16, 6, 4, 5, 28, 66, 124; **C2**:69,80, 72, 79, 76, 71, 86, 82, 87, 85, 88, 89, 70, 77, 78, 81; **C3**: 8, 10, 11, 27, 74, 83, 84, 73, 75, 68, 91, 137, 110, 118, 47, 53, 52, 60, 64, 63, 65, 67, 90, 114, 109, 126, 111, 96, 7, 134, 93, 98, 100, 101, 127, 99, 125, 108, 135, 115, 136; **C4**: 24, 25, 37, 104, 123, 128, 130, 131, 103, 116, 92, 94, 95, 102, 122, 132, 106, 113; **C5**: 29, 61, 30, 40, 41, 45, 31, 56, 58, 34, 43, 57, 120, 38, 62, 107, 119, 121, 129, 48, 50, 54, 55, 32, 33, 42, 44, 51, 35, 36, 46, 59, 105, 133, 49, 112, 117

C2. *Afrocarpus falcatus* community ("Harenna forest"): This community consists of 16 plots, which all are from Harenna and hence named "Harenna Forest." The community has eight indicator species with significant indicator values, namely *Afrocarpus falcatus, Maytenus undata, Acanthus eminens, Cassipourea malosana, Fagaropsis angolensis, Croton macrostachys* and *Erythrococca abyssinica* (Table 4.5). The associated trees and shrubs species of the community are *Alangium chinense, Celtis africana, Coffea arabica, Ocotea kenyensis, Filicium decipiens, Warburgia ugandensis,* and *Strychnos mitis.* The common climber species of the community are *Oncinotis tenuiloba* and *Landolphia buchananii.* The herbaceous layer mainly consists of *Thalictrum rhynchocarpu, Panicum monticola, Hypoestes forskaoli, Desmodium repandum* and *Achyranthes aspera.* Most trees are Humid Afromontane forest species and widespread Afromontane species, e.g., *Afrocarpus falcatus, Fagaropsis angolensis* and *Cassipourea malosana*. This community is located in the altitudinal range between 1625 m and 1830 m. The terrains is very gentle and mostly with slope angles of less than 10%.

C3. *Coffea arabica* community ("Coffee forest"): This community represents 41 plots from all forests. The Yayu forest contributes around 56% (23 plots), seven plots each are in Berhane-Kontir and Harenna, and 4 in Bonga. The community has five indicator species with significant indicator values. These are *Coffea arabica, Maytenus gracilipes, Rhus ruspoli, Landolphia buchananii,* and *Paullinia pinnata* (Table 4.5). The other associated trees and shrubs species of the community are *Trichilia dregeana, Celtis africana, Canthium oligocarpum, Clausena anisata, Ehretia cymosa, Maesa lanceolata,* and *Mimusops kummel.* The common lianas species of the community are *Landolphia buchananii* and *Paullinia pinnata*. The ground layer of this community is usually open, in some places dominated by *Oplismenus undulatifolius, Sanicula elata,* and in others place by coffee seedlings. Most of the tree species in this community are Afromontane endemics or near-endemics (e.g., *Coffea arabica, Canthium oligocarpum, Vepris dainellii,* and *Mimusops kummel*). The community occupies the altitudinal range of between 1200 m and 1850 m, and occurrs mostly on gentle slopes.

C4. *Trilepisium madagascariense-Dracaena fragrans* community ("Yayu forest"): This community comprises 18 plots, of which 15 plots are in Yayu, 1 in Berhane-Kontir and 2 in Bonga; and is named "Yayu Forest." The community has 10 indicator species with significant indicator values including *Dracaena fragrans, Albizia grandibracteata, Hippocratea goetzei, Tiliacora troupinii, Teclea nobilis, Trilepisium madagascariense, Scutia myrtina, Tiliacora funifera,* and *Olea capensis ssp. Macrocarpa* (Table 4.5). The other associated tree and shrub species of the community include *Olea welwitschii, Morus mesoygza, Trichilia degreana, Diospyros abyssinica, Vepris daniellii, Pittosporum viridiflorum,* and *Phyllanthus fischeri.* The climbing species of the community are chiefly *Hippocratea pallens* and *Tiliacora funifera.* The field layer varied very much and among the commonest species are *Desmodium repandum, Elatostema monticolum, Peperomia molleri* and *Oplismenus undulatifolius.* Some of the tree species in this community are Guineo-Congolian forest species (*e.g., Dracaena fragrans*). This community occurs in the altitudinal range between 1310 m and 1535 m on steep slopes.

C5. *Whitfieldia elongata-Zanha golungensis* community ("Berhane-Knotir forest"): This community comprises 37 plots of which 28 are in Berhane-Kontir and 9 in Yayu and is named "Berhane-Kontir Forest." The community has many indicator species with significant indicator values, such as *Whitfieldia elongata, Rungia grandis, Argomuellera macrophylla, Alchornea laxiflora, Pouteria altissima, Manilkara butugi, Hippocratea pallens, Erythrococca trichogyne, Hippocratea parvifolia, Celtis zenkeri* and *Zanha golungensis* (Table 4.5). Many tree and shrub species are associated to the community, such as *Diospyros abyssinica, Celtis philippensis, C. toka, C. zenkeri,* and *Blighia unijugata. Whitfieldia elongata, Rungia grandis* and *Argomuellera macrophylla* are the most abundant species of undersorey layer of the community. *Uvaria angolensis, Hippocratea pallens* and *Hippocratea parvifolia* dominate the climbing plant species. The field layer is very sparse, composed of *Achyrospermum schimperi, Hilleria latifolia, Leptaspis zeylanica* and *Olyra latifolia*. Many tree species are characteristic of the Guineo-Congolian forest and transitional rainforest, e.g., *Argomuellera macrophylla, Pouteria altissima, Celtis philippensis, Celtis toka,* and *Celtis zenkeri.* This community is located between 950 m and 1500 m a.s.l. on varying topography.

Table 4.5 Indicator values (% of perfect indication) of each species for each community (1-5) and the Monte Carlo test of significance observed for each species. These values were obtained by combining the relative abundances and relative frequencies of each species

Species	1	2	3	4	5	*P*
Chionanthus mildbraedii	**82**	1	2	0	0	*0.010*
Psychotria orophila	80	0	1	1	0	*0.010*
Dracaena afromontana	73	0	1	0	0	*0.010*
Phoenix reclinata	72	0	2	1	0	*0.010*
Deinbollia kilimandscharica	69	0	0	1	0	*0.010*
Galiniera saxifraga	63	0	2	0	0	*0.010*
Syzygium guineense	48	29	1	0	0	*0.010*
Allophylus abyssinicus	48	2	1	3	0	*0.010*
Elaeodendron buchananii	46	0	4	11	0	*0.010*
Jasminum abyssinicum	44	34	1	0	0	*0.010*
Rytigynia neglecta	44	18	1	1	0	*0.010*
Oxyanthus speciosus	43	15	6	2	0	*0.010*
Embelia schimperi	43	1	1	0	0	*0.010*
Hippocratea africana	42	17	3	1	0	*0.010*
Ilex mitis	42	0	0	0	0	*0.010*
Culcasia falcifolia	41	0	0	0	0	*0.010*
Millettia ferruginea	37	0	9	6	3	*0.020*
Macaranga capensis	28	3	0	0	0	*0.010*
Schefflera myriantha	26	2	1	2	0	*0.010*
Acacia brevispica	8	0	2	0	4	*0.320*
Dalbergia lactea	35	6	4	3	0	*0.020*
Justicia schimperiana	30	0	7	5	1	*0.020*
Albizia grandibracteata	29	0	2	0	0	*0.020*
Apodytes dimidiata	28	4	2	0	0	*0.020*
Pouteria adolfi-friederici	26	12	1	1	0	*0.040*
Rubus apetalus	23	0	0	0	3	*0.040*
Lepidotrichilia volkensii	36	22	6	1	0	*0.020*
Vepris dainellii	32	1	17	27	2	*0.010*
Rothmannia urcelliformis	25	0	4	6	9	*0.090*
Ficus sur	11	7	2	0	0	*0.240*
Combretum paniculatum	20	0	14	15	5	*0.200*
Tragia brevipes	9	0	9	0	1	*0.410*
Bersama abyssinica	21	19	20	6	5	*0.540*
Afrocarpus falcatus	0	**79**	2	0	0	*0.010*
Maytenus undata	0	54	1	0	0	*0.010*
Acanthus eminens	5	44	0	0	0	*0.010*
Erythrococca abyssinica	14	38	0	1	1	*0.010*

Table 4.5 continued

Species	1	2	3	4	5	*P*
Fagaropsis angolensis	4	32	0	1	0	*0.010*
Croton macrostachys	1	27	4	2	1	*0.020*
Cassipourea malosana	1	30	18	6	1	*0.040*
Garcinia buchananii	0	28	1	0	14	*0.090*
Ocotea kenyensis	16	21	2	0	0	*0.020*
Oncinotis tenuiloba	20	20	3	1	0	*0.020*
Flacourtia indica	8	15	7	0	1	*0.130*
Ficus thonningii	1	10	2	0	4	*0.160*
Alangium chinense	2	40	1	0	0	*0.010*
Polyscias fulva	6	8	0	2	7	*0.770*
Coffea arabica	6	0	**75**	8	8	*0.010*
Paullinia pinnata	0	0	37	15	3	*0.020*
Rhus ruspoli	0	0	29	21	1	*0.020*
Landolphia buchananii	7	2	42	35	6	*0.020*
Maytenus gracilipes	17	1	32	20	2	*0.040*
Trichilia dregeana	0	0	25	22	5	*0.060*
Celtis africana	0	10	35	11	6	*0.050*
Canthium oligocarpum	0	0	30	26	3	*0.050*
Mimusops kummel	0	0	24	20	11	*0.080*
Ehretia cymosa	3	17	24	14	2	*0.110*
Maesa lanceolata	5	0	16	0	0	*0.120*
Antiaris toxicaria	0	0	17	4	14	*0.240*
Sapium ellipticum	2	0	10	10	1	*0.300*
Pterolobium stellatum	1	0	12	10	2	*0.300*
Allophylus macrobotrys	0	5	10	0	2	*0.280*
Clausena anisata	15	0	20	18	4	*0.340*
Cissus quadrangularis	0	0	5	4	5	*0.870*
Dracaena fragrans	1	0	13	**76**	4	*0.010*
Albizia grandibracteata	0	0	12	50	3	*0.010*
Hippocratea goetzei	1	6	11	44	8	*0.020*
Tiliacora troupinii	0	0	4	39	3	*0.010*
Olea capensis ssp. macrocarpa	1	0	10	32	1	*0.010*
Trilepisium madagascariense	0	0	2	45	2	*0.020*
Scutia myrtina	0	0	9	19	0	*0.030*
Tiliacora funifera	12	0	11	28	2	*0.020*
Ficus lutea	0	0	5	14	9	*0.050*
Teclea nobilis	15	4	11	27	5	*0.040*
Pittosporum viridiflorum	6	0	11	31	1	*0.100*
Phyllanthus fischeri	5	0	3	14	1	*0.340*
Olea welwitschii	16	0	8	18	4	*0.320*
Canthium giordanii?	7	0	16	20	3	*0.290*

Table 4.5 continued

Species	1	2	3	4	5	*P*
Pavetta abyssinica	7	1	1	9	0	*0.360*
Celtis toka	0	0	6	8	4	*0.460*
Dracaena steudneri	5	0	6	11	6	*0.690*
Ekebergia capensis	1	3	1	9	4	*0.670*
Whitfieldia elongata	0	0	0	0	**68**	*0.010*
Zanha golungensis	0	0	1	0	43	*0.010*
Rungia grandis	0	0	0	0	39	*0.010*
Argomuellera macrophylla	0	0	2	26	54	*0.010*
Alchornea laxiflora	0	0	3	0	35	*0.010*
Uvaria angolensis	0	0	5	0	34	*0.010*
Manilkara butugi	0	0	0	1	34	*0.010*
Hippocratea pallens	0	0	1	0	32	*0.010*
Erythrococca trichogyne	0	0	3	0	35	*0.020*
Pouteria altissima	0	0	5	0	25	*0.020*
Hippocratea parvifolia	0	0	6	0	26	*0.030*
Celtis zenkeri	0	0	1	0	26	*0.030*
Capparis tomentosa	0	0	1	0	22	*0.030*
Metarungia pubinervia	0	0	3	0	24	*0.050*
Tiliacora troupinii	0	0	1	1	21	*0.010*
Salacia congolensis	0	0	3	0	16	*0.020*
Ritchiea albersii	0	0	9	9	25	*0.040*
Blighia unijugata	0	0	18	13	31	*0.040*
Cordia africana	0	0	9	2	17	*0.050*
Acacia montigena	0	0	6	0	11	*0.110*
Diospyros abyssinica	0	0	12	31	49	*0.100*
Strychnos mitis	0	0	16	0	19	*0.170*
Margaritaria discoidea	0	8	2	0	9	*0.180*
Eugenia bukobensis	0	0	12	9	14	*0.610*
Gouania longispicata	7	0	1	0	10	*0.720*

4.3.5 Ordination

The distribution of sample plots over complex environmental gradients across the four studied forests was explained well by indirect ordination analysis using Detrended Correspondence Analysis (DCA) in Figure 4.2. Maji was excluded from the analysis because the dataset was incomplete. Environmental data are subsequently used to interpret the ordination. The DCA is chosen because it met the criteria of (1) ecological interpretability, and (2) effective spreading out of the points according to sites (Hill and Gauch 1980). The DCA result tends to strengthen the cluster analysis result in Figure 4.1. The ordination of the study plots of the four forests forms five groups based on the species composition. Four groups reflect the four forest regions: Bonga, Harenna, Yayu and Berhane-Kontir, while 5th group, “Coffee Forest,” represents plots from the mid altitude (1300–1700 m) across all forests where wild coffee occurs abundantly. This is a forest belt in each forest where the floristic composition and/or coffee abundance are very similar. The high degree of dispersion of the plots inside the DCA diagram indicates the floristic heterogeneity of the forests.

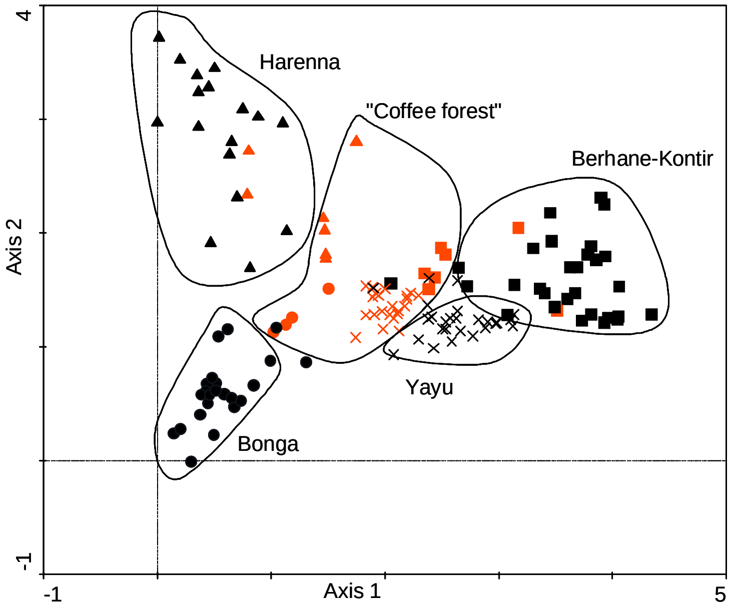

Figure 4.2 Ordination based on Detrended Correspondence Analysis (DCA) with abundance of woody species from four studied forests of Ethiopia. One symbol represents one site; the gray symbols represent the coffee community

The lengths of the maximum gradient axes for the different groups are greater than 4.5 standard deviation unit (Table 4.6), indicating an almost total species turnover between the forests (McCune and Grace, 2002). The eigenvalue for the first axis (0.56) is much higher, indicating that this axis is strongly related to the most important environmental variables. The size of each eigenvalue tells us how much variance is represented by each axis. Axis 1 of the ordination diagram reflects the gradient in altitude and axis 2 reflects the gradient of complex environmental factors. The distance between the forests indicates the relative degree of similarity or difference in terms of floristic composition or other complex environmental variables (Figure 4.2). This ordination also illustrates that there is some over-lapping between the forests, e.g., between the Yayu and Berhane-Kontir forests.

Table 4.6 Eigenvalues of the first four axes of DCA and the amount of variance explained by each axes in four Afromontane rainforests of Ethiopia

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.56	0.34	0.25	0.18	6.41
Lengths of gradient (SD)	4.52	3.63	2.99	2.93	
Cumulative % variance of species data	8.70	13.90	17.80	20.50	

In order to gain a clearer structure in the "Coffee Forest" (Figure 4.2), the DCA was repeated after removal of all the plots in the Bonga, Harenna, Yayu, and Berhane-Kontir 'forests.' The outcome of this ordination was the formation of four "Coffee Forest" sub-communities following the regions (Figure 4.3). This illustrates that the "Coffee Forest" areas observed in the cluster analysis and ordination (Figure 4.1 and 4.2) are heterogeneous and occur on the different environmental gradients, although they have some affinity on a broader scale.

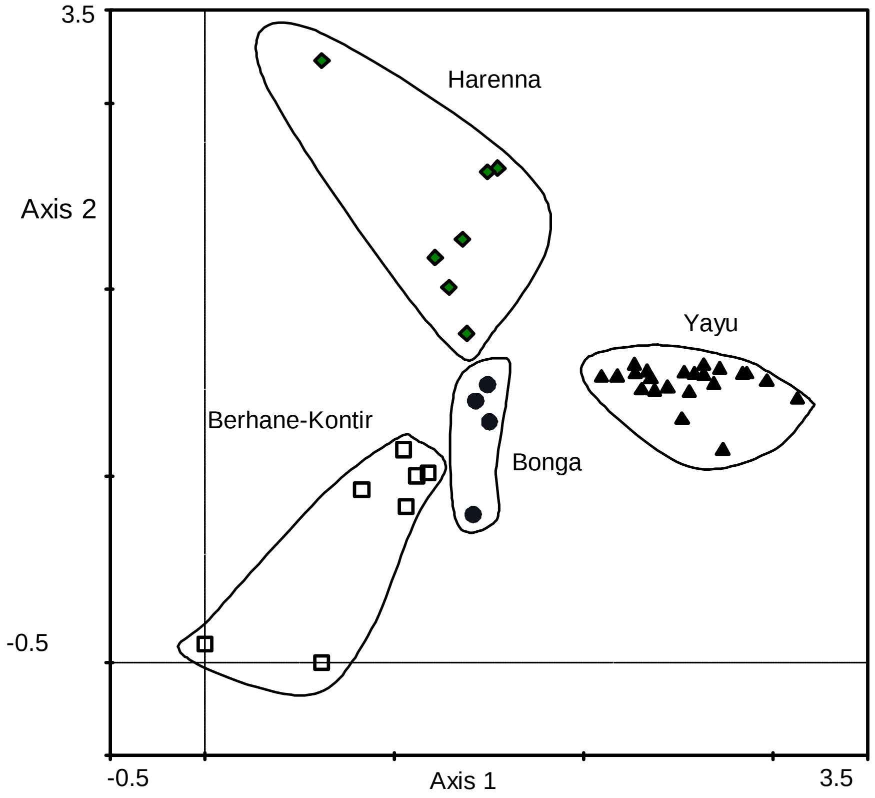

Figure 4.3 Ordination diagram of "Coffee Forest" using DCA, which follows regional differences in four studied Afromontane rainforests of Ethiopia

The result of the DCA is summarized in Table 4.7. The eigenvalue of the first axis is higher, indicating the long gradient between the samples. The variances of the species data by DCA axes are small (Table 4.7), indicating that considerable "noise" remains unexplained. However, lower percentage variances for species data are normal in vegetation data and do not impair the significance of species-environmental relations (McCune and Grace 2002).

Table 4.7 Summary of the eigenvalues of the first four axes of DCA and the variance explained; Coffee Forest in the four studied Afromontane rainforests of Ethiopia

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.41	0.28	0.12	0.11	2.79
Lengths of gradient (SD)	2.95	2.91	1.72	2.27	
Cumulative % variance of species data	14.50	24.40	28.80	32.70	

4.3.6 Phytogeographical affinities

A synopsis of the general distribution of all the vascular plant species of the five studied Afromontane rainforests is presented in Table 4.8. The majority of the plant species is widely distributed within tropical Africa. However, the widespread pantropical or cosmopolitan flora elements are smaller in the studied Ethiopian rainforests. The distribution of 155 trees and shrub species within the phytogeographical regions is presented in Table 4.9 and Appendix 2. The assignment of species to phytogeographical regions follows Friis (1992). About 39% of the species are characteristic of Afromontane species, 15% are Guineo-Congolian species and 46% linking elements (connecting species). As illustrated in Table 4.9, a significant number of tree and shrub species from the Berhane-Kontir and Yayu forests contain Guineo-Congolian elements or linking species, while species from Harenna and Bonga contain a high proportion of Afromontane elements.

Table 4.8 Phytogeographical classification of the vascular plant species recorded in the studied Afromontane rainforests of Ethiopia (according to Flora of Ethiopia and Eritrea)

Combined categories	No. of taxa	%
Cosmopolitan	10	1.5
Endemic	31	5.0
Pantropical	14	2.2
Taxa distributed outside Africa	35	5.4
Widespread tropical Africa	347	53.0
Tropical northeast Africa	79	26.0
Widespread in Eastern Africa	70	8.0

Ecologically, most of the species recorded in the studied rainforests are typical elements of moist montane rainforest (Appendix 1). About 70% of the species rely on these forests for their survival, and nearly 62 % is classified as transitional rainforest (Appendix 1). Some species distributed over a wide ecological range even beyond Afromontane rainforest region.

Table 4.9 Distribution types of 155 trees and shrubs in the studied Afromontane rainforests of Ethiopia

Centres of distribution	BO	HA	BK	YA	MA	Total species	Total (%)
Afromontane	47	48	38	36	29	60	39
Guineo-Congolian	0	0	24	12	2	24	15
Linking species	30	34	58	38	25	71	46
Total species considered	155 species						

A total of 31 endemic plant species were recorded in all five Afromontane rainforests (Table 4.10), forming about 5% of the species recorded. Five of these species belong to the Asteraceae, and three species to the Acanthaceae, Euporbiaceae, Orchidaceae and Urticaceae families. The remaining species belong to 12 families. In the Harenna forest, 17 endemic species were recorded, in Berhane-Kontir 14, in Bonga 14, in Yayu 7, and in Maji 4 species.

Table 4.10 Endemic forest species recorded in the studied Afromontane rainforests of Ethiopia

Species	Family	Habitat	Forest region	Growth form
Aframomum corrorima	Zingiberaceae	Moist montane forest	BK, YA, BO	Herb
Botheriocline schimperi	Asteraceae	Moist montane forest	HA	Herb
Brillantaisia grotanellii	Acanthaceae	Riverine forest	BK, MA	Shrub
Ceropegia sobolifera	Asclepiadaceae	Transitional forest	BK	Liana
Clematis longicauda	Ranunculaceae	Moist montane forest	BO, BK	Liana
Conyza abyssinica	Asteraceae	Moist montane forest	HA	Herb
Dorstenia soerensenii	Moraceae	Moist montane forest	BO	Herb
Droguetia iners	Urticaceae	Moist montane forest	HA	Herb
Erythrina brucei	Papilionaceae	Moist montane forest	HA	Tree
Euphorbia omariana	Euphorbiaceae	Moist montane forest	BO, BK, HA	Herb
Impatiens rothii	Balsaminaceae	Moist montane forest	HA	Herb
Justicia dicilipteroides	Acanthaceae	Transitional forest	BK	Herb
J. heterocarpa	Acanthaceae	Transitional forest	YA, HA	Shrub
Kalanchoe petitiana	Crassulaceae	Moist montane forest	HA	Herb
Laggera tomentosa	Asteraceae	Moist montane forest	HA	Herb
Liparis abyssinica	Orchidaceae	Moist montane forest	BO	Herb
Millettia ferruginea	Papilionaceae	Moist montane forest	All	Tree
Panicum ruspolii	Gramineae	Moist montane forest	HA	Grass
Phyllanthus limmuensis	Euphorbiaceae	Moist montane forest	BO,YA	Liana
P. mooneyi	Euphorbiaceae	Moist montane forest	BO, HA	Herb
Pilea bambuseti	Urticaceae	Moist montane forest	BO	Herb
Polystachya rivae	Orchidaceae	Moist montane forest	BK	Epiphyte
P. caduca	Orchidaceae	Moist montane forest	BK, HA	Epiphyte
Satureja paradoxa	Labiatae	Moist montane forest	BO	Herb
Scadoxus nutans	Amaryllidaceae	Moist montane forest	BK, BO	Epiphyte
Solanecio gigas	Asteraceae	Moist montane forest	All	Shrub
Tiliacora troupinii	Menispermaceae	Moist montane forest	All ex. HA	Liana
Urtica simensis	Urticaceae	Moist montane forest	HA	Herb
Vepris dainelii	Rutaceae	Various habitats	All	Tree
Vernonia leopoldi	Asteraceae	Moist montane forest	HA	Shrub
Wendlandia arabica	Rubiaceae	Transitional forest	BK	Shrub

4.4 Discussion

4.4.1 Floristic composition

In Ethiopia, the available floristic data are either site specific (e.g., Hedberg 1964; Tadesse and Nigatu 1996; Woldemariam 2003) or covering a wide range of vegetation types (e.g., von Breitenbach 1963; Friis 1992; Hedberg and Edwards 1989; Edwards et al. 2000), hence direct comparison with other similar studies is not possible. The floristic list from the present study constitutes more than 10% of the flora of Ethiopia. Many authors have noted that the floristic impoverishment of Ethiopian rainforest as compared to other Africa rainforests is due to the difference in the anthropogenic influences and environmental factors (White 1978; Friis 1992; Bekele 1994; Friis et al. 2001). However, the Ethiopian rainforest support the last resort of the wild populations *Coffea arabica,* the world most prestigious crop, with its notably high genetic diversity beside other species.

About 53% of the rainforest species observed in the present study are rare. Rare taxa are those having low abundance or small ranges (Gaston 1994). Any combination of biological or physical factors or both could restrict the species either abundance or geographical range (Cowling 1990; Goldblatt 1997). On the other hand, the disparity in the species composition between the studied rainforests might be due to the differences in the sampling size and intensity, and in historical and environmental factors. In all forests, very few species (e.g., *Coffea arabica, Landolphia buchananii, Oplismenus undulatifolius, Vepris dainelii* and *Hippocratea africana*) have an absolute frequency occurrence of more than 50%. This suggests that species abundance is unpredictable in the rainforests of Ethiopia. A detailed analysis concerning the abundance and frequency patterns of most common species is given in Chapter 5.

The top 10 species-rich families (Table 4.2) in each forest are very similar even though their order changes. Some of these families (e.g., Euphorbiaceae, Rubiaceae, Moraceae, Asteraceae, and Fabaceae) are always among the top 10 species-rich families in many neotropical forests and in Asia (Gentry 1988, 1995). However, there are some families with restricted range of distribution. Most of these families are found in the Berhane-Kontir forest. This forest stretches to the transition forest between the lowland forest and the Afromontane rainforest (Friis 1992), and hence is composed of a very different suite of plant families than the other rainforests (e.g., Nyctaginaceae, Violaceae).

4.4.2 Patterns of diversity

Effects of human activities on biodiversity can be measured and monitored based on indices of alpha, beta and gamma diversity (Halffter 1998). The richness and evenness of the studied rainforests vary considerably (Table 4.3). This difference is primarily a function of differences in site productivity, habitat heterogeneity and/or disturbance factors. For example, the low species richness and evenness in the Maji forest is due to anthropogenic disturbances, such as burning, grazing, and wood collection, which has significantly reduced species richness. Lower evenness indicates the dominance of a few species. On the other hand, high evenness in the Bonga forest indicates little dominance by any single species but repeated coexistence of species over all plots or sites. Therefore, the implications of evenness values is that, when there is a high evenness value in a given forest, the location of conservation sites might not be of such importance compared to when the evenness value of the forest is low.

Several studies have highlighted the influence of human activities on species richness in the terrestrial ecosystems (Petraitis et al. 1989; Maestre 2004). There is a significant correlation between disturbance and plant species richness. The low values of the Shannon diversity index of the Maji forest also support the hypothesis of few early successional species dominances and/or the dominance of few species due to selective cutting of some species (Bone et al. 1997). The difference between Fisher's α, and the Shannon diversity index is that the former is less affected by the abundance of the commonest species whereas the later is differently affected (Magurran 1988). Two different communities may have the same species richness and Fisher's α, but a different Shannon diversity index if they have different degrees of dominance of the commonest species. For instance, the higher Shannon diversity index and the low Fisher α index in the Bonga forest as compared to the Berhane-Kontir forest is a testimony to the difference in the dominance of the commonest species in each forest. Generally, the difference in the values of alpha diversity between the studied sites is an indicator of how one forest is better off concerning factors that reduce species richness. According to Gaston (1996), alpha diversity is the diversity that usually escapes disturbance (both natural and artificial) and exists in certain homogenous environments, and explains temporary richness of species.

Beta diversity, i.e., species turnover along any environmental gradient, is expected to be high in a fragmented tropical landscape because of the disparity of habitats (Shmida and Wilson 1985; Moreno and Halffter 2001). Habitat diversity is the ultimate determinant of beta diversity. If the species composition of a geographically widespread biome does not change with distance, for example, then the location of conservation sites is not important (Bridgewater et al. 2004). If, however, there are considerable floristic differences, careful study of the composition of sites is essential to ensure that selection of conservation sites adequately represents most species. This means that a careful analysis of beta diversity is vital for the selection of conservation areas. In the present study, a high level of species turnover was observed in the Berhane-Kontir forest reflecting the high degree of habitat diversity due to topographic and moisture gradients. However, areas with equivalent habitat diversities may have different rates of turnover (Cowling 1990) and hence this may sometimes not always explain a high level of habitat diversity. The low value of beta diversity in the Bonga forest might be associated to high habitat homogeneity or to a large proportion of generalist species (e.g., Moreno and Halffter 2001).

Measuring and monitoring species diversity at the regional level/landscape allows the assessment of the dynamic processes among the spatial components of biodiversity (Halffter 1998). The ultimate explanation for the patterns of species diversity among regions may be due to the processes that determine the basic characteristics of the geographical range of species, which result from topographical, biogeographical and historical disturbance (Gaston 1996; Angermeier and Winston 1998; Lovett et al. 2000). In the present study, the observed high regional diversity in the Berhane-Kontir forest is indicative of the existence of varied climates and physical environments in the region (Trejo and Dirzo 2002). As indicated in previous sections, this forest is a type of transitional forest. A transitional forest is usually located between two different vegetation formations, in the present case between lowland and Afromontane vegetation, and supports species of both formations. Similar studies from the neotropical montane forest show that transitional forests have elevated species richness (Ferraz et al. 2004). The Maji forest had the lowest gamma diversity compared to the other forests. At least four points can be assumed for this low diversity: (1) geographical isolation, (2) human influence, (3) effects of local climactic variation and 4) size of the forest. According to local evidences, human influence has been observed for many years, and most of the area occupied by forest today probably used to be farmland. In addition, geographical isolation might also have contributed to the low diversity in this forest, because it is surrounded by large tracts of dry and lowland vegetation.

4.4.3 Plant community–environmental relations

Plant community distribution in landscapes is the manifestation of physical gradients (e.g., elevation gradients, soil heterogeneity, microclimate), biotic response to these gradients, and historical disturbances (Delcourt et al. 1983; Urban et al. 1987; Lima and Zollner 1996; Urban et al. 2000). Various ordination and clustering methods have been found to be robust and useful in ecological studies that consider patterns of vegetation composition and factors affecting species abundances (e.g., Økland 1986; Pitkänen 1997, 2000; McCune and Grace 2002).

In the present study, the multivariate analyses were consistent in their indication of the patterns of floristic grouping within the studied Afromontane rainforests. All methods supported each other, and the main inference to be drawn from the present study is that there is a clear indication of floristic heterogeneity in these forests. The fact that Afromontane rainforests contain distinct floristic groups becomes relevant in terms of efforts to better understand and define the forest with respect to conservation. The floristic heterogeneity of the rainforests is based on the difference in altitude of the locality, local landscape, exposure, rainfall, type and depth of the soils, geological history, and anthropogenic factors (von Breitenbach 1961; Hedberg 1964; Friis 1992; Woldemariam 2003).

Several authors (e.g., Hedberg 1964; Nigatu and Tadesse 1989) have noted the presence of an altitudinal zonation in the forest vegetation of Ethiopia. Altitudinal gradients are complex gradients and involve many different interacting factors, such as topography, soil, moisture and climate (Hedberg 1964; Austin et al. 1996), which in turn influence the growth and development of plants and the patterns of vegetation distribution. Of these complex variables, which are difficult to separate, temperature and other climatic variables seem to be most important for describing species richness or community via the altitudinal gradient (Woodward 1987; Körner 2000). The position of each rainforest area with respect to altitudinal gradient was difficult to separate, as most of the forests had overlapping ranges of altitude, especially between 1400 and 1800 m. However, there is a vegetation variation along the altitudinal gradient in each forest. A good example is the Harenna forest, where a clear vegetation zonation is observed. The lowest most portion of the forest, between 1400 m and 1500 m, is relatively dry and dominated by *Afrocarpus falcatus-Strychnos mitis*. At higher elevations, between 1600 m and 1800 m, is the zone of high humidity with the *Afrocarpus falcatus-Syzygium guineense* community. In each of these zones, many different trees and shrub species are associated.

The amount and patterns of rainfall distribution are also differing in the different Afromontane rainforests. There is a general pattern of rainfall maxima in the southwest, particularly around the Berhane-Kontir forest (> 2000 mm total annual rainfall), while rainfall decreases toward southeast around the Harenna forest (800-1000 mm). This is probably the reason for the different plant communities found in each forest region. The difference in the composition of species, at least in the dominant canopy species, between the southwest and southeast rainforests is evident. In the Harenna forest, *Afrocarpus falcatus* mainly dominate the tree canopies, whereas in the southwest forests (e.g., Berhane-Kontir) a mixture of broadleaved species dominates the canopies, e.g., *Pouteria* spp.*, Olea welwitschii, Manilkara butugi* and *Ficus* spp.

Other environmental factors such as slope, soil and anthropogenic factors can influence the distribution patterns of plant communities. In Ethiopia, many researchers have indicated the influences of these factors (von Breitenbach 1963; Nigatu and Tadesse 1989; Woldemariam 2003).

As expected, the formation of the five plant communities in the present study is a result of the differences in several environmental factors. The major separating feature of the identified plant communities is the difference in dominant plant species or indicator species in each community. Indicator species have been commonly used in reserve selection and for making decisions about the reserve design (Howard et al 1998; Sarakinos et al. 2001). It appears that species frequently show marked preferences for specific environmental conditions. Except for the coffee community, which is the amalgamation of plots from all forest sites, all other plant communities identified in the present analysis follow regional differences. Generally, geographical isolation is the main source of variation, which contributes to the variation in physical and climatic factors between the communities or forests. In each region, a number of biotic and abiotic factors may further influence the plant community. For example, Woldemariam (2003) identified three plant communities (i.e., *Coffea arabica*, *Argomuellera macrophylla* and *Dracaena fragrans*) from the Yayu forest, and defined altitude, slope and landforms (distance from riverbank) as the major environmental factors characterizing the communities. In the present analysis, the same dataset (i.e., for Yayu) was used in combination with the datasets from Harenna, Bonga and Berhane-Kontir, and similar communities were recognized in Yayu. The only difference is that most of the afore-mentioned Yayu communities appear together with the communities in the Berhane-Kontir forest. Indeed, the environmental factors that Woldemariam (2003) mentioned for Yayu can also be applicable in a similar way to explain plant community formation in the studied rainforests.

The species composition of the five community types observed in the present analysis is compatible with that of the forest vegetation of Ethiopia. The indicator species of the **C1** community, *Galiniera saxifraga* and *Psychotria orophila*, are the characteristic features of Afromontane rainforest (Friis 1992), where the canopy layer is occupied by mixed broadleaved species, e.g., *Pouteria adolfi-fridericii* and *Olea welwitschii. Afrocarpus falcatus,* the indicator species of the **C2** community, is the characteristic species of southeast Afromontane rainforest. *Coffea arabica,* the indicator species of the **C3** community, is the characteristic species of the Afromontane rainforest. The indicator species of the **C4** and **C5** communities**,** *Whitfieldia elongata, Argomuellera macrophylla, Rungia grandis* and *Metarungia pubinervia,* are the characteristic species of the Guineo-Congolian forest (Friis 1992). These two communities are mainly from the Berhane-Kontir and Yayu forests. Even though Maji was not included in the community analysis, observations from floristic data show that this site is more related to the Berhane-Kontir and Yayu communities.

Summing up, the plant communities designated as **C4** and **C5** are composed of plots from the Yayu and Berhane-Kontir forests. Some tree species associated to these community types are considered to be Guineo-Congolian floral elements. The Berhane-

Kontir and Yayu forests can be therefore categorized as “transitional rainforest.” This is in accordance with Friis (1992) finding. On the other hand, Harenna and Bonga, although differing in plant community, are both related to Afromontane forest. Finally, all studied rainforests shared the *Coffea arabica* community as species linking geographically separated Afromontane rainforests, although these differed in some aspects.

4.4.4 Floristic similarities between the forests

The relation between geographical distance and floristic similarity can largely be explained by the fact that environmental variables change with geographical distance, which lead to the floristic dissimilarity (Terborgh and Andresen, 1998; Pyke et al., 2001; Tuomisto et al. 2003). The Sorensen’s similarity coefficient reveals low floristic similarity between the studied forest regions. Comparatively, the Bonga and Harenna forests had higher species similarity despite the geographical distance. If the floristic similarity were due to geographical distance, a high floristic similarity would have been observed between Bonga and Berhane-Kontir which are located very close to each other (around 150 km), than the Harenna forest that is 10 times farther away. Some of the possible explanations for the overall low floristic similarities between the studied Afromontane rainforests could be random variation, historical factors, geographical distance, and environmental determinism (Cowling 1990; Lovett et al. 2000; Tuomisto et al. 2003).

As a group, a comparison between the southeast (Harenna) and southwest (Bonga, Yayu, Berhane-Kontir and Maji) Afromontane rainforests reveals 60% and 44% floristic similarity at family and species levels. The southwest rainforest is species rich compared to the southeast. This is contrary to the conclusion reached by Nigatu and Tadesse (1989), who had reported little difference between the southwest and southeast Afromontane rainforests with wild coffee. The southwest rainforest comprises relatively large tracks of forest, and at the same time has extensions to other forest vegetation. Most importantly, the southeast rainforest is isolated from the rest of the rainforests and this may have limited the dispersal and migration of plant species. Furthermore, vegetation changes due to human impact have a long history in Ethiopia (Hamilton 1974; Hamilton 1981; Bonnefille and Hamilton 1986; Darbyshire et al. 2003). Using pollen analysis, Bonnefille and Hamilton (1986) noted the destruction of montane forest in southeastern Ethiopia as far back as ca. 2000 years. Although there are only few palynological analyse from southwest Ethiopia, it can be assumed that these historical factors may have led to the variation in floristic diversity between the two highlands.

4.4.5 Phytogeography and endemism

The distributional pattern of the Afromontane rainforest species reveals frequent occurrences in other mountain areas in Africa. Many tree species have disjunct populations scattered throughout the Afromontane region (White 1978, 1983), and since such plants do not generally have long-distance dispersal methods, it is likely that their disjunct populations were once more-or-less continuous (Moreau 1933; Livingstone 1975; Coetzee 1978; Iversen 1991). During the Tertiary period, the overall climate of the continent was more or less comparable, the topography was more even than today, and most plants had a wider distribution (Coetzee 1978). After the highlands in East Africa appeared in the Miocene and Pliocene periods and due to climatic change, many of these widely occurring species became restricted to the mountain regions in the different parts of the continent (Moreau 1933; Livingstone 1975; Coetzee 1978; Hall and Swaine 1981; Hamilton 1992; Plana 2004). This may holds true for the Afromontane rainforest fragments of Ethiopia.

Locally, Afromontane rainforest flora occurs beyond the Afromontane region and is often shows extension to the Guineo-Congolian center of endemism. The Guineo-Congolian flora elements are widely distributed in the Berhane-Kontir, Yayu and Maji forests. Examples of these species include *Pouteria altissima, Celtis toka, C. philippensis, C. zenkeri, Blighia unijugata, Trilepisium madagascariense, Moru mesozygia,* and *Argomullera macrophylla*. This corresponds with the finding of White (1983), who confirmed that most of the Afromontane rainforest species are rather similar to the Guineo-Congolian species and have their closest relatives in the lowland tropics rather than in the highlands. In addition to Guineo-Congolian elements, many tree and shrub species have a wide geographical area. In a similar way, White (1978, 1983) argued that most Afromontane tree species have wide geographical distribution and ecological amplitude.

On the other hand, the local endemic flora account for nearly 5% of the total species observed in the studied Afromontane rainforests. Low endemicity is a common phenomenon in the Afromontane rainforest of SW Ethiopia (Friis et al. 2001) and Afromontane Region (White 1978). A comparison of the studied rainforests shows that the Harenna forest had the highest number of endemic species followed by Berhane-Kontir and Bonga. Endemism may be the result of several mechanisms, but underlying them all is the principle of geographical and ecological isolations (Kruckeberg and Rabinowitz 1985; Giménez et al. 2004). The Harenna forest and the surrounding vegetation are known for their high endemicity both in flora and fauna (Hedberg 1986; Hillman 1988). Due to this strong element of endemism, it has been suggested that this area be considered as a subcenter of endemism in it own right (Friis 1983). A high endemicity in this region could be attributed to a high diversity of environmental gradients and associated vegetation isolation. The dynamics of the ecological conditions, and recent geological, physiographic and topographical changes can also induce speciation (Kruckeberg and Rabinowitz 1985).

4.4.6 Forest use and its impact

The current forest and forest product uses are similar in all studied rainforests. Many people are dependent on the forest for their livelihoods, i.e., as sources of both timber and non-timber products. In the present study, over 70 economically important plant species are recorded across all studied rainforests (Appendix 3). It appears that these forests are the major source of income for the local communities living close to the forests. Forest is also a land reserve for farmland expansion whenever extension is required. Among the non-timber forest products, spices, honey, and coffee play a major role in the households' economy. In addition, the local communities get a substantial amount of wild food and traditional medicine from the forests. Relevant species include *Carissa spinarum, Cordia africana, Ocimum lamiifolium, Ficus mucuso, F. sur, Trilepisium madagascariense, Trichilia dregeana, Syzygium guineense, Clematis simensis, Passiflora edulis, Rhamnus prinoides, Piper capense, P. guineense, Rubus apetalus, R. rosifolius, R. steudneri, Capsicum frutescens, Solanum nigrum, Manilkara butugi, Mimusops kummel, Urtica simensis, Phoenix reclinata, Dioscorea praehensilis, D. sagittifolia, Ensete ventricosum,* and *Aframomum corrorima.*

Regardless of the location, wild coffee management has affected and will continue to affect the diversity, composition and structure of the forests (for details see chapter 7). Furthermore, beekeeping also has the potential to influence the diversity of forest species as the traditional beehives are usually made up of limited tree species because of their easy workability, light weight and good odour for bees. Some of the tree species used for beehives are *Cordia africana*, *Polyscias fulva, Croton macrostachyus*, *Schefflera abyssinica*, *Afrocarpus falcatus* and some liana species, depending on their availability. Exploitation of such species might have an impact on the future population structure of the species and may lead to the extinction of the species, since harvesting focuses on the trees in the reproductive stage. Spices harvesting is specialized in the Bonga and Yayu, and to some extent in the Berhane-Kontir forest. In Harenna and Maji, spices are either absent or rare; hence, people are not engaged in these activities. Observations during fieldwork revealed that spices harvesting or exploitation did not affect the floristic diversity of the forest.

The exceptionally heavy livestock grazing in the Harenna forest makes it unique. Here, hundreds of animals can be observed grazing in the forest daily. Seedlings and saplings of many plant species (natural regeneration) seemed to be lacking due to either repeated browsing or trampling on young plants or both. In other forests, grazing was not common.

Other than the non-timber forest products, exploitation of timber forest products is common in all forests. This includes firewood collection, pole and post harvesting, and logging (both legal and illegal). As historical evidences indicate, these activities can influence forest diversity and composition.

Unsustainable utilization of the forest and forestlands are threatening the Afromontane rainforests resulting in a continuous habitat loss and degradation. Therefore, management strategies are required that should address the balance between the use and the continuity of the forest.

4.4.7 Implications for biodiversity conservation

Currently, forest covers less than 3% of the total landscape of Ethiopia (Rogers 1992; EFAP 1994), and Afromontane rainforest constitute the largest forest remnants. The present study reveals that Afromontane rainforests support a significant number of plant species, i.e., > 10 % of the flora of Ethiopia. Most Afromontane rainforest species are rare and restricted in their range of distribution. It is the only forest ecosystem with wild populations of *Coffea arabica* even globally. Afromontane rainforests maintain a high number of economically useful plant species such as *Piper capense*, *P. guineense*, *Dioscorea bulbifera*, *D. praehensilis*, *Aframomum corrorima*, and *Trichilia dregeana*. These forests can be a gene reserve for many useful forest species beside the wild coffee. As they are located on the mountains, they are important in watershed management and as water catchments and erosion barriers. Furthermore, the Afromontane region is considered to be the most threatened habitat in Africa and needs immediate conservation measures (White 1983; CI 2005). The Afromontane region of Ethiopia (including other regions in Africa) was recently designated as the "Eastern Afromontane Hotspot," which is one of the globally important regions for biodiversity conservation. If a region is to qualify as a hotspot, it must contain at least 1,500 species of vascular plants (> 0.5 percent of the world total) as endemics and must have lost at least 70% of its original habitat (Myers 1988, 2003). As they fulfill these requirements, the Afromontane rainforests of Ethiopia deserve high priority for conservation, i.e., keeping loss, including protection, preservation, and careful management of biological resources and the environment to prolong its services. Afromontane rainforests can be managed as multiple-use systems for biodiversity conservation and sustainable uses of forest products, at the same time effectively retaining them in as natural a state as possible. According to Brundtland (1987), sustainable concept needs to meet the needs and aspirations of the present generation without compromising the ability to meet those of future generations.

In a country like Ethiopia, where there is an increasing loss of biological diversity, an expanding human population, and limited funds for conservation, it is essential that efforts to conserve biodiversity be guided by scientific knowledge. To balance both ecological and socioeconomic goals of conservation, the selection of conservation areas needs appropriate criteria (Perlman and Adelson 1997; Schwartz 1999; Myers et al. 2000; Sarakinos et al. 2001). To assess the conservation value of Afromontane rainforests, many conservation criteria can adopt such ecological, economic and social aspects. The present study emphasizes the ecological values of Afromontane rainforest ecosystems aiming to maintain species and genetic diversity, safeguard ecological processes and minimize species replacement. An attempt is made to prioritize the Afromontane rainforests with the occurrence of wild coffee populations on the basis of floristic composition and diversity, threat of human influence and geographical location.

The empirical analysis in the present study reveals that the forests of Berhane-Kontir, Harenna, Bonga, Yayu, and Maji differ in species diversity. Regarding gamma and beta diversity, the Berhane-Kontir forest ranks first followed by Harenna, Bonga, Yayu, and Maji. Among others, these diversities are quite useful for prioritizing conservation sites (Perlman and Adelson 1997). The Berhane-Kontir forest depicts an area of ecological transition, where the niches of many species overlap. This forest also contains a substantial number of plant species from other forest vegetation (e.g., lowland forest), compared to the Bonga, Harenna, and Maji forest. The forest of Berhane-Kontir also shows a high level of variability in environmental gradients, such as elevation, slope, aspect, soil types, and human forest uses; this expresses a high habitat diversity. The integration of environmental gradients into conservation priorities also helps to ensure that ecological processes are kept intact. The persistence of species-rich habitats and ecological transition in the Berhane-Kontir forest can therefore contribute to the conservation of biodiversity at the large scale. Even though, there has been a conversion of the forest into different land uses, a large track of the forest is still intact, especially on the western and northern side of the forest. The native Mejenger people living in and around the forest are highly dependent on the forest for their livelihoods. The ethnobiology of these people with respect to the forest and its products are remarkably high. The long-established honey production system of the Mejenger people can also support future conservation efforts. The Berhane-Kontir forest therefore deserves a high priority for conservation. In a similarly way, Woldemariam (2003) has already indicated the potential of the Yayu forest for biodiversity conservation and for conservation of wild coffee genetic resources.

The Harenna forest also deserves a high priority for conservation. Geographically, this forest is isolated from the rest of the Afromontane rainforests with wild coffee populations. As for both beta and gamma diversity, the Harenna forest is the second next to the Berhane-Kontir forest. Regarding floristic analysis, Harenna forest differs from the other rainforests in terms of dominant canopy species, e.g., *Afrocarpus* *falcatus, Ocotea kenyensis, Filicium decipiens* and *Warburgia ugandensis.* In particular, *A. falcatus* is one of the few best-quality timber species that dominate the forest. *Afrocarpus* is also one of the Afromontane endemic and threatened tree species in the country. According to proclamation number 94/1994 (Government of Ethiopia), *A. falcatus*, is one of the few tree species that is given legal protection in Ethiopia. Harenna forest supports many more Ethiopian endemic species than other studied rainforests (Chapter 4.4). According to EWNHS (1996), the Harenna forest is one of the few important forests in Ethiopia for the conservation of highland forest bird species. In addition to these, many wild animals, such as lions, leopards, bushbuck and many others live in the forest (Hillman 1988). Despite this high value, the Harenna forest is experiencing serious human pressure, mainly through agricultural expansion, settlements, overgrazing and conversion of the undisturbed forest into semi-managed forest to improve the productivity of wild coffee. Considering the anthropogenic nature of the threats to biodiversity in this region, the conservation approaches to be designed may need some overlap between human and biodiversity land-use requirement, as some part of the forest is already affected. For these reasons, it is not paradoxical to recommend the Harenna forest for high priority biodiversity conservation.

Whatever sites are selected for conservation, management strategy should focus on delineating areas that are relatively undisturbed within each region, so that they may act as repositories of biodiversity and possibly as a source of forest genetic resources including wild coffee, and also on sustainable use of the already exploited forest. Conservation should also focus on the management of forests to retain the natural balance, diversity and evolutionary change in the forest environment. Thus, conservation approaches should focus on multiple-use and/or multiple-site conservation networks of areas in the Afromontane rainforest region. For example, the concept of biosphere reserve is an appropriate approach for conservation of Afromontane rainforests with wild coffee populations. According to UNESCO (2005), biosphere reserve comprises the complementary activities of nature conservation and use of natural resources (equivalent to multiple-use networks of areas), and is organized into three interrelated zones, known as the core area, the buffer zone and the transition area. The core area gives long-term protection to the landscapes, ecosystems and species and should be large enough to be effective as an *in-situ* conservation unit. The buffer area is clearly delineated and surrounds the core area and can be for research, environmental education, training, tourism, and recreation purposes. The core area and the buffer zone are surrounded by a transition zone, which may also constitute a protective buffer zone and can be used for settlement or agriculture. This method incorporates ecosystem management and human development into a conservation context. As most of the Afromontane rainforests with wild coffee populations are fragmented and surrounded by semi-managed forest systems and agricultural lands, the adoption of the biosphere concept is very realistic. Consequently, Afromontane rainforest conservation can be well-suited to social, economic and demographic factors that make conservation compatible with human needs and aspirations rather than in conflict.

Finally, to capture the diversity of organisms within the different regions, conservation areas have to be replicated across the different geographical regions (Noss 1996; Nekola and White 1999; Fairbanks et al. 2001). The redundancy of conservation areas acts as an insurance against stochastic events that may jeopardize species' persistence and possibly captures greater genetic diversity for those species that occur in more than one area, e.g., *C. arabica* (Lucas 1984). Therefore, if resources are not limiting, the conservation of Afromontane rainforests with wild coffee populations should be extended to other sites, i.e., Bonga, Maji and other forests.

5 VEGETATION STRUCTURE OF AFROMONTANE RAINFORESTS OF ETHIOPIA

5.1 Introduction

The vertical and spatial organization of species in a community is the outcome of the processes of recruitment, growth and competition in a physical landscape (Kohyama 1992; Larsen and Bliss 1998). The structure of canopy heights plays a very important role in shaping different microenvironments that ultimately determine the conditions that limit plant growth (Richards 1952; Webb et al 1976; Barkman 1979; Bekele 1994). These microenvironments strongly influence the competitive outcomes of different species living in the understory floor (Barkman 1992; Kent and Coker 1992). Studying the vegetation structure of Afromontane rainforests is of paramount importance for understanding the basic processes and to design appropriate management plans. However, standardized approaches are required to characterize plant community structures in order to delineate guidelines for their management and conservation, and to assess their potential for maintenance of plant species diversity.

In the present study, the vegetation structure of four Afromontane rainforests is characterized using size-class distribution, density, basal area and stratification. Most plant communities consist of a large number of species and hence it is not possible to include all species in a survey. Woody plants only are therefore used for the present structural analysis. The objectives of the study are to evaluate the community structure of the woody vegetation, i.e., mainly vertical structure and size-class distribution, and to compare the similarities and/or dissimilarities of the different rainforests in terms of vegetation structure.

5.2 Material and methods

5.2.1 Study sites

The study was carried out in four Afromontane rainforests, namely Bonga, Berhane-Kontir, Harenna and Maji. For a comparison, the Woldemariam (2003) dataset was used for Yayu. A detailed description of each study site is given in Chapter 3.

5.2.2 Dataset and analysis

All woody plants ($\geq$ 2 m height and $\geq$ 2 cm diameter) were measured for diameter at breast height (at 1.30 m above the ground) and height. Vegetation profiles was drawn from transects of 61 m x 7.6 m following Richards (1952). Stratification analysis is the most common application for the study of vegetation profiles. All woody plants $\geq$ 2 m height and $\geq$ 2 cm dbh are included in the drawing. The relative position of the individuals plants within the strip, their diameter, height, crown shape and crown mass were estimated visually. In total, six profiles were considered for the stratification analysis: Berhane-Kontir (2), Bonga (1), Harenna (2) and Maji (1). Frequency and abundance of all woody plant species were recorded on a plot basis. The Importance Value (I.V.) of Cottam and Curtis (1956) is used to describe and compare the species dominance of the forests. The I.V. of a species is defined as the sum of its relative dominance (Rdom), its relative density (Rden), and its relative frequency (Rf). Relative dominance is the total basal area of a species/total basal area of all species ×100, relative density is the number of individuals of a species/total number of individuals' ×100, and the relative frequency is the frequency of species/sum frequencies of all species ×100.

5.3 Results

5.3.1 Size class distribution

In all forests, a considerable number of individuals were found in the lower diameter classes (Figure 5.1). For example, 69% of the individuals in the Bonga forest were found in the dbh class between 2 and 5 cm, and 45% in Harenna. The number of individuals within the largest diameter class > 47 cm ranged between 1% (Bonga) to 4% (Harenna). The biggest diameter was recorded in the Harenna forest, i.e., 200 cm for *Afrocarpus falcatus* (Harenna), followed by 187 cm for *Schefflera abyssinica* (Bonga), 150 cm for *Pouteria altissima* (Berhane-Kontir) and 143 cm for *Manilkara butugi* (Maji).

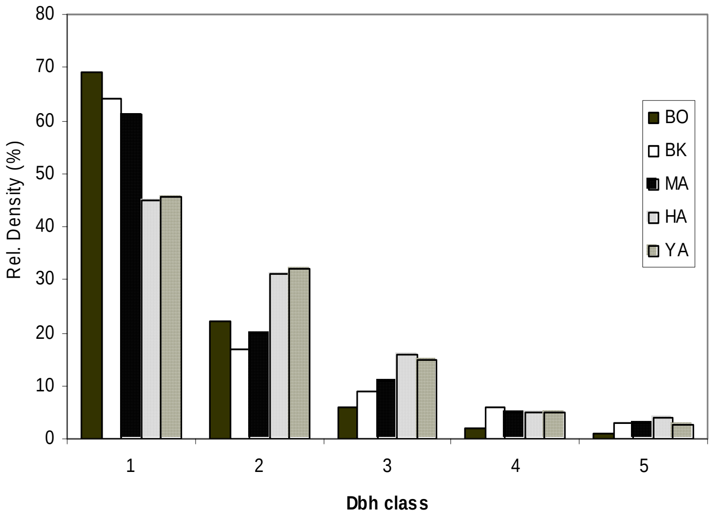

Figure 5.1 Diameter class frequency distribution of all woody plants within the studied rainforests of Ethiopia. Diameter at breast height (dbh) Class: 1 = 2-5 cm; 2 = 5- 11 cm; 3 = 11-23 cm; 4 = 23- 47 cm and 5 = > 47 cm

The patterns of diameter class distribution indicate the general trends of population dynamics and recruitment processes of a given species (Figure 5.2). The evaluation of selected tree species reveals six main patterns of population distribution. These include 1) inverted J-shape, which shows a pattern where species frequency distribution has the highest frequency in the lower diameter classes and a gradual decrease towards the higher classes e.g., *Blighia unijugata*, 2) broken inverted J-shape, e.g., *Afrocarpus falcatus*, 3) J-shape, which shows a type of frequency distribution in which there is a low number of individuals in the lower diameter classes but increases towards the higher classes, e.g., *Syzygium guineense*, 4) broken J-shape e.g., *Pouteria altissima*), 5) U-shape, which shows a type of frequency distribution in which there is a high number of lowest and highest diameter classes but a very low number in the intermediate classes, e.g., *Olea welwitschii*, and 6) bell-shape, which is a type of frequency distribution in which number of individuals in the middle diameter classes is high and lower in lower and higher diameter classes, e.g., *Celtis zenkeri*.

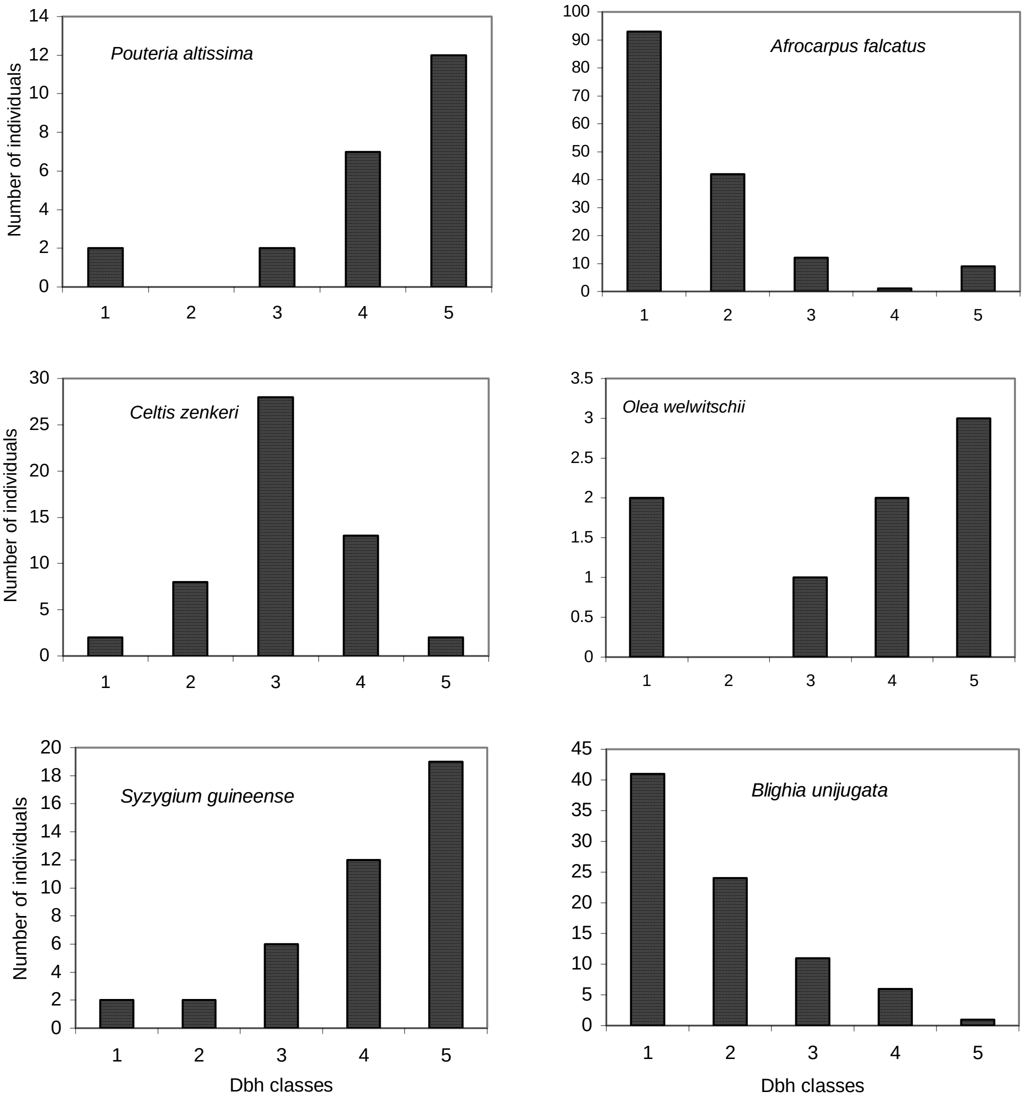

Figure 5.2 Diameter class frequency distribution of selected tree species in the studied Afromontane rainforests of Ethiopia. Dbh class: 1 = 2-5 cm; 2 = 5- 11 cm; 3 = 11-23 cm; 4 = 23- 47 cm and 5 = > 47 cm)

The patterns of height class distribution of the woody species reveals a high proportion of individuals in the lowest height class and few individuals in the largest height class (Figure 5.3). For example in Maji, about 90% of individuals are represented in the height class of 0.5 to 5 m and only <1% reaches a height of more than 30 m. It is only in the Harenna forest that the higher height class, i.e., > 30 m, is relatively well represented (6%).

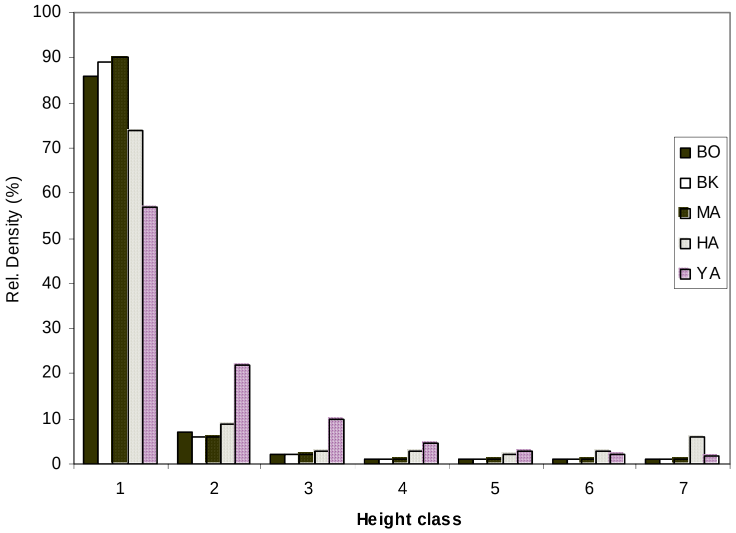

Figure 5.3 Height class frequency distribution of the woody plants in the studied Afromontane rainforests of Ethiopia. Class 1 =0.5-5 m; 2 = 5-10 m; 3 = 10-15 m; 4 = 15-20 m; 5 = 20-25 m; 6 = 25-30 m; 7 = > 30 m

5.3.2 Abundance and basal area

The total basal area per hectare and density of woody plants for each forest is shown in Table 5.1. The basal area ranged from 46 to 54 m^2 in the order Berhane-Kontir > Maji > Harenna > Bonga > Yayu (Table 5.1). The highest density of woody plants was recorded in Yayu (69130 individuals/ha) and the lowest in Harenna (9309 individuals/ha).

Table 5.1 Density and basal area of woody plants in the studied Afromontane rainforests of Ethiopia

Characteristics	BO	BK	HA	MA	YA
Total plots	28	37	24	10	48
Total density	21540	24296	8937	7273	132729
Min density/plot	169	303	89	432	955
Max density/plot	1459	1756	1980	1209	7684
Median of density/plot	777	570	178	665	2642
Density/ha	19232	18981	9309	18183	69130
Basal area (m^2/ha)	47	54	49	53	46

In each forest, the 10 dominant species with the higher importance value are listed in Table 5.2. Coffee is the only dominant species occurring throughout all forests, and next to coffee four species, namely *Landolphia buchananii*, *Syzygium guineense*, *Dracaena fragrans* and *Diospyros abyssinica* are represented in the dominant categories of at least two forests. The Maji and Harenna forests are dominated by a few species, whereas the other forests have a relatively comparable abundance of many species. In all forests, small-tree or shrub growth forms were the most dominant, although a few tall tree species such as *Olea welwitschii, Trilepisium madagascariense, Pouteria altissima,* and *Afrocarpus falcatus* were represented in the dominance categories in some forests. The tallest trees contribute the biggest share to the total relative dominance. Coffee is the only species with the highest relative frequency of occurrence in each forest.

Table 5.2 Importance Value (IV) of the 10 most common species in each Afromontane rainforests of Ethiopia. Species are ranked in order of decreasing importance value (Ad-abundance; Rf-relative frequency; Rden-relative density; Rdom-relative dominance; T-tall trees; Tm-medium trees; Ts-small trees; S-shrubs and L- lianas)

Region	Species	Ad (No. of indv./ha)	Rf (%)	Rden (%)	Rdom (%)	IV (%)	Growth forms
BO	*Schefflera abyssinica*	16	1.20	0.09	29.79	31.08	Ts
	Olea welwitschii	69	1.88	0.34	22.96	25.19	S
	Coffea arabica	3836	2.23	20.97	0.46	23.65	S
	Chionanthus mildbraedii	2252	2.31	10.46	5.85	18.63	L
	Syzygium guineense	125	2.14	0.71	8.70	11.55	T
	Justicia schimperiana	1857	1.03	9.82	0.02	10.87	Ts
	Galineria saxifraga	921	2.14	5.03	0.90	8.07	Tm
	Psychotria orophila	1117	2.40	5.50	0.10	8.00	L
	Vepris dainellii	705	2.14	3.67	1.92	7.73	S
	Elaeodendron buchananii	273	2.05	1.18	3.73	6.96	Ts
	Total other species (108)	8059	80.48	42.22	25.57		
	Total	19230	100	100	100		
MA	*Coffea arabica*	12888	3.74	70.30	3.99	78.02	Ts
	Trilepisium madagascariense	421	2.59	2.30	29.82	34.71	T
	Celtis africana	92	3.16	0.50	12.97	16.64	Tm
	Dracaena fragrans	1925	2.87	10.50	0.00	13.37	Ts
	Manilkara butugi	27	1.72	0.15	9.13	11.00	Tm
	Trichilia dregeana	46	2.87	0.25	6.49	9.62	Tm
	Millettia ferruguinea	115	2.59	0.63	6.06	9.28	S
	Pouteria altissima	25	2.30	0.14	6.21	8.65	Tm
	Vepris dainellii	379	3.45	2.07	1.39	6.91	Ts

Table 5.2 continued

Region	Species	Ad (No. of indv./ha)	Rf (%)	Rden (%)	Rdom (%)	IV (%)	Growth forms
MA	*Trichilia prieuriana*	60	3.16	0.33	3.11	6.60	Tm
	Total other species (86)	2357	71.55	12.85	20.82		
	Total	18335	100	100	100		
BK	*Argomuellera macrophylla*	5101	2.68	31.04	0.57	34.29	S
	Coffea arabica	3389	2.76	20.62	0.81	24.19	Ts
	Diospyros abyssinica	49	1.70	0.30	19.02	21.03	Tm
	Whitfieldia elongata	695	2.92	4.23	6.24	13.39	S
	Rothmannia urcelliformis	20	1.38	0.12	10.58	12.08	Ts
	Blighia unijugata	146	1.70	0.89	9.33	11.92	Tm
	Pouteria altissima	920	2.51	5.6	0.12	8.24	T
	Dracaena fragrans	1061	1.54	6.46	0.10	8.10	S
	Eugenia bukobensis	9	0.49	0.05	7.16	7.70	Ts
	Strychnos mitis	847	2.11	5.16	0.1	7.36	Tm
	Total other species (179)	4197	80.21	25.53	45.97		
	Total	16433	100	100	100		
HA	*Coffea arabica*	38631	2.31	49.06	1.45	52.82	Ts
	Afrocarpus falcatus	824	2.99	6.63	18.67	28.29	T
	Landolphia buchananii	325	2.99	2.75	0.38	6.13	L
	Celtis africana	341	2.72	1.54	4.97	9.23	Tm
	Jasminum abyssinicum	222	2.86	1.72	0.04	4.62	L
	Oxyanthus speciosus	178	2.72	1.54	0.96	5.22	Ts
	Bersama abyssinica	159	2.72	0.88	0.09	3.69	Ts
	Syzygium guineense	88	2.18	0.45	15.14	17.77	Tm
	Lepidotrichilia volkensii	276	2.59	2.69	0.35	5.63	Ts
	Cassipourea malosana	167	2.59	1.33	0.94	4.85	Tm
	Total other species (127)	5928	73.33	31.42	57.00		
	Total	47139	100	100	100		
YA	*Dracaena fragrans*	9317	3.28	17.49	-	20.76	S
	Coffea arabica	22180	3.00	15.99	-	18.99	Ts
	Landolphia buchananii	4877	3.28	7.30	-	10.58	L
	Diospyros abyssinica	895	3.28	4.88	-	8.15	Tm
	Albizia grandibracteata	1585	3.21	2.77	-	5.98	Tm
	Canthium giordanii	590	3.00	2.06	-	5.06	Ts
	Rhus ruspoli	1252	3.00	1.78	-	4.78	S
	Paullinia pinnata	5496	2.86	5.84	-	8.70	L
	Maytenus gracilipes	7296	2.79	2.89	-	5.68	S
	Trichilia dregeana	543	2.72	0.92	-	3.64	Tm
	Total other species (84)	12250	69.58	38.08	-		
	Total	66281	100	100	-		

5.2.3 Stratification

The vertical structures of the Bonga, Harenna, Yayu, Maji and Berhane-Kontir forests are generally similar, i.e., 2-3 strata: emergent/upper stratum (> 30 m tall), middle tree stratum (15-30 m tall) and small trees and shrubs layer (2-15 m tall). A few trees of the upper stratum, which are not in lateral contact, are raised well above the middle tree stratum and have a large number of branches. The middle tree stratum is often narrow and may be either discontinuous or continuous. The lower tree stratum usually forms a dense canopy. The herb layer is usually sparse and consists of forest grasses and ferns. Lianas and strangling epiphytes are abundant.

The profile diagram of the Bonga forest reflects the upper canopy of an *Olea* stand at 1970 m a.s.l. (Figure 5.4). Except for a few 30-40 m emergent trees (mostly *Olea welwitschii,* sometimes *Pouteria adolfi-feridericii*), the height of the canopy varies between 15 and 20 m. The most characteristic species of the middle stratum include *Elaeodendron buchananii, Polyscias fulva, Millettia ferruginea,* and *Syzygium guineense.* The understory layer consists of small trees and shrubs with dense crowns between 2 and 15 m, with mainly *Coffea arabica, Dracaena afromontana, Chionanthus mildbraedii, Psychotria orophila* and *Galineria saxifraga*. The herb layer is patchy and the patches are variable in size and density.

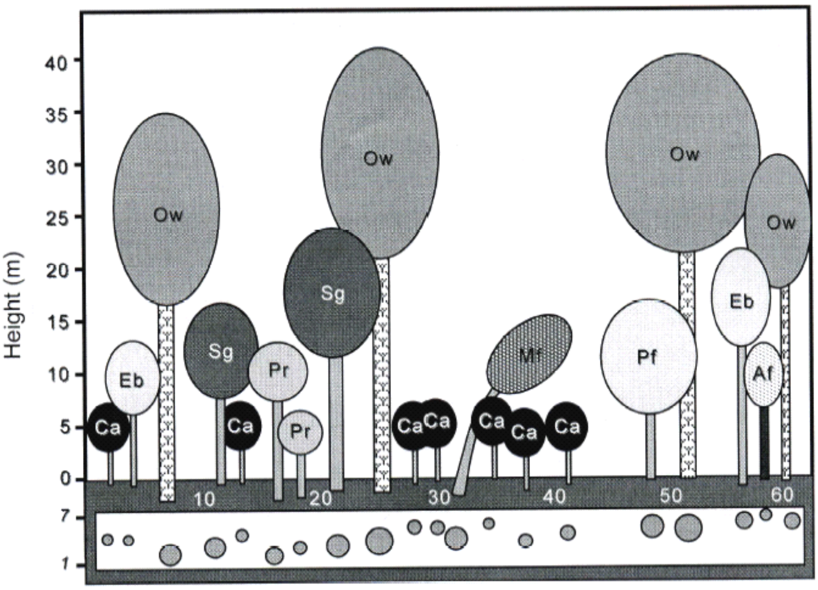

Figure 5.4 Profile diagram of an *Olea welwitschii* stand (61 m x 7.6 m) in the Bonga forest at 1970 m a.s.l. Ca = *Coffea arabica*; Eb = *Elaeodendron buchananii;* Ow = *Olea welwitschii;* Da = *Dracaena afromontana;* Pr = *Phoenix reclinata;* Mf = *Millettia ferruginea;* Pf = *Polyscias fulva;* AF = *Afrocarpus falcatus;* Sg = *Syzygium guineenese*

The profile diagram of the Berhane-Kontir forest (Figure 5.5 and 5.6) shows the upper canopy stands of *Pouteria* and *Manilkara* at 1100 m and 1750 a.s.l., respectively, which comprises various species i.e., *Pouteria altissima, Milicia excelsa, Antiaris toxicaria, Olea welwitschii* and *Manilkara butugi* depending on the altitude. The middle stratum is relatively dense as compared to the emergent layers, and is composed of species like *Celtis spp.*, *Morus Mesozygia*, *Baphia abyssinica*, *Blighia unijugata*, *Diospyros abyssinica* and others. The shrub and small tree layer is occupied by *Argomuellera macrophylla, Rungia grandis, Whitfieldia elongata, Dracaena fragrans, Alchornea laxiflora* and *Coffea arabica.* Tree seedlings and herbaceous layers are generally sparse.

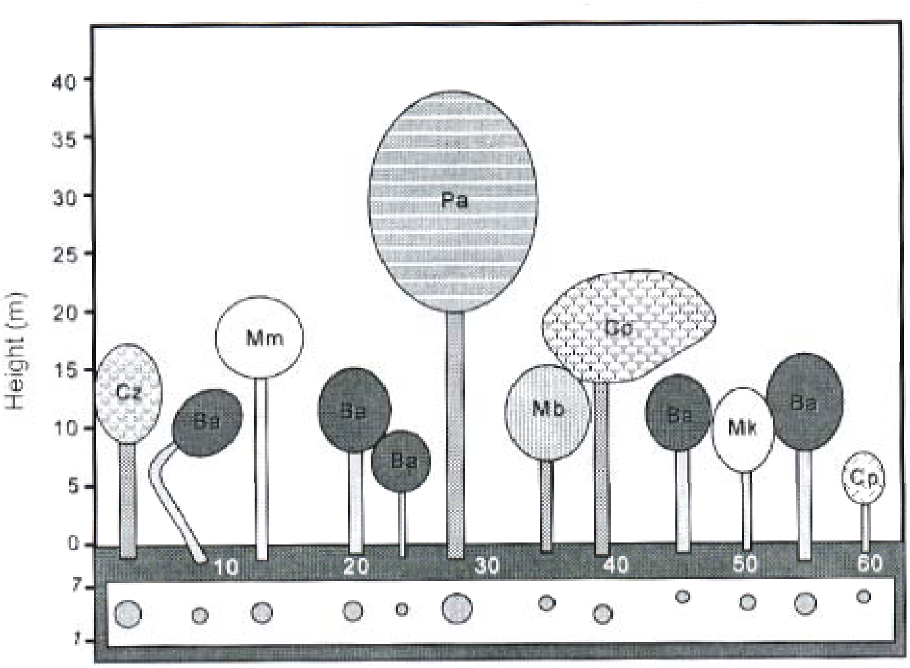

Figure 5.5 Profile diagram of a *Pouteria altissima* stand (61 m x 7.6 m) in the Berhane-Kontir forest at 1100 m a.s.l. Ba = *Baphia abyssinica*; Co = *Cordia africana*; Cp = *Celtis philippensis*; Cz = *Celtis zenkeri*; Mb = *Manilkara butugi*; Mm = *Morus Mesozygia*; Pa = *Pouteria altissima*

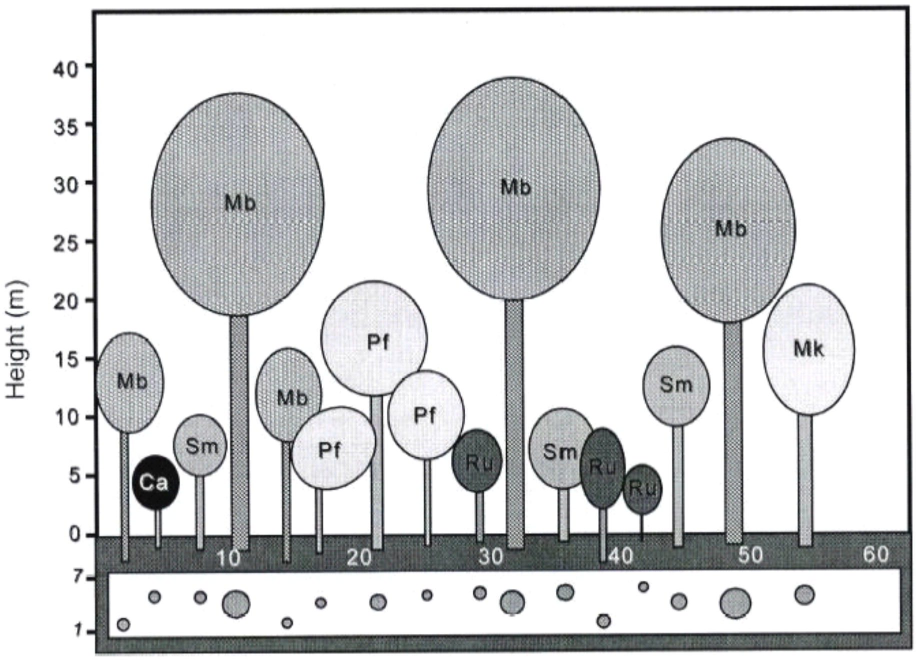

Figure 5.6 Profile diagram of a *Manilkara butugi* stand (61 m x 7.6 m) in the Berhane-Kontir forest at 1750 m a.s.l. Mb = *Manilkara butugi*; Mk = *Mimusops kummel*; Pf = *Polyscias fulva*; Ru = *Rothmannia urcelliformis*; Sm = *Strychnos mitis* Ca = *Coffea arabica*

Figure 5.7 and 5.8 show the profile diagrams of the *Afrocarpus* stands in the Harenna forest at 1670 and 1470 m a.s.l., respectively. Both profiles show the dominance of *Afrocarpus* in the upper canopy and mixed species in the lower canopy. The middle stratum of this forest mainly dominated by *Ehretia cymosa*, *Diospyros abyssinica*, *Cassipourea malosana*, *Chionanthus mildbraedii*, *Alangium chinense*, *Strychnos mitis*, *Celtis africana* and *Ocotea kenyensis.* The shrub and small tree layer is sparse and composed of *Coffea arabica*, *Acanthus eminens*, *Suregada procera*, *Lepidotrichilia volkensii* and *Phyllanthus sepialis.* Very few tree seedlings and herbaceous were observed .

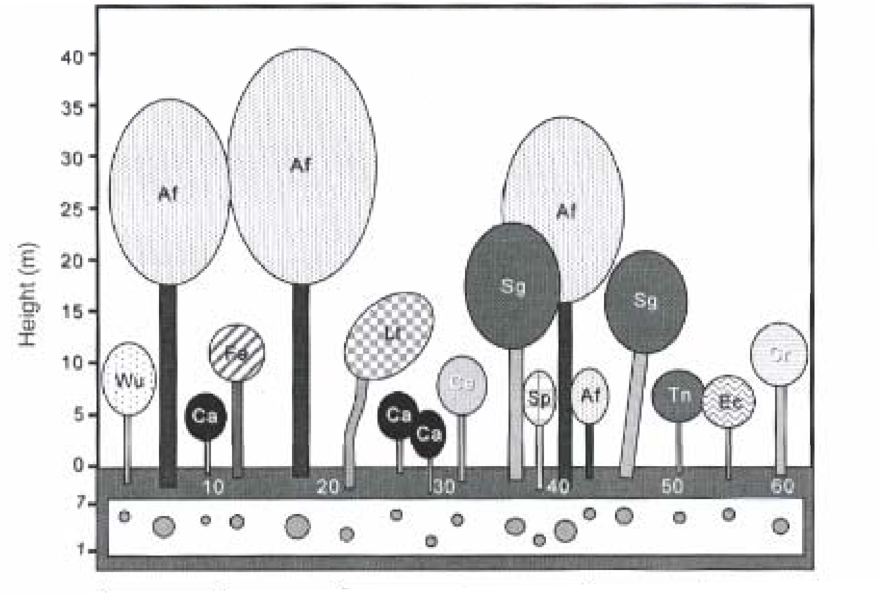

Figure 5.7 Profile diagram of an *Afrocarpus falcatus* stand (61 m x 7.6 m) in the Harenna forest at 1670 m a.s.l. Af = *Afrocarpus falcatus*; Ca =*Coffea arabica*; Ce = *Celtis africana*; Cr = *Croton macrostachyus*; Ec = *Ehretia cymosa*; Fa = *Fagaropsis angolensis*; Lt = *Lepidotrichilia volkensii*; Sg = *Syzygium guineenese*; Sp = *Suregada procera*; Tn = *Teclea nobilis*; Wu = *Warburgia ugandensis*

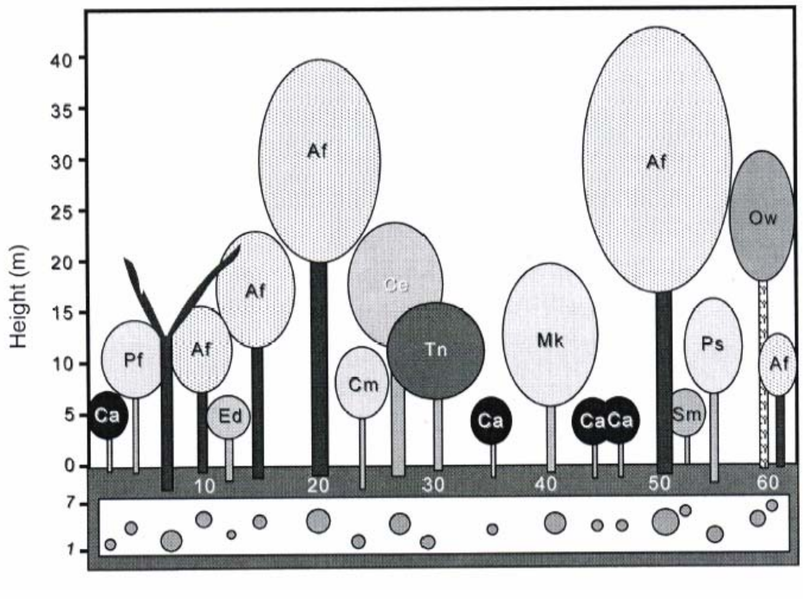

Figure 5.8 Profile diagram of an *Afrocarpus falcatus* stand (61 m x 7.6 m) in the Harenna forest at 1470 m a.s.l. Af = *Afrocarpus falcatus*; Ca = *Coffea arabica;* Ce = *Celtis africana*; Cm = *Cassipourea malosana;* Fd = *Filicium decipiens;* Mk = *Mimusops kummel;* Ow = *Olea welwitschii;* Ps = *Psydrax schimperiana;* Tn = *Teclea nobilis;* Sm = *Strychnos mitis*

The profile diagram of the *Trilepisium* stand in the Kassi-Bero (= Maji) forest is shown in Figure 5.9. The upper canopy layer is occupied by the discontinuous tree species *Trilepisium madagascariense.* Because of over harvesting of emergent species, the understorey trees (e.g., *Diospyros abyssinica*, *Millettia ferruginea*, *Celtis africana*, and *Mimusops kummel*) may sometimes form the main canopy. The shrub and small tree layers are dominated by *Tricholcladus ellipticus, Clausena anisata, Argomuellera macrophylla, Maytenus gracilipes* and *Dracaena fragrans.* The ground layer is discontinuous and forming patchy at different sites in the forest.

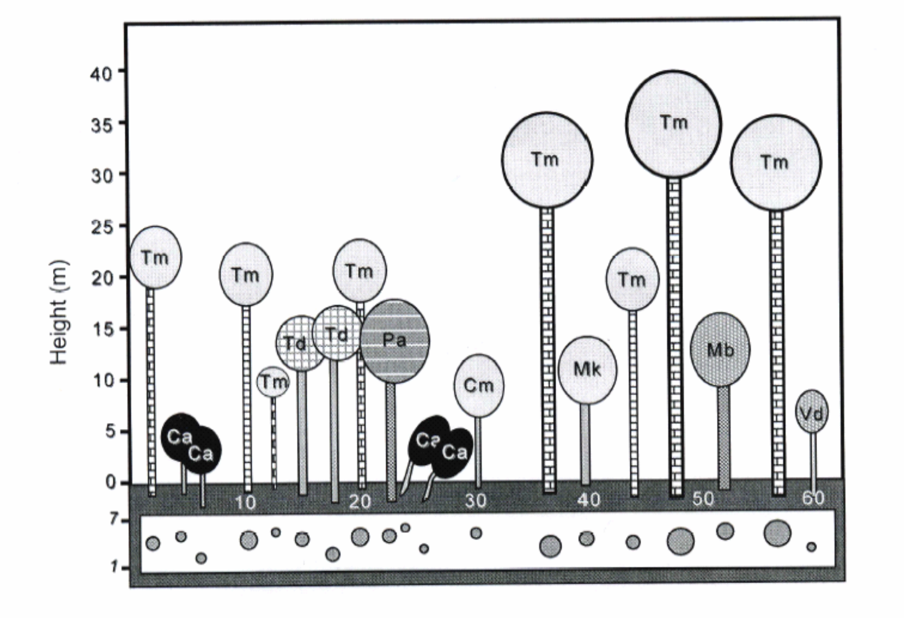

Figure 5.9 Profile diagram of a *Trilepisium* stand (61 m x 7.6 m) in the Kassi-Bero forest (Maji) at 1610 m a.s.l. Td = *Trichilia dregeana*; Tm=*Trilepisium madagascariense*; Ca = *Coffea arabica*; Cm = *Cassipourea malosana*; Pa = *Pouteria altissima*; Vd = *Vepris dainelii*; Mb = *Manilkara butugi*; Mk = *Mimusops kummel*

5.3.4 Growth forms

All species from the present surveys are categorized into five major growth forms (Table 5.3). This classification is based on information from the fieldwork and from the Flora of Ethiopia and Eritrea. The growth forms classification adapted for the present analysis is very simple and general as compared to other classifications (e.g., Raunkiaer 1934; Hedberg 1964). Analysis of the growth form data shows that herbs accounted for almost 35% of the total number of species followed by trees and climbers. Altogether, trees, climbers, and shrubs accounted for about 56% of the total species richness, while the epiphytes, which are a very prominent growth form, actually accounted for around 9% of the total species richness. Except for shrubs, all growth forms are common in the Berhane-Kontir forest but not so in the Maji forest.

Table 5.3 Species diversity according to growth forms in the studied Afromontane rainforests of Ethiopia

	Total taxa		No. of taxa/ Site				
Growth forms*	No.	%	BK	YA	BO	MA	HA
Trees	139	22	106	76	69	56	83
Shrubs	85	13	35	29	33	23	44
Climbers	136	21	88	35	58	33	52
Herbs	231	35	96	60	88	23	81
Epiphytes	60	9	49	5	37	11	27

**The definitions of growth forms are indicated in Appendix 1.*

5.4 Discussion

In most forests, the overall patterns of population structure is an inverted J-shaped type, which indicates a normal population distribution with a high number of individuals in the lower size classes and only few individuals in the higher size classes. The reproductive capacity of the forest must be sufficient to sustain the forest, and the population structure of most species must have a reverse J-shaped distribution (seedlings/saplings are over-represented and bigger trees are present in progressively lower numbers). This pattern is an indicator of healthy regeneration of the forest and species, and shows a good reproduction and recruitment capacity. On the other hand, the diameter classes of some tree species reveal different distribution patterns (Figure 5.2). The J-shaped patterns show poor reproduction and hampered regeneration due to the fact that either most trees are not producing seeds due to age or there are losses due to predators after reproduction (e.g., *Syzygium guineense*). In addition, *Syzygium* fruits are usually used as food by many animals and also humans, which could also be a reason for this pattern. A bell-shape follows a Gauss distribution pattern. This pattern indicates a poor reproduction and recruitment of species, which may be associated with the overharvesting of seed bearing individuals (e.g., *Celtis zenkeri*). A U-shaped pattern indicates selective cutting and removal of medium-sized trees (e.g., *Olea welwitschii*) probably for house construction or farm tools. Broken J-shape and inverted J-shape, exhibit a distribution pattern where individual plants are removed from different classes by natural or human-related factors. In Ethiopia, logging has been extremely selective and mostly confined to a few highly valuable timber tree species; most of the above-mentioned species are examples of these species. It could be due to these effects that some tree species in the Afromontane rainforests have a distorted population structure. Bekele (1994), Teketay (1997), Woldemariam et al. (2000), and Tesfaye et al. (2002) have reported similar results from the different Afromontane forests of Ethiopia.

Afromontane rainforests have a high density of individuals, which, however, differs between sites. These differences may be explained by the complex interactions of the different historic factors. For example, the high plant densities in the Yayu forest might be attributed to the successional stage of the forest. Many natural disturbances, such as fire, may affect the succession processes of a forest. The Yayu forest probably has been subjected to some disturbance in the past. During early successional development, many pioneer species may establish and grow together in high density until they reach the climax stage where many individuals are eliminated due to competition (Ewel 1983). The low density in the Harenna forest is related to heavy human-related disturbance.

The high dominance and/or abundance of a few species (e.g., *C. arabica*) in each rainforest could be attributed to a number of factors, such as the overharvesting of the desired species, disturbance factors, successional stage of the forest, and/or survival strategies of the species. For instance, the high dominance of *C. arabica* in the Harenna and Maji forests compared to other sites are indicative of human influence via selective removal of other plant species to promote coffee development. On the other hand, some plant species may have a wide range of dispersal mechanisms and/or rapid reproduction strategies. Species able to survive and flourish after disturbance tend to be those that reproduce rapidly and abundantly (McKinney 1997) and are dispersed widely. Generally, species dominance varies across the forests. Gentry (1988) hypothesized that species dominance is never predictable in tropical forests and is most likely determined by stochastic processes. According to Lovett et al. (2000), centers of richness and rarity are in different places for different plant species and different species prefer different habitats. Thus, from a forest management point of view, the conservation priorities should not use one taxonomic group as an indicator for areas like the Afromontane rainforests but also species and habitat diversity, size of the forest, and threat of human influences.

There was little difference among the studied Afromontane rainforests concerning the basal area per hectare. Site productivity, competition, and/or density affect the basal area of the forests and stands. All studied rainforests showed comparable density of tree individuals per hectare, which contributed to the total basal of the forest stand (Figure 5.2). However, the present basal area values are slightly higher than those of reported for tropical forests (Phillips et al. 1994); this might be due to a high density of individuals in the Afromontane rainforests. Gentry (1988) reports that the density of woody plants in the montane forests of Africa is relatively high as compared to other tropical montane forests. This may have contributed to the high basal area in the studied Afromontane rainforests.

The vertical structure shown in the profile diagrams illustrates the general vegetation stratification in the studied Afromontane rainforests. In all forests, there were 2-3 strata of tree layers, i.e., the emergent, middle and lower canopy layers. Nevertheless, in each forest the upper canopy layer was occupied by different tree species, which probably explains the difference in climatic, edaphic and/or historical factors in each forest (see Chapter 4). Two-layer stratification is common in species-poor forests in Ecuador (Grubb et al. 1963). A similar result is reported from Afromontane forests of Ethiopia (Bekele 1994). The degree of canopy stratification within a community related to the degree of ‘functional’ stratification (e.g., canopy density) in the canopy (Mitchley 1988; Collins and Wein 1998; Liira et al. 2002), the character of physical environment (Kent and Coker 1992), and the microclimate (Grubb et al. 1963; Stoutjesdijk and Barkman 1992).

In addition to physical environments, human factors can modify the vertical stratification of the forest. For example, the low density and/or abundance of upper canopy trees in the Bonga and Maji forests compared to the other studied rainforests indicate the human-related influence during the past. Logging has occurred in most forests of Ethiopia in the past (Bekele 1994; Tesfaye et al. 2002). In particular, there is a long history of human settlements in the Bonga area and surroundings. These human activities must have contributed to the reduction of the upper canopy trees, as most of these species are used for timber, e.g., *Pouteria adolfi-friederici,* and *Olea welwitschii*.

There have been attempts to classify plant species not only into a natural system according to similarities in their reproductive parts and assumed relationship but also into growth forms according to similarities in general physiognomy or in form and function of their vegetative parts (Raunkiaer 1934; Hedbeg 1964; Mitchley and Willems 1995 and others). The growth form composition of communities may greatly affect the processes that are responsible for the vertical structuring in the canopies (Givnish 1982; Kohyama 1992). According to Raunkiaer (1934), growth forms of vascular plants represent a complex of characteristics closely linked to the ecological behaviour of the species and their site conditions. However, factors causing variation in species richness may differ between growth forms.

The forest of Berhane-Kontir had the highest species richness based on growth form compared to the other forests. For instance, a high richness of tree species in this forest may be related to the diversity of habitats (Chapter 4), and as a result, there is a greater local diversification of tree species than in the other rainforests. In a similar way, the altitudinal gradient in the Harenna forest probably promoted the richness of tree species. Climber and epiphyte species are also more numerous in the Berhane-Kontir forest, probably for the same reasons. Furthermore, the richness of epiphyte growth forms in the Berhane-Kontir forest indicates high rainfall and humidity gradients in the region. This corresponds with the findings of Zotz et al. (1999), who report epiphyte richness as an indicator of moisture gradients in tropical rainforests. In the contrast, a very low richness of epiphyte growth forms was recorded in Maji, suggesting a high level of disturbance (Chapter 4). Diversity and abundance of epiphytes are recognized as an indicator of disturbance trends in tropical montane rainforests (Barthlott et al. 2001). Generally, herbaceous growth forms are abundant in all studied rainforests indicating a diversity of local habitats due to the difference moisture regimes, disturbance and edaphic gradients across the different regions (Whittaker et al. 2001).

5.5 Conclusion

Despite the floristic variation (chapter 4), the studied Afromontane rainforests revealed similar vegetation structures, i.e., size-class distribution, basal area, growth forms and vertical stratification. This could be attributed to similar historical events (e.g., human uses) and/or environmental factors. However, there is a variation in the density of the upper canopy trees indicative of the past logging or disturbance differences between the forest regions. It can be concluded that similar forest management schemes (e.g., thinning, harvesting level, etc.) can be employed in all forests. The physiognomic similarities could be the reason why the forests all support wild coffee populations in a similar way.

6 DISTRIBUTION AND ECOLOGY OF WILD COFFEE IN THE AFROMONTANE RAINFORESTS OF ETHIOPIA

6.1 Introduction

Coffea arabica is native to the Afromontane rainforests of Ethiopia. It is the only member of the genus *Coffea* that occurs in Ethiopia and is geographically isolated from all other *Coffea* species. Some studies have indicated a high genetic variability of wild Arabica coffee populations in the Afromontane rainforests of Ethiopia (Meyer 1965; Monaco 1968; Gebre-Egziabher 1990; Teketay et al. 1998; Aga et al. 2003; Tesfaye et al. 2005). However, this great wealth of genetic resources and the associated habitats are disappearing due to the continuous degradation and loss of the Afromontane rainforests. Adequate attention is not being given to the conservation of the forests with wild coffee populations (Gebre-Egziabher 1990; Teketay et al. 1998; Teketay 1999; Woldemariam et al. 2002). There is an urgent need to conserve the habitats of wild Arabica coffee in order to maintain and prolong its great genetic wealth and the associated forest biodiversity.

Globally, considerable information has been generated on the biology and ecology of cultivated *Coffea arabica* (e.g. Lashermes et al. 1996; Lashermes et al. 2000; Anthony et al. 2001). Nevertheless, limited information is available concerning the ecology and distribution patterns of *C. arabica* in its natural habitat (Woldemariam 2003). The relationship between coffee distribution and environmental factors has been studied at a local level in a few sites in Ethiopia (Gebre-Egziabher 1978, 1986; Tadesse and Nigatu 1996). But the distribution of wild coffee in relation to regional factors is not well documented. To formulate effective conservation approaches, the knowledge of the ecological and distributional patterns of geographically confined species such as *C. arabica* is essential.

In view of this, the present study was conducted to (1) examine how wild coffee populations are distributed in four Afromontane rainforests of Ethiopia, and (2) evaluate the relative importance of regional variables such as rainfall, altitude and local variables (e.g., soil characteristics, slope and canopy cover) on coffee distribution and abundance patterns.

6.2 Material and methods

6.2.1 Study sites

The study was carried out in four undisturbed Afromontane rainforests (Figure 3.1), namely Harenna, Maji, Bonga, and Berhane-Kontir. For a comparison, the Woldemariam (2003) dataset was used for Yayu. A detailed description of each study site is given in Chapter 3.1.

6.2.2 Methods and data analysis

This study was conducted along the different environmental gradients in four Afromontane rainforests. In each forest, quadrats of 20 m x 20 m were used to collect coffee-related data. The quadrats were placed 300 m along transects spaced one kilometer apart. A total of 147 plots were allocated in all forests: Harenna n = 24, Berhane-Kontir n = 37, Yayu n = 48, Bonga n = 28, and Maji n = 10. In each plot, all coffee plants were recorded and categorized into 1) seedling (if height was < 0.5 m), 2) sapling (if height was 0.5-2 m), and 3) tree (if height was > 2 m). Additionally, height and diameter of all coffee plants ≥ 0.5 m height and ≥ 2 cm diameter at breast height (dbh, i.e.,1.3 m above ground) were measured, respectively. All plant species growing in association with coffee were identified and their height and diameter measured. Additionally, exposition, slope, altitude, disturbance factors, and soil types were recorded. Although not systematic, casual observations were made in the field and information concerning the potential role of dispersal agents was gathered by interviewing the local people.

To examine the relationships between the abundance of coffee and various biotic and abiotic factors, regression analyses were performed using the software Stata Version 8 (Stata 2004). Two-way correlation and linear regression were run to investigate the relationship between coffee abundance and species richness, abundance of all species, tree canopy cover, altitude and slope using pooled data of all forest regions. Climograms were used to explain the patterns of coffee distribution versus rainfall and temperature in the study areas.

6.3 Results

6.3.1 Distribution and abundance of wild coffee

Wild populations of Arabica coffee occur over wide ranges of geographical regions in Ethiopia (Figure 3.1). The potential range of wild coffee populations lies between 6 and 8° latitude on the highlands, although this forest belt is already fragmented and being changed to non-forest land uses. Locally, however, the distribution of wild coffee is clumpy/patchy. These patches were either very dense and vast or thin and sparse. Patches of *C. arabica* occurred very close to each other (less than 20 m distance between the patches), frequently within an area, or there were large areas with no *C. arabica* patches (greater than 100 m distance between the patches). The trends were similar in all studied rainforests except in the Yayu forest, where the distribution of wild coffee was widely distributed across the forest.

In its natural habitat, *Coffea arabica* is exposed to the combined action of different environmental factors and hence the abundance of wild coffee varied across the different study sites/plots (Table 6.1). The highest abundance of wild coffee plants per plot was recorded in Yayu and the lowest in the Bonga/Berhane-Kontir forests. Table 6.1 illustrates characteristics of the study plots in the studied Afromontane rainforests. A low frequency of occurrence was observed in Harenna (71%) and the highest in Maji and Yayu forests (100%). The relationships between abundance of coffee and slope, species richness, altitude and canopy cover will be discussed in detail in the following sections.

Table 6.1 Characteristics of the study plots in the studied Afromontane rainforests of Ethiopia. All characteristic are expressed per plot

Characteristic	BO	BK	HA	MA	YA
Range of coffee abundance	1-816	1-1007	1-1743	42-1123	117-2020
Median of coffee abundance	51	46	18	385	901
% frequency of coffee	93	91	71	100	100
Range of slope (%)	0-50	5-45	0-30	0-35	5-50
Median slope (%)	23	20	5	13	25
Range of altitude (m)	1772-2050	940-1780	1492-1830	1500-1620	1310-1550
Median of altitude (m)	1942	1220	1657	1590	1460
Range of number of species*	26-50	14-51	19-40	18-42	11-37
Median of species per plot*	43	31	30	28	22
Range of abundance of plants	616-1196	182-1083	86-412	86-404	44-3788
Median of abundance of plants *	657	485	149	258	1548
Range of canopy cover	5-90	10-100	10-90	10-90	30-92
Median of canopy cover	55	80	60	73	75

**Woody plants*

6.3.2 Climatic factors

Wild coffee is adapted to a wide range of climates (e.g., around 1000 mm to over 2000 mm total annual rainfall; 11 to 19^{0}C monthly minimum temperature and 23 to 29^{0}C monthly maximum temperature). The distribution patterns of mean monthly rainfall and temperature were similar across the different meteorological stations located closest to the study sites, although the total mean annual rainfall varied. Harenna had the lowest mean annual rainfall and Mizan Teferi (equivalent to Berhane-Kontir) had the highest (Table 3.1). On the other hand, the lowest mean monthly minimum temperature is around Bonga and the highest is around Mizan Teferi. And the mean monthly maximum temperature follows the same trends (Table 3.1, Figure 3.2). The distribution and occurrence of wild coffee plants was limited not only by macroclimatic but also by microclimatic factors. Due to the effects of canopy cover, the microclimate on the forest floor might differ from the climatic data recorded at stations outside the forest. Thus, direct climate effects led to differences in regional vegetation rather than in coffee occurrence.

The other most important climatic factor that was observed to affect coffee distribution was run-off. Massive amounts of coffee seeds were observed moving down slope in run-off after heavy rain in the Berhane-Kontir forest. On the other hand, the performance of coffee at the bottom of the valley was either low or there was none.

6.3.3 Topographic factors

The relationship between the abundance of wild coffee and altitude was non-linear (Table 6.1 and Figure 6.1). Along the gradient of altitude, coffee followed a bell-shaped type of distribution. Coffee was found only between 940 and 2050 m. The lower limit was recorded in the Berhan-Kontir forest and the upper limit in Bonga. The highest densities of coffee plants were recorded between 1300 and 1600 m (Figure 6.1).

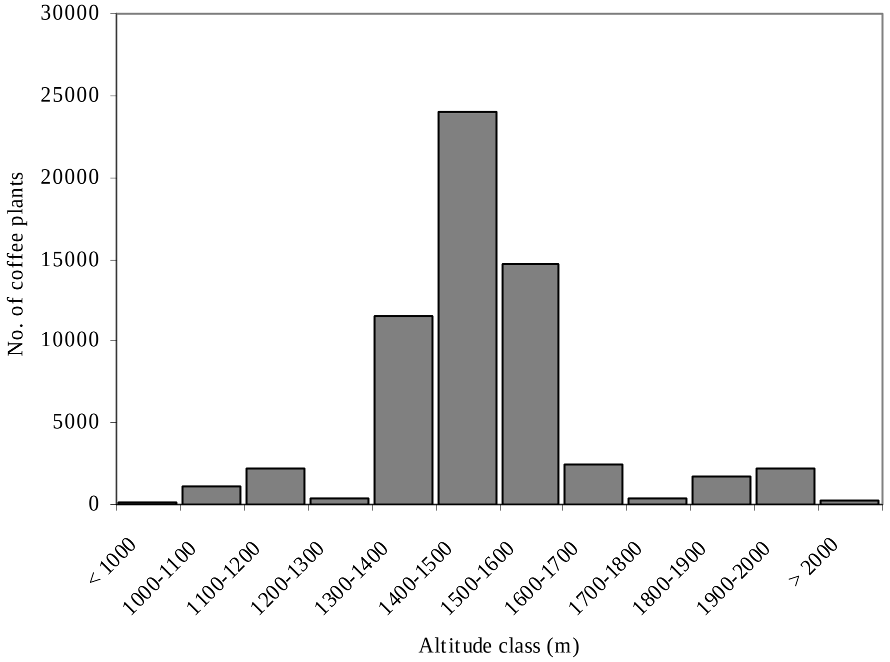

Figure 6.1 Abundance of wild coffee along the altitudinal gradient using pooled data from all studied Afromontane rainforests of Ethiopia

The relationship between abundance of coffee and percent slope angle is shown in Table 6.1 and Figure 6.2. Wild coffee populations were recorded between 0 and 55% slope angles. The highest density of coffee was observed between the 10 and 20% slope classes. As slope angle increased, abundance and occurrence of wild coffee plants started to decrease, although this was not statistically significant ($P < 0.71$). This could be associated not only to slope values but also to other related environmental factors (e.g. soil depth, nutrient status of the soil, etc.) and human impact along the slope gradient.

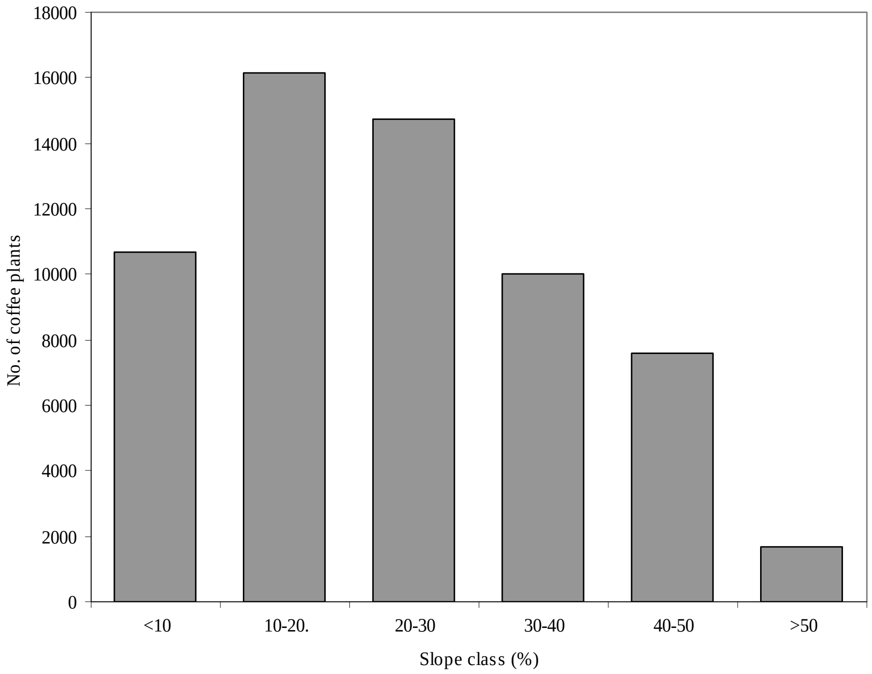

Figure 6.2 Abundance of wild coffee along slope classes using pooled data from all studied Afromontane rainforests of Ethiopia

6.3.4 Effects of edaphic factors

The description of soil pits and soil horizons across the different coffee forests revealed the existence of different soil types, namely Nitosols, Regosols, Cambisols, and Acrisols (Appendix 4 and 5). Results from the soil chemical analyses showed a pH of 4.2 to 6.6 (Appendix 4). A breakdown of these values showed that 32% of the soils were very strongly acidic (pH = 4.21 to 4.95), 21% strongly acidic (pH = 5 to 5.5), 25% moderately acidic (pH = 5.5 to 5.91) and 21% slightly acidic (pH = 6 to 6.6). In all soil pits, pH decreased with increasing soil depth. Available phosphorus was low in most soil samples. Some 67% of the soil samples had less than one ppm in total phosphorus and 27% had between one and 6.97 ppm; one soil pit (with 3 soil samples) in the Berhane-Kontir forest had 54.9, 55.58 and 63.86 ppm phosphorus. Organic matter in the soils ranged from 0.37% to 9.92% with an average of 3.14%. Total nitrogen ranged from 0.04% to 0.6% with an average of 0.19%. The exchangeable K (meq/100g) ranged from 0.04 to 2.96 with an average of 0.55. Generally, all soils were reddish-brown to dark reddish-brown, well drained and clayey in texture.

6.3.5 Human impacts and other biotic factors

Little is known about the effect of biotic factors on the distribution patterns of wild *Coffea arabica*. Relevant biotic factors can be human activities, grazing, dispersal agents and competition. The direct influence of man is deemed crucial in affecting coffee distribution. It is apparent that human activities can create three scenarios: 1) facilitate seed dispersal from one place to the other, 2) create microenvironments for recruitment and regeneration of coffee by removing the competing undergrowth and herbs in the forest, and 3) enhance propagation, e.g., establish young plants in the forest. Slight disturbance such as selective tree cutting in the forest may create favorable environmental conditions for coffee recruitment. However, serious disturbance like overgrazing can limit the regeneration capacity of coffee plant.

Local evidences suggest that baboons and birds (mainly hornbills) are very important dispersal agents for coffee. Coffee fruits have a sweet fleshy pulp that can be used as food by different animals and humans. During the fieldwork, a large number of birds and baboons were observed in the coffee canopy. However, many more animal species are probably involved in the dispersal processes.

In the natural forest, coffee grows under different intensities of canopy cover (Table 6.1). In Figure 6.3, a comparison of coffee abundance is made between the > 15 m tall canopy cover and the small-tree canopy cover of between 10 and 15 m height. A combination of less than 60% small-tree canopy cover (Figure 6.3a) and greater than 60% higher tree canopy cover (Figure 6.3b) appears to be the favorable for the abundance of wild coffee populations.

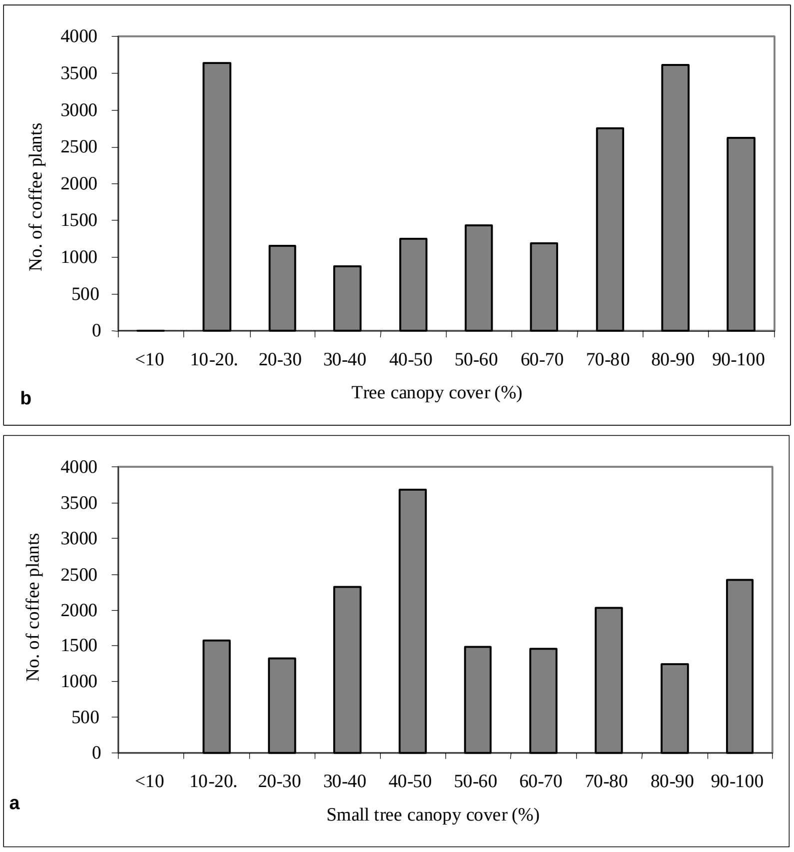

Figure 6.3 Relationship between the forest canopy covers (%) and abundance of wild coffee in the forest of Harenna, Bonga, Maji and Berhane-Kontir, Ethiopia

6.3.6 Relationship between abundance of coffee and other species

Over 600 plant species representing different growth forms were recorded in the forests where wild coffee populations occur as understory (see Chapter 4 and Appendix 1). Figure 6.4 presents the relationship between species richness and abundance of coffee. There was a significant negative relationship between species richness and abundance of coffee plants (*P* < 0.000; $r^2 = 0.11$). However, only 11% of the variation in abundance of coffee plants accounted for the variation in species diversity. This is related to disturbance factors and competition. On the other hand, there was a significant positive relationship between the abundance of coffee plants and total abundance of all other plant species (*P* <0.000; $r^2 = 0.19$).

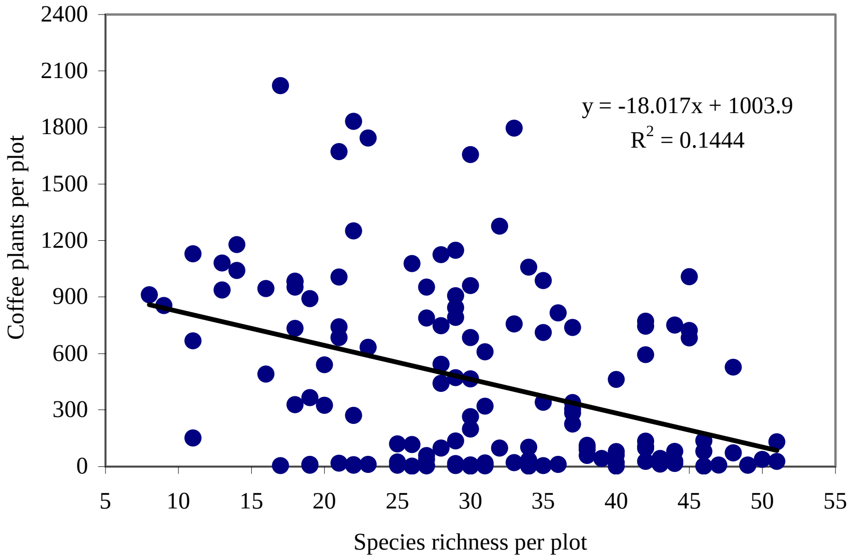

Figure 6.4 Number of wild coffee plants plotted against species richness using pooled data from all studied Afromontane rainforests of Ethiopia

The two-way correlation analysis of coffee abundance and abundance of individual species revealed at least two kinds of relationships. The first group of species (e.g., *Paullinia pinnata*, *Diospyros abyssinica*, *Landolphia buchananii*, *Canthium oligocarpum*, *Blighia unijugata*, *Trichilia dregeana*, *Mimusops kummel*, *Ehretia cymosa*, and *Cassipourea malosana)* showed a significant positive relationship with coffee abundance. A second group shows a significantly negative relationship (e.g., *Argomuellera macrophylla, Psychotria orophila, Whitfieldia elongata, Baphia abyssinica*).

An analysis of the percentage co-occurrence of some plant species and coffee shows about 14 species with an absolute frequency occurrence (co-exist) of >50 %. These species can be considered as “coffee indicator species.” These include *Landolphia buchananii* (87%), *Diospyros abyssinica* (73%), *Vepris dainelii* (71%), *Dracaena fragrans* (71%), *Maytenus gracilipes* (60%), *Beresama abyssinica* (58%), *Celtis africana* (57%), *Ehretia cymosa* (50%), *Clausena anisata* (53%), *Teclea nobilis* (58%), *Mimusops kummel* (50%), and *Hippocratea africana* (53%). The majority of these species are small-to-medium-sized trees except *Landolphia buchananii* and *Hippocratea africana*, which are climbers.

6.4 Discussion

6.4.1 Effects of topography and substrate

Many environmental factors (such as soil nutrient status, slope, and altitude) that change along the topographic gradient are found to exert an important control on distribution patterns of species (e.g., Whittaker and Niering 1965; Vuilleumier 1970; Coblentz and Riitters 2004). For instance, the magnitude of topographic changes in forest structure and composition corresponds well with change in nutrient status of the soil (Takyu et al. 2002; Enkoi 2003; Enkoi and Abe 2004).

As illustrated in the present study, wild coffee populations occur over wider ranges of climate in the rainforests of Ethiopia. Apparently, it is difficult to disintegrate the impact of climate from other environmental factors. Studies (e.g., Friis 1992; Eilu et al. 2004) showed that tree species distributions are influenced by both local environmental variables (e.g., soil, slope) and as well as regional environmental factors (e.g., rainfall, altitude). This may holds true for coffee.

The highest densities of coffee individuals were recorded between 1300 and 1600 m suggesting the optimum altitude of wild coffee. Tadesse and Nigatu (1996) report similar results for the Harenna forest. Several other studies (e.g., Hamilton 1975; Friis 1992; Wolf 1994; Lovett et al. 2001) have shown the influence of altitudinal gradients on tree species distribution. Friis (1992) argued the existence of critical altitudes for groups of species in northeastern tropical Africa, which also holds true for wild populations of coffee. It appears, however, that the altitudinal range of wild coffee is increasing to higher altitudes in the Harenna forest and lowland forests in the southwest areas, which might be related to changes in rainfall distribution patterns. Fourteen years ago, wild coffee trees were recorded around 1700 m in the Harenna forest as the upper altitudinal limit (Tadesse and Nigatu 1996). In the present study (2003/04), coffee plants were recorded at 1850 m as the upper altitudinal limit in the Harenna forest. Therefore, the lower and upper altitudinal limit of coffee may need further investigation.

As exemplified in the present study, abundance of wild coffee plants was not strongly related to slope angle. Gebre-Egziabher (1978) and Woldemariam (2003) reported a negative correlation between slope angle and the abundance of wild coffee in some areas. The negative correlation of the abundance of coffee with the slope angle is due to steeper slopes which have shallower soils more influenced by bedrock, and are, hence, less moist and less acidic (Gebre-Egziabher 1978).

In its natural habitat, coffee grows on different soil types. These soils are acidic to slightly acidic and have low available phosphorus. Many studies (e.g., Purseglove 1968; Murphy 1968; Tewolde 1978; Willson 1985; Mamo 1992; Dubale 1996; Dubale and Shimber 2000) reported the same findings in different rainforests. The coffee plants growing on these soils apparently are able to secure their phosphorus requirements mainly from that released through organic matter decay or weathering. According to Hall and Swaine (1976), soil fertility covaries with rainfall; forest under high rainfall grows on leached soils with low pH, poor saturation of the cation exchange complex, low total exchangeable bases, and low concentrations of available phosphorus and total nitrogen. Eilu et al. (2004) reported similar results from the Albertine rift forests, western Uganda, where tree distribution was affected by soil pH, which was correlated with mechanical soil properties and gross climate.

6.4.2 Influence of dispersal agents and forest canopy

Several studies indicate the influences of human beings and their activities on the patterns of wild coffee distribution in the Ethiopian rainforests (Meyer 1965; Purseglove 1968; Gebre-Egziaber 1978; Tadesse and Nigatu 1996; Teketay et al. 1998; Wondimu 1998). The human interactions with the forest include shifting cultivation, timber and fuelwood harvesting, and collection of various non-timber forest products including wild coffee berries. These human activities have contributed positively or negatively or both to the present patterns of wild coffee distribution in the rainforests. In the present study, most plots that were affected by human influence were found to contain a high number of coffee plants compared to the plots that were located in the inaccessible parts of the forests. In the accessible part of the forests, rural communities collect most of the coffee berries, at the same time modifying micro-sites for new recruitment of coffee plants by removing undergrowth around the mother coffee trees. In the inaccessible parts of the forests, non-human dispersal agents play an important role in governing the pathways of coffee berries and the distribution patterns of the wild coffee populations thus differ according to the dispersal agents. In human-influenced environments, expansion of coffee populations may occur due to habitat modification. However, in the inaccessible part of the forest where human influence is irregular, coffee distribution patterns are affected by competition from other plants, environmental patchiness and dispersal agents. Certainly, the abundance, growth and survival of newly regenerating plants (seedlings) vary across microsites (Whittaker and Levin 1977; Peterson and Picket 1990), and this, in turn, influences the spatial distribution of tree species across their geographical ranges (Núñez-Farfán and Dirzo 1988; Christie and Armesto 2003). This holds true for wild coffee plants distribution in the studied rainforests. This results in the clumped distribution patterns of wild coffee populations in the studied rainforests.

In most forests, small populations of coffee seedlings were observed occurring patchily even where coffee mother trees were scarce. Here, birds and mammals could have acted as seed dispersal agents leading to coffee plant migration. In most tropical forests, up to 90% of all tree species rely on animals for dispersal of their seeds (Ganzhorn et al. 1999). Hence, one other possible reason for the clumped distribution of coffee populations in the studied rainforests could be habitat preference by dispersal agents (Calvino-canvela 2002).

Furthermore, the forest canopy structure appears to influence the abundance and distribution of the wild coffee populations. According to Tang et al. (1999), the variation in forest canopy structure and foliage height distribution affects understory light availability on the forest floor. The extent of canopy cover by shrubs and small-tree layers might influence the intensity of light reaching the forest floor, which, in turn affects coffee abundance and occurrence. Therefore, the distribution of wild coffee in the Afromontane rainforests is also affected by the structural arrangement of the forests.

6.4.3 Coffee distribution and species richness

Species distribution patterns reflect the multitude responses that make up the capacity of a species to survive and reproduce under a particular set of conditions (MacArthur 1972; Buckley and Kelly 2003). Although the absence of a species from a site or habitat may not indicate that the species cannot tolerate those conditions, the presence of a species signifies that it can. The locally patchy distribution of wild coffee plants in the rainforests might be due to habitat patchiness, substrate/geology, dispersal limitation, competition or degree of human influence (Vuilleumier and Simberloff 1980). Therefeore, the difference in the abundance and distribution of wild coffee plants among the studied sites and plots could also be related to these factors. A high number of wild coffee plants was recorded in the plots where there was some sort of disturbance and/or on sites where there was little undergrowth, e.g., the Maji or Yayu forests. In contrast, in the Harenna forest where frequent livestock grazing is common, the abundance of coffee per plot was very low compared with the other forest regions (Table 6.1). Heavy disturbance may lead to the establishment of few coffee plants only on suitable micro-sites where the disturbance is minimal. It can be concluded that severe disturbance may limit recruitment and establishment of coffee, while intermediate disturbances (e.g., thinning of undergrowth) enhance the regeneration of coffee plants. Woldemariam (2003) reported similar findings from the Yayu forest.

The low abundance of coffee corresponding to an increase in species richness might be due to the overwhelming competition from other species. Coffee is highly sensitive to competition from shrubs and small trees (Teketay 1999). It is because of this inability of coffee plants to competition that farmers usually remove or thin-out the competing trees and shrubs in order to improve the productivity of wild coffee when they exercise management in the forests. This type of wild coffee management, however, reduces floristic composition and vegetation structure of the forests and eventually leads to the disappearance of the forest species (see Chapter 7).

The positive co-existence of some forest species with coffee may indicate their similar ecological requirement or niche. Gebre-Egziabher (1986) also reported on the beneficial co-existence between wild coffee plants and certain forest species. On the other hand, the negative relationship between coffee and other plant species indicates intolerable competition by some species. The majority of these species are species with a stature comparable to that of coffee (e.g., *Argomuellera macrophylla, Psychotria orophila,* and *Chionanthus mildbraedii).* Species with ecological requirements similar to coffee can be regarded as indicator species of the habitat of coffee plants.

6.4.4 Implications for conservation

The wild populations of *Coffea arabica* are restricted to the Afromontane rainforests of Ethiopia. These rainforests contain high variability of wild coffee populations (Monaco 1968; Tesefaye et al. 2005). The present study revealed the presence of long gradients in the studied Afromontane rainforests (Chapter 4). Environmental heterogeneity in the rainforests may contribute to the variability of wild Arabica coffee populations in the rainforests. The existence of this high variability guarantees the availability of large gene pools with the desired characteristics for the future improvement of coffee through breeding programs. Notwithstanding, most of these Afromontane rainforests with wild coffee populations have not been a focus of the conservation agenda in the past (Gebre-Egziabher 1990; Demel et al. 1998; Woldemariam et al. 2002). As a result, the rainforest fragments are unsustainably exploited and partly converted into semi-managed forest coffee systems, while the remaining forests are inadequately conserved. Wild coffee conservation in the rainforests should be considered as the continued existence of evolutionary processes and the availability of wild relatives of the coffee genes in the future. Hence wild coffee populations in the Afromontane rainforests need conservation and vice versa.

The empirical analyses in the present study revealed that the occurrence and abundance of wild coffee populations differ among the Yayu, Bonga, Berhane-Kontir, Harenna and Maji forests. Underlying factors are the variations in human influence and environmental factors. For instance, the highest abundance of wild coffee plants was observed between 1300 and 1600 m altitudes (critical zone of wild coffee) and on flat to gentle slopes. The distribution patterns of wild coffee populations in the rainforests can assist in prioritizing the studied rainforests for conservation. In the present study, the Yayu, Harenna and Berhane-Kontir forests contain large tracks of forests with the critical zone of wild coffee occurrence. On the other hand, the Bonga forest is located close to the upper altitudinal limit of wild coffee occurrences, and hence the abundance of wild coffee plants was not comparable to that in the Harenna and Berhane-Kontir forests. Furthermore, a greater proportion of the Maji forest is already affected by human interference. As a result, the Bonga and Maji forests have a lower priority for conservation of wild coffee populations than the Harenna, Yayu and Berhane-Kontir forests.

Woldemariam (2003) indicated the importance of the Yayu forest for conservation of wild coffee populations. A comparison of his data with the present findings also showed that the Yayu forest has the highest abundance of wild coffee plants compared with Harenna and Berhane-Kontir forests. Because of the status of the wild coffee populations and habitat suitability, the Yayu forest should deserve a high priority for conservation. The Berhane-Kontir forest also has areas with wild coffee populations under intact conditions, while the Harenna forest is relatively strongly influenced by human interference. Regarding plant diversity, the later two forests (i.e., Harenna and Berhane-Kontir) are quite different and deserve conservation (Chapter 4). However, Harenna by virtue of its location and the current human pressure, is as important with respect to wild coffee conservation as Yayu. More importantly, the study of genetic variability (which is underway) within and between wild populations of Arabica coffee in the different forest regions can provide more evidence as to which site to select for conservation of the wild coffee populations. To conserve the greatest possible number of wild coffee populations the rainforests must be maintained and not converted to other types of land use. Nature reserves should be established for conservation and sustainable use of the forest and the genetic resources of coffee.

7 EFFECTS OF WILD COFFEE MANAGEMENT ON SPECIES DIVERSITY OF TWO RAINFORESTS OF ETHIOPIA

7.1 Introduction

Ecological and historical studies have demonstrated the dramatic human influences on the forest vegetation of Ethiopia (Logan 1946; von Breitenbach 1963; Hamilton 1981; Bonnefille and Buchet 1986; Bonnefille and Hamilton 1986; Kuru 1988; McCann 1992; Rogers 1992; Friis 1992; Woldemariam et al. 2002). The main driving forces behind deforestation are the expansion of agricultural land, unrestrained exploitation of forest resources, overgrazing and establishment of new settlements into forested land coupled with increasing population pressure. As a result, forest biodiversity is disappearing rapidly in the forest fragments of Ethiopia (Teketay 1992; Senbeta et al. 2002; Woldemariam 2003; Senbeta 2004).

In the Afromontane rainforests, where wild *Coffea arabica* grows as understorey plant, the local communities by tradition manage the forest for coffee production. The traditional coffee management system focuses on the reduction of the density of trees and shrubs in order to improve the productivity of the wild coffee plants. The level of management ranges from the undisturbed forest coffee to the disturbed semi-forest coffee systems. Although these coffee production systems have been in existence for many years, there is limited information available concerning their relative influence on the forest biodiversity (Woldemariam 2003). The problem of coffee forest management, from a biodiversity point of view, has been its tendency to smooth the variation in natural forest structures, leading to homogenization of the age structure, size distribution and species composition of the forest. This reduces the diversity of the forest ecosystem.

In view of the above, understanding coffee management and its effects on the forest biodiversity is necessary for the sustainable management of the forest. Alternatively, this offers a possibility to evaluate the effect of coffee forest management on biodiversity, which will make it possible to consider diversity in management planning. Therefore, a comprehensive analysis of the ongoing forest coffee management for coffee production is helpful to elucidate the extent of its influence on the forest coffee. This study focuses on two Afromontane rainforests, namely Berhane-Kontir (southwest) and Harenna (southeast). Woldemariam (2003) carried out a similar study in the Yayu forest, and currently a comparable analysis is underway around the Bonga area. These findings and the present study together can explain the effects of wild coffee management on forest diversity, and can also indicate possible future management interventions at a regional or local level. The objectives of the present study are 1) to assess the impact of the wild coffee management on the species composition, structure and diversity of the rainforests, and 2) to evaluate the influence of wild coffee management on the population structure of the coffee.

7.2 Material and methods

7.2.1 Study sites

The study was carried out in two Afromontane rainforests, Harenna and Berhane-Kontir, located in the SE and SW highlands of Ethiopia, respectively (Figure 3.1). A long history of forest exploitation and coffee use is deeply rooted into the socio-cultural activities of the people in these areas. A detailed description of each study site is given in Chapter 3.1.

7.2.2 Methods

Prior to vegetation sampling, a reconnaissance survey was carried out at each site to identify the major vegetation gradients and/or vegetation variability. Accordingly, two forest systems were recognized in both forests, i.e., undistributed forest coffee (FC) and disturbed semi-forest coffee (SFC) systems. These systems are the result of the different human management interventions. In the FC system, human influence is limited to coffee- berry collection without changing the floristic and structural complexity of the forest. In contrast, in the SFC system, selective cutting of competing trees, shrubs and lianas to promote the productivity of coffee has been taking place for a number of years beside coffee-berry collection.

Along transects in each forest, quadrats of 20 m x 20 m were laid down to collect vegetation data. A total of 114 plots, 55 plots from Berhane-Kontir (FC, n = 37 and SFC, n = 18) and 59 plots from Harenna (FC, n = 24 and SFC, n = 35) were established, henceforth abbreviated as Berhane-Kontir Forest Coffee (BKFC), Berhane-Kontir Semi-Forest Coffee (BKSFC), Harenna Forest Coffee (HAFC) and Harenna

Semi-Forest Coffee (HASFC). In each study plot, all vascular plant species were identified and counted. In addition, height and diameters of all woody plants (with dbh $\geq$ 2 cm and $\geq$ 0.5 m height) were measured. Furthermore, environmental data such as slope, altitude, aspect, and disturbance factors were recorded for each plot. Diameter at breast height and height of the coffee plants were measured and the plants categorized into seedlings (< 0.5 m high), saplings (0.5-1.5 m) and trees (> 1.5 m).

7.2.3 Data analysis

The Shannon diversity (H') and evenness (E') indices were calculated using equation 4.1 and 4.2 (Chapter 4.2.3). Floristic similarities between the systems were evaluated using Sorensen similarity coefficient equation 4.8 (Chapter 4.2.3). The vegetation structure of the different forest systems are compared on the basis of size-class distribution, density and basal area. An ordination techniques was carried out to determine the relationships between the forest systems and environmental variables. The ordination was based on a Canonical Correspondence Analysis (CCA) (ter Braak 2003), a technique that assumes unimodal distributions of species along environmental gradients and depicts the variation in the species scores along the ordination axes (see Chapter 4.2.4 for details). A total of 100 species and 4 environmental variables (slope, altitude, aspects and human disturbance) were included in the analysis. The ordination is presented in a two-dimensional diagram in which the sites are represented by points. Automatic forward selection of environmental variables was used to determine the relative importance of environmental variables in the input data, and the variance explained by them. Monte Carlo permutation tests were used to determine the statistical validity of the association between vegetation ordination scores and the independent environmental variables.

7.3 Results

7.3.1 Floristic composition and diversity

In both forests, the FC had the highest number of plant species and SFC the lowest (Table 7.1). For example, 275 species and 199 species were recorded in the BKFC and BKSFC, respectively. At Harenna, however, the variations in floristic composition between the two forest systems are low. In both forests, Shannon diversity and evenness exhibited high variation between the two forest systems (Table 7.1). As expected, the diversity was high in the FC and low in the SFC systems. In the SFC system of both forests, the evenness (E') values were low compared to the FC. At each site, however, there was a high floristic similarity between the two forest systems (Table 7.1).

Table 7.1 Summary of parameters in two forest coffee systems in the Harenna and Berhane-Kontir forests, Ethiopia (BKFC= Berhane-Kontir Forest Coffee; BKSFC= Berhane-Kontir Semi-Forest Coffee; HAFC=Harenna Forest Coffee; HASFC=Harenna Semi-Forest Coffee)

	BKFC	BKSFC	HAFC	HASFC
Total area sampled (ha)	1.48	0.72	0.96	1.40
Mean number of species/plot^1	32.00	17.00	30.00	27.00
No. of families^1	83.00	75.00	73.00	62.00
No. of genera^1	193.00	147.00	150.00	135.00
No. of total species^1	275.00	199.00	194.00	178.00
Shannon diversity (H')^2	2.82*	1.23*	2.60*	0.90*
Evenness^2	0.52*	0.22*	0.52*	0.14*
Fisher's, α^2	26.23	18.65	19.66	15.42
Sørensen similarity index^2	0.62		0.79	

*^{1}Vascular plants; ^{2}Woody plants;*significantly different (p = 0.05)*

In both forests, the order of family dominance rank changed from one forest system to the other, i.e., between FC and SFC (Table 7.2). For instance, in the BKFC, Rubiaceae and Euporbiaceae are the dominant and co-dominant families, whereas in the BKSFC Moraceae and Euphorbiaceae take the first and second dominance.

Table 7.2 Dominant families in each forest coffee system in the Harenna and Berhane-Kontir forests, Ethiopia in order of decreasing importance (abbreviations as in Table 7.1)

HAFC	HASFC	BKFC	BKSFC
Rubiaceae	Fabaceae	Rubiaceae	Moraceae
Euphorbiaceae	Rubiaceae	Euphorbiaceae	Euphorbiaceae
Celastraceae	Euphorbiaceae	Moraceae	Rubiaceae
Fabaceae	Rutaceae	Rutaceae	Annonaceae
Rutaceae	Celastraceae	Celastraceae	Celastraceae

In Harenna, the species diversity of growth forms between the two forest systems was low with the ratio (*SFC/FC)* ranging between 0.83 (understory and shrubs) and 1 (canopy trees) (Table 7.3). In the Berhane-Kontir forest, the species diversity ratio of growth forms between the systems ranged between 0.45 (for understory and shrubs) and 1.23 (for herbs). In the Berhane-Kontir forest, reduction of around 50% of species of some growth forms such as understory trees and shrubs, and lianas was observed (Table 7.3). On the other hand, the species diversity ratio in the Harenna forest is around 1. In both forests, herbs were the dominant life forms in the SFC systems.

Table 7.3 Number of plant species per growth form in two forest coffee systems in the Harenna and Berhane-Kontir forests, Ethiopia (abbreviation as in Table 7.1)

Growth form	Number of species per forest system					
	HASFC	HAFC	HASFC/ HAFC	BKSFC	BKFC	BKSFC/ BKFC
Canopy trees	5	5	1.00	8	11	0.73
Medium trees	26	27	0.96	22	38	0.58
Understory and shrubs	50	60	0.83	25*	55*	0.45
Lianas	40	45	0.88	41*	70*	0.59
Herbs	46	48	0.95	75	61	1.23
Epiphytes	22	25	0.88	38	35	1.09

**significantly different (p = 0.05)*

7.3.2 Ordination

In the Canonical Correspondence Analysis (CCA), the SFC systems in both forests are depicted along the human impact gradient (along axis 1) and the FC systems are represented along the opposite end. Small tree canopy cover (SCC) is represented along axis 1 (Figure 7.1). Axis 2 depicts altitudinal gradient, where the plots from Harenna are located at a higher altitude while the Berhane-Kontir plots are located on the lower altitude. Most plots in the Berhane-Kontir forest are located on steep slopes unlike in the Harenna forest. The first four axes explain 11.6%, 16.0%, 17.8% and 18.5% of the variance of species data. The Berhane-Kontir forest is represented on different environmental gradients unlike Harenna forest, where the plots form clusters.

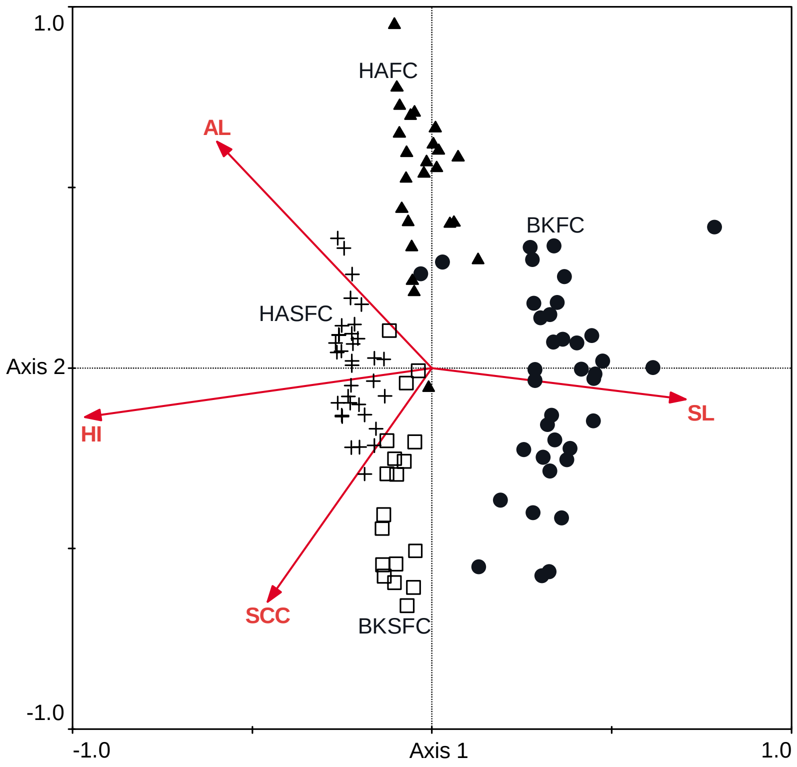

Figure 7.1 CCA ordination diagram based on the abundance of woody species of the two forest coffee systems in the Harenna and Berhane-Kontir forests; each symbol represents one forest system. The angle of the lines with a particular axis is a measure of the degree of correlation (shallow angle mean higher correlation). The length of the lines illustrates the significance of the axis in explaining environmental variables (AL-Altitude; HI-Human impact; SCC- Small tree canopy cover; SL- Slope)

7.3.3 Vegetation structure

In the FC system of both forests, the highest densities of individuals were recorded in the lower dbh classes and few in the higher dbh classes (Table 7.4). In contrast, in the SFC systems, the highest densities were in the lowest and highest dbh classes in both forests. In the SFC systems in both forests, coffee plants dominate the diameter class between 2 and 10 cm (Table 7.4). Within the indicated diameter class, coffee holds about 98% in the BKSFC system and 88% in the HASFC system. The difference in the basal area between SFC and FC was observed only in the Berhane-Kontir forest and there was little difference in the Harenna forest.

Table 7.4 Basal area and density in each forest coffee system in Harenna and Berhane-Kontir forests, Ethiopia (dbh = diameter at breast height; other abbreviations as in Table 7.1)

Variables	Forest systems			
	BKFC	BKSFC	HAFC	HASFC
No. of plots	37	18	24	35
BA (m^2)/ha	34	58	49	47
Density (individuals/ha), 2 cm $\leq$ dbh $\leq$ 10 cm	1805	2355	1122	2137
Proportion of coffee plants (%), 2 cm $\leq$ dbh $\leq$ 10 cm	23*	98*	4*	88*
Density (individuals/ha), 10 cm < dbh $\leq$ 20 cm	266	60	291	178
Density (individuals/ha), dbh > 20 cm	234	134	181	340

**significantly different (p = 0.05)*

A comparison of the Importance Value (IV) (the sum of relative frequency, relative dominance and relative density) of the 10 dominant species in each forest systems is presented in Table 7.5. In both forests, *C. arabica* was the most abundant and frequent expect the BKFC. In the BKFC system, *Argomuellera macrophylla* had the highest IV followed by *C. arabica*. In the SFC systems, *C. arabica* had IV of 97 and 126 in the BKSFC and HASFC, respectively. In both BKSFC and HASFC systems, the dominant growth forms are medium to large trees (Table 7.5), whereas in both BKFC and HAFC systems, the most abundant and frequent species include different growth forms, e.g., lianas, shrubs, and trees. In the BKFC system, for example, the most abundant and frequent species were small trees and shrubs like *Dracaena fragrans*, *Eugenia bukobensis*, *Whitfieldia elongata* and *Argomuellera macrophylla.* In the BKSFC system, except for *C. arabica*, most of the dominant species were medium to tall tree species such as *Mimusops kummel*, *Celtis africana*, *Trichilia dregeana*, and *Pouteria altissima.*

Table 7.5 Importance value (IV) of the 10 dominant species in each forest coffee system in the Harenna and Berhane-Kontir forests, Ethiopia. Small tree = < 15 m height; medium tree = 15-30 m height, and Tall tree = > 30 m height at maturity

Species	Growth form	HAFC	HASFC	BKFC	BKSFC
Coffea arabica	Small tree	53	97	24	126
Afrocarpus falcatus	Tall tree	28	17		
Syzygium guineense	Medium tree	18	12		
Olea welwitschii	Tall tree		15		
Celtis africana	Medium tree	9	11		7
Landolphia buchananii	Liana	6			3
Lepidotrichilia volkensii	Shrub	6			
Cassipourea malosana	Medium tree	5			
Warburgia ugandensis	Medium tree		7		
Croton macrostachyus	Medium tree		6		
Pouteria adolfi-friedericii	Tall tree		5		
Jasminum abyssinicum	Liana	5			
Oxyanthus speciosus	Small tree	5			
Bersama abyssinica	Small tree	4			
Argomuellera macrophylla	Shrub			34	
Diospyros abyssinica	Medium tree		6	21	6
Whitfieldia elongata	Shrub			13	
Blighia unijugata	Medium tree			12	5
Rothmannia urcelliformis	Small tree			12	5
Dracaena fragrans	Shrub			8	
Eugenia bukobensis	Small tree			8	
Pouteria altissima	Tall tree			8	19
Strychnos mitis	Medium tree		11	7	
Cordia africana	Medium tree				11
Mimusops kummel	Medium tree				12
Trichilia dregeana	Medium tree				4
Morus Mesozygia	Medium tree				6

7.3.4 Structure of coffee populations

In both forests, coffee had the highest number of individuals in the lowest and highest height classes but very few individuals in the intermediate classes in the SFC systems (Table 7.6). The highest abundance of coffee was recorded in the SFC systems, in both forests and the lowest in the FC systems. The abundance ratio of *SFC/FC* of the height classes showed variation between the two forests. The ratio ranged between 4 and 12 in the Harenna, and 0.29 to 2.6 in the Berhane-Kontir forest.

Table 7.6 Height class frequency distribution of wild coffee in each forest coffee system in the Harenna and Berhane-Kontir forests, Ethiopia

Height class	BKSFC	BKFC	BKSFC/ BKFC	HASFC	HAFC	BKSFC/ BKFC
< 0.5 m	873	1051	0.83	10159	2440	4.16
0.5-1 m	257	718	0.36	5308	876	6.06
1-1.5 m	230	805	0.29	3672	424	8.66
1.5-2 m	252	279	0.90	1499	192	7.81
> 2 m	2997	1150	2.61	5846	481	12.15
Individuals/ha	6401	2705	2.36	18917	4597	4.12
Max dbh (cm)	16	10		7	7	
Max ht (m)	13	12		6	5	

Maximum height and dbh of coffee plants were recorded in the Berhane-Kontir forest (Table 7.6), in SFC (12 m height and 16 cm dbh) and in the FC (12 m height and 10 cm dbh), while in Harenna, maximum dbh was 7 cm in both systems and maximum height was 6 m in the SFC and 5 m in the FC. The highest density of coffee plants (individuals/ha) was recorded in Harenna.

7.4 Discussion

7.4.1 Floristic diversity and composition

The conversion of forest coffee system into semi-forest coffee system affects the floristic composition and diversity of the forests. The floristic variation between the coffee systems is high in the Berhane-Kontir compared to that in the Harenna forest. In Harenna, the local communities exploit the “undisturbed forest” for different purposes other than for coffee in similar ways, e.g., for grazing. Ungulates, especially cattle, compact soil and destroy understory plant diversity (Gerhardt and Hytteborn 1992).

Generally, diversity values (e.g., Shannon diversity) were very low in the SFC systems of both forests, which is indicative of the high abundance of one or a few species. The Shannon diversity index is sensitive to numerical dominance by few species (Bone et al. 1997), hence, the low diversity of the SFC system can be attributed to a large number of *Coffea arabica* individuals. The ordination analysis also demonstrates the importance of human management influence and shows clear distinction between the FC and SFC plots of both forests.

The family dominance ranks also changes when the FC is converted into a SFC system, reflecting the targeted removal of species. For instance, Rubiaceae predominantly consist of shrubs and small trees and is the dominant family in the BKFC. However, the Moraceae family with medium to tall trees take over the dominance in the BKSFC system, which is indicative of the deliberate removal of small stature plants from the SFC system. The removal of around 50% of the small trees and shrubs in the BKSFC system (Table 7.3) shows how these growth forms are apparently endangered. The conversion of FC to SFC affected not only the floristic composition but also the structural arrangement of the forest, leading to the formation of tall-tree canopy and coffee-canopy layers without any intermediate canopy layer.

Species richness and diversity increase with increasing structural and floristic diversity of the habitat (Gallina et al. 1996; Donald 2004), but increased habitat disturbance changes the structure of the communities. The conversion of FC to SFC system has led to the loss of floristic diversity due to the clearance of understory trees and shrubs (Woldemariam 2003; Donald 2004). In south and southwestern Ethiopia, most plantation or garden coffees are grown on land formerly under forest, so coffee production is partly a historical cause of deforestation in these regions. The loss of species diversity in the SFC system is likely to have negative effects on forest biodiversity and even on future long-term coffee production.

The loss of plant species may have analogous consequences on animal species diversity. Such associations are used to argue that one of the ecosystem functions provided by diverse plant communities is the maintenance of rich animal communities (Knops et al. 1999). In addition, the coffee plants, although self-pollinating, have recently been shown to be strongly influenced by an abundance of pollinating insects. For instance, the introduction of African bees into Central America has led to a significant increase in the yield of coffee, in some places by over 50% (Roubik 2002). In Indonesia, the fruit set of highland coffee increases with the species diversity of pollinating bees, rising from 60% in the presence of 3 bee species to 90% where 20 bee species are present (Klein et al. 2003). Consequently, modification of forest species diversity might affect the functional role of the forest (e.g., pollination) and disrupt the economic and the livelihood of the people who are dependent on the forest.

7.4.2 Vegetation structure

The pattern of size-class distribution (i.e., diameter) has often been used to represent the population structure of a forest (e.g., Khan et al. 1987). The overall distribution patterns of diameter classes in the FC systems suggest that the stands consist of species with relatively wide age classes. However, in the SFC systems the highest densities of non-coffee plants were found in the higher size classes, suggesting the continuous removal of young plants. The highest densities of coffee plants within the lower diameter classes in the SFC systems (Table 7.4) of both forests also indicate the reduction in the structural complexity of the forests. Most plant species of a size (i.e., both in diameter and height) comparable to that of coffee plants are continuously eliminated from the SFC system and subsequently lead to the dominance of coffee plants, both in the vertical and horizontal structure. The dominance of medium to tall-tree growth forms in the SFC systems of both forests indicates the trends of forest management in the system. Woldemariam (2003) reported similar findings in Yayu. If human pressure continues to influence the natural population dynamics of a species, in the long-term species, forests and even coffee production will be affected. The currently existing coffee shade trees will sooner or later mature and finally reach a post-reproductive stage. This will lead to the extinction of these species, especially in the case of rare, endemic and ecologically restricted species unless alternative management schemes are developed.

7.4.3 Structure of coffee populations

A comparison of the size-class distribution of coffee plants in the SFC and FC shows significant differences among all size classes. This can be associated to the difference in the level of management. Coffee management in the SFC usually focuses on the improvement and maintenance of mature coffee plants that produce seeds immediately and to some extent on young plants (mainly seedlings). Therefore, many farmers are more concerned with seed production than maintaining the coffee population structure and thus the abundance of mature (i.e., > 2 m tall) coffee plants are higher in the SFC. Coffee seedlings are maintained in certain areas of the holding for future planting. This continued management of coffee in the SFC system suppresses tree regeneration, reduces tree density and eventually leads to the disappearance of the forest species, while promoting a high number of bigger coffee plants.

The assessment of the size-class distribution of the coffee plants in the two forests showed a higher plant height and dbh in the Berhane-Kontir forest. These could be related to 1) the intensity of coffee management (frequent removal of competitors from around the coffee plants), and 2) much longer period of coffee management (especially in the SFC systems) as compared to Harenna. In the Harenna forest, coffee is not well managed and hence a higher number of coffee individuals per hectare were recorded. A high number of coffee individuals per unit area can restrict diameter growth.

7.4.4 Implications for biodiversity conservation

The conversion of forest coffee into semi-forest coffee system has influenced and will continue to influence the diversity of rainforests if alternative management measures are not put in place. The present analysis reveals that the community structure is drastically changed in terms of floristic composition, species density and structure in both the Berhane-Kontir and the Harenna forest. Despite the differences in the magnitude of disturbance between the Harenna and Berhane-Kontir forests, conversion of forest coffee into semi-forest coffee has influenced both forests. In the Harenna forest, the difference between forest coffee and semi-forest coffee was low because of similar disturbance trends in both systems. Observations in the forests of Bonga and Maji show similar trends, i.e., changes in structural and floristic composition. Woldemariam (2003) reports similar findings for the Yayu forest. Thus, the inferences drawn about the impact of forest coffee management on forest biodiversity can be reliable. The conversion led to a reduction in the understory trees and shrubs, and climbers that could have influenced the forest microclimate, which in turn might have impaired the regeneration processes of tree species. Apparently, conversion of forest coffee to semi-forest coffee has implications for the conservation of forest biodiversity, i.e., floristic composition and diversity, wild coffee populations and associated animal species.

The conservation and sustainable use of species, plant communities and their supporting ecological processes within the semi-forest coffee system is urgently required. In such situations, conservation sites should be established to cover a range of sites with different frequencies and intensities of human disturbances, i.e., in both managed and unmanaged forest systems. A great deal has already been said about the undisturbed forest and the possible conservation options in Chapter 4 and Chapter 5. In all forest regions with wild coffee populations, the forest coffee is usually surrounded by the semi-forest coffee system. It can therefore serve as buffer zone for the conservation of undisturbed forest coffee systems. Concerning the semi-forest coffee system, the conservation strategies should focus on the balance between plant diversity and coffee production.

The major management problem in the semi forest coffee system is the repeated removal of young shade trees, shrubs and climbers to avoid competitor of coffee plants. The uniform population structure of coffee plants may have also implications on the long-term population dynamics of coffee. Traditional wild coffee management methods are not based on systematic analysis, and hence opinions among the farmers vary on how to manage the forest. For instance, what percentage of the non-coffee trees should be thinned to increase the productivity of coffee is one contentious issue. This illustrates the importance of specific ecological conditions for the sustainable management of semi-forest coffee systems. The first ecological condition for sustainable management of semi-forest coffee system is the preservation of the natural regeneration of shade trees, which are crucial for this coffee production system. Thus, in this system, there should be a balanced proportion of seedlings, saplings and tree-sizes of shade trees, which are an indicator of normal plant population distribution. The plant community must have a certain species and size-distribution pattern to maintain its structure and species composition. Additionally, other plant species should also be maintained in the system. A second ecological condition necessary for the sustainable management of semi-forest coffee systems is that the development of those species considered desirable should be promoted. Enrichment planting should be carried out where the density of shade trees is reduced due to wind throw or death of individuals. A third ecological option for sustainable management of semi-forest coffee system is the capability of the forest ecosystem to overcome varying degrees of disturbances. The different components of the system (e.g., soil, understory layer) should be managed, e.g., soil erosion control. The self-regulating systems of forest communities do not always function in a favorable way, especially when disturbance is serious.

Most importantly, the establishment of “biodiversity conservation spots” (“**biopot”)** to maintain and enhance the conservation of biodiversity, i.e., of both plants and animals, in the semi-forest coffee system is a very crucial step. A **biopot** is an area (spot) to be designate for biodiversity conservation in a semi-forest coffee system. In other words, it is equivalent to “**biodiversity conservation spots**” in the semi-forest coffee system left in reserve for biodiversity conservation. In these biopots, thinning or removal of the understory trees or shrubs or of any life forms is not allowed but only coffee berry collection. For effectiveness, biopots should be located at the points where at least four or more of the plots of different owners come together. Altogether, the owners are advised to leave at least a quarter of a hectare for conservation of species. However, depending on the size of the holdings in the different forest regions, the minimum area can be redefined. These biopots can serve as habitats for wild animals and can also serve as a source and sink for plant migration. In a landscape, with continuing human influence a conservation strategy involving biopots can be an alternative for saving some of the dwindling biological resources. On all accounts, the farmers should be assisted in the design and implementation of conservation measures.

8 SYNTHESIS AND CONCLUSIONS

8.1 Synthesis

Diversity of Afromontane rainforests

Afromontane rainforests of Ethiopia with wild coffee populations occur in the SE and SW highlands of Ethiopia mainly at altitudes between 1000 and 2000 m. In spite of a wide geographical distribution, Afromontane rainforests are fragmented and isolated from each other due to human and natural factors. The disjunct occurrences of Afromontane rainforests reveal that these forests were much more widespread in the past (Coetzee 1978; Iversen 1991). Many of these forest fragments with wild coffee populations are located in the SW and only one patch occurs in SE Ethiopia. Floristically, the southwest Afromontane rainforests are more linked to the lowland Guineo-Congolian forest while the southeast rainforest is more connected to the dry Afromontane forest. The findings presented in Chapter 4 and Chapter 5 suggest that Afromontane rainforest fragments with wild coffee populations are floristically distinct, and that the common features of the geographically isolated Afromontane rainforests are the occurrence of wild coffee populations and the physiognomic similarity. It could be due to the structural similarities that wild coffee populations are the common entity of these forests. In the studied Afromontane rainforests, species diversity is high in the region of highest rainfall gradient, i.e., Berhane-Kontir forest. On the other hand, the Maji forest is recognized as one of the poorest floristic regions due to human influences. Due to the diversity of habitats in the rainforests diverse growth forms occur. In particular, the diversity of epiphytic plants is remarkably high indicating a diversity of vertical and horizontal ecological gradients. As a whole, due to human-induced activities, the Afromontane rainforests with wild coffee populations are suffering from continuous fragmentation. However, conservation and sustainable use of the Afromontane rainforests with wild coffee populations is possible in view of the findings of this study.

Major factors related to wild coffee occurrence

Wild populations of *Coffea arabica* are distributed over a wide range of geographical regions in Ethiopia, but sporadic locally. The wide geographical distribution of wild coffee reflects the capability of the species to exist over various environmental gradients. Locally, the patchy distribution of wild coffee populations is related to the major spatial discontinuities caused different edaphic, biotic and topographic features. The results presented in Chapter 6 suggest that in the Afromontane rainforests altitude is one of the most important environmental factors affecting the distribution and abundance of wild coffee. Wild coffee is also strongly limited by the density of understory vegetation (trees and shrubs). More importantly, heavy disturbance may limit the performance of wild coffee, while intermediate disturbance may enhance the abundance of wild coffee populations. Generally, human exploitation of the rainforest has the potential to influence the patterns of wild coffee distribution (Chapter 6 and Chapter 7).

Effects of wild coffee management on forest

The traditional wild coffee management (i.e., thinning of understory trees, shrubs and climbers) in the Afromontane rainforests may lead to the formation of forest vegetation dominated by coffee plants both in composition and in structure (Chapter 7). The current wild coffee management may lead to a type of coffee plantation with only a few scattered shade trees. This study confirms that not only is the floristic composition and structure of Afromontane rainforest with wild coffee populations deteriorating, but the population structure of coffee plants is also being influenced by human activity. If the conversion of forest coffee into semi-forest coffee system continues, most of the coffee forests will be lost, leading to the loss of forest biodiversity.

8.2 Conclusions

The studied Afromontane rainforests have proved to be high in species diversity and a refuge for wild Arabica coffee populations. They are the last resort for the perpetuity of wild plants, and hence their continuation as a forest ecosystem is obligatory for the conservation of an array of species occupying different niches within the forest. These give them an exceptional key function for the conservation of the genetic resources of coffee in the country. Furthermore, they shelter a greater number of other economically useful plant species on which the local communities are dependent on for their livelihoods. Despite their ecological and economic importance, however, the

Afromontane rainforests of Ethiopia are losing ground due to habitat conversion. Forest loss due to habitat modification, over-harvesting, commercial plantations, and agricultural expansion is increasing at an alarming rate and threatening the forest genetic resources including the wild coffee gene pools. The long-term survival of the Afromontane rainforests will therefore depend on large-scale conservation efforts. Conservation of forest genetic resources including wild coffee populations will only be possible if use of the Afromontane rainforests sustainable. Therefore, the following recommendations are made for effective conservation and sustainable use of the Afromontane rainforests with wild coffee populations:

1. Primarily, the identification of the undisturbed forest sites for coffee conservation is necessary, i.e., establishment of *in-situ* conservation sites. At least representative areas of Afromontane rainforest need to be kept aside for biodiversity conservation. In particular, special attention needs to be given to the forests with wild coffee populations in order to maintain the diversity of wild coffee genetic material. In addition, *ex-situ* conservation approaches, such as field gene banks, seed banks and on-farm coffee conservation, must be supplemented.
2. The critical issue concerning conservation of Afromontane rainforests with wild coffee populations is the development of alternative livelihoods for the local communities that depend on the forest and forest products. Poverty is the major problem in the region and hence development strategies that address both poverty alleviation and sustainable utilization of the forest are required. The local communities can be supported through enhancing the market situation of coffee or other non-timber forest products by giving the farmers fair prices for their harvest so that their income is improved. Establishing management schemes involving the government and local communities, including certification of the forest and its products, makes it possible for local authorities to better monitor resources utilization. Additionally, the products would achieve better prices with a quality guaranty, which would greatly reduce illegal trading and over-harvesting, (e.g., wild coffee, spices). Sustainable use of non-timber forest products such as honey, spices and coffee should be supported and encouraged by the government and NGOs.

3. An integration of indigenous knowledge with modern conservation approaches in the planning and implementation process is crucial for improving the likely local participation in the conservation processes. Local knowledge not only provides information on the use of species, but can also contribute valuable information on how to maintain and conserve the genetic materials, species and ecosystems. Effective conservation and sustainable use of the Afromontane rainforests with wild coffee populations therefore need the involvement of many stakeholders including local communities.
4. For the semi-forest coffee system, a conservation strategy should be developed and implemented that allows the conservation of forest biodiversity, in particular shade tree diversity. In this case, potential shade trees, rare shade trees and mother trees of the most important shade species should be kept and maintained for long-term sustainable coffee production and at the same time for the conservation of the shade tree species. Above all, the establishment of biodiversity conservation spots (**biopots**) in the semi-forest coffee systems is crucial to reduce loss of biodiversity.
5. The most important component of Afromontane rainforest conservation approaches is the rehabilitation of degraded forestland in and around the forests. On these degraded lands, multipurpose tree species can be introduced that will create alternative livelihoods for the local communities. At the same time, these areas buffer the forest conservation zone and promote a sustainable use of forested land.
6. Finally, the country should develop land-use policies and planning that promote land uses according to suitability. Any rural development strategy should gear toward multifaceted approaches, which consider rural development based on the carrying capacity of the resource bases.

The following points need further research:

1. There is a deficit of scientific knowledge of all aspects of the regeneration ecology of Afromontane forest species, as well as succession processes after any kind of natural or human impact. Information on the distribution and reproductive biology of most plant species is also lacking.
2. The role of dispersal agents and abiotic factors that affect the patterns of wild coffee distribution need further investigation.
3. Reproductive biology and germination ecology of wild coffee in the rainforest is of paramount importance for future forest-coffee conservation.
4. There is a need to determine the appropriate density of shade trees to maximize the productivity of coffee and forest biodiversity in the semi-forest coffee system. This can help to develop management strategies on how to maintain potential trees in the system.
5. Further study is required to identify the impacts of different coffee production systems on the faunal diversity at both local and regional levels.

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10 APPENDICES

Appendix 1. List of vascular plant species of the Afromontane rainforests of Ethiopia

Introduction

Species are arranged in alphabetical order, species within families, and family within the groups of Pteridophyta, Gymnospermae, Dicotyldonae, and Monocotyledonae. The Flora of Ethiopia and Eritrea publications were followed for scientific names. Each species is followed by a general description of the ecological requirements. These are indicated in [ ] following the scientific name of the species and may include habitats not represented in the Afromontane rainforests, as they indicate ecological range of the species. One or more of the following habitat types denote the habitat of each species in the list.

The abbreviations used in the list are as follows:

- **1. Forest**
  - **1a. Moist montane forest**
  - **1b. Dry montane forest**
  - **1c. Transitional rainforest**
  - **1d. Lowland forest**
  - **1e. Riverine forest**
  - **1f. Forest edges, disturbed sites, secondary forests**
- **2. Woodland**
- **3. Bushland**
- **4. Thickets, secondary scrub**
- **5. Rocky outcrops**
- **6. Grasslands**
- **7. Roadsides, wasteland, old cultivation**
- **8. Swamps, wet habitats**

Growth forms for each species are indicated by capital letters following the ecology of the species. The abbreviations of the growth forms are as follows: **Tall Tree (TT**) **-** self-supporting woody plant that grows from a single main trunk, with height of greater than 30 m at maturity, evergreen or deciduous; **Medium Tree (MT) -** woody plant that grows from a single main trunk, with height of 15-30 m at maturity, evergreen or deciduous; **Small Tree (ST) -** self-supporting woody plant that grows from a single main trunk with height of less than 15 m at maturity, evergreen or deciduous**; Rosette Tree** (**RT) -** self-supporting plant characterized by thick and unbranched stems covered by dense, dry leaves that remain attached to the plant when they die; **Shrub (S) -** self-supporting multistemmed woody plant; **Climber** (**C) -** plant that grows up over other plants, including both woody and herbaceous climbers; **Herb** (**H) -** Herbaceous plant; **Epiphytes** (E)**-** plant that grows on other plants; **G-** grasses and sedges.

A. **PTERIDOPHYTA**

ADIANTACEAE (C. Presl) Ching
Adiantum philippense L. [1, 3, 5, 7], H
Cheilanthes farinosa (Forssk.) Kaulf. [1, 3, 7], H
Coniogramme africana Hieron. [1a,1c,7] E
Doryopteris concolor (Langsd. & Fisch.) Kuhn [1, 3, 6], E
Pellaea doniana Hooker, [1,3,6] AFM, E
P. viridis (Forssk.) Prantl [3,5,6], E

ASPIDIACEAE S.F. Gray
Ctenitis cirrhosa (K. Schum.) Ching [1a, 7], H
Didymochlaena truncatula (Swartz) J. Sm. [1a, 1c,7], H
Dryopteris inaequalis (Schlech.) Kuntze[1a, 1c,7], H
Polystichum fuscopaleacum Aliston [1a], E
Tectaria gemmifera (Fee) Alston [1,2,7], E

ASPLENIACEAE L.
Asplenium aethiopicum (Burm. F.) Becherer [1,3,6], AFM,E
A. anisophyllum Kze.[1,7],E
A. buettneri Hieron [1,3],E
A. bugoiense Hieron [1a,7],E
A. ceii Pichi-Serm. [1a] E
A. elliotti C.H.Wright [1],E
A. erectum Willd. [1a, 1c, 6], E
A. friesiorum C.Chr. [1a],E
A. hypomelas Kuhn.[1-2],E
A. inaequilateriale Willd [1a,1c,7],E
A. linkii Webb [1a,1c,7]E
A. mannii Hook. [1a,1c,7],E
A. sandersonii Hook [1a,1c,7],E
A. stenopterum Peter [1a,1c,7],E
A. theciferum (Kunth.) Mett. [1a,1c,7],E

ATHYRIACEAE Alston
Athyrium schimperi Fee [1a],E

CYATHEACEAE Kaulf.
Cyathea manniana Hook. [1a, 1c, 7], RT

DENNSTAEDTIACEAE Pichi-Serm.
Blotiella glabra (Bory) Tryon [1a, 2, 7], H
Microlepia speluncae (L.) S. Moore [1c,2,7], H
Pteridium aquilinum (L.) Kuhn [1c,2,3], H

LOMARIOPSIDACEAE Alston
Elaphglossum deckenii (Kuhn) C. Chr. [1, 2, 7], E

LOXOGRAMMACEAE Ching
Loxogramme lanceolata (Sw.) Presl. [1,2,7], E

LYCOPODIACEAE Mirbel
Lycopodium clavatum L.[1c,2,7], E

MARATTIACEAE Bercht. & J. Presl
Marattia fraxinea Gmel [1a,1c,7], E

OLEANDRACEAE Pichi-Serm.
Arthropteris monocarpa (Cord.) C. Chr. [1a, 6], E
Oleandra distenta Kunze [1,3].E

POLYPODIACEAE Bercht. & J. Presl
Drynaria volkensii J. Sm [1,2,4b,7], E
Microsorium punctatum (L.) Copel. [1a, 1c, 7], E
M. scolopendrium (Burm. f.) Copel.[1a,1c,6],E
Phymatosorus scolopendria (Burm. F.) Ching[1c],E
Platycerium elephantotis Schweinf. [1, 2, 7], E
Pleopeltis excavata (Willd.) Sledge [1a, 1c, 7], E
P. macrocarpa (Willd.)Kaulf.[1a,1c,3,6,7], E

PTERIDACEAE (Gray) Gaudich
Pteris catoptera Kunze [1, 2, 4, 7], E
P. cretica L. [1,2,4,7], E
P. dentata Forssk. [1,2,4,7], E

SELAGINELLACEAE Milde
Selaginella kraussiana (Kze.) A. Br. [1a, 1c, 2, 6, 7], E

THELYPTERIDACEAE Pichi-Serm.
Cyclosorus dentatus (Forssk.) Ching [1a, 7], H

VITTARIACEAE C. Presl
Vittaria guineensis Desv. [1a,6,7], E

B. **GYMNOSPERMAE**

CUPRESSACEAE Bartling
Juniperus excelsa Bieb.1b, 3, 4b], TT

PODOCARPACEAE Endl.
Afrocarpus falcatus (Thunb) C.N. [1a, 1b, 3], TT

C. ANGIOSPERMAE-DICOTYLEDONAE

ACANTHACEAE Juss.
Acanthus eminens C.B.Cl. [1a, 1c, 4, 8], S
Asystasia schimperi T. Anders [1a,6,7], H
Brillantaisia grotanellii Pichi-Sermoli [1a,1c,8],S
Crossandra massaica Oliv [1c,1d],H
Dicliptera laxata C.B.Cl. [1a,1c, 1f], H
Hypoestes aristata (Vahl) Röm. & Schultes [1a,1b,1f,6],H
H. forskaoli (Vahl) Röm. & Schultes [1a, 1b, 1f, 6], H
H. triflora (Forssk.) Roem & Schult [1a, 1b, 1f, 6], H
H. verticillaris (L. f.) Röm & Schult [1a, 1b, 1f, 6], H
Isoglossa somalensis Lindau [1a-d,1f,7], CW
I. punctata (Vahl) Brummit & J.R.I.Wood [1a, 1c, 1e], CW
Justicia betonica L. [1c,1d], H
J. diclipteroides Lindau [1a-d, 1f, 6], H
J. flava (Forssk.) Vahl [1a-d, 1f, 6, 7], H
J. glabra Roxb. [1a-d, 1f, 6], H
J. heterrocarpa T. Anderson [1a-d, 1f, 6], H
J. schimperiana (Hochst.ex A.Rich.) T.Anders [1a-d,f, 7], S
Mellera lobulata S. Moore [1a-d, 1f, 6], H
Metarungia pubinervia (T. Anders) Baden [1c-d, 2, 3], S
Monothecium glandulosum Hochst [1a-d, 2, 3], H
Rungia grandis T. Anders [1c-d, 3-5], S
Ruspolia seticalyx Lindau [1c-d, 3-5], H
Thunbergia fasciculata Lindau [1c-d, 3-5], C
Whitfieldia elongata (Beauv.)Wild. &T.Dur [1c-d,3-5], S

ALANGIACEAE DC.
Alangium chinense (Lour.) Harms [11c-d, 3-5], ST

AMARANTHACEAE Juss.
Achyranthes aspera L. [1a-d, 1f, 2-5, 7], H
Amaranthus hybridus L. [1f, 2-5, 7], H
Celosia argentea Schinz [1a-d, 1f, 2-5, 7], H
C. schweinfurthiana Schinz [1a-d, 1f, 2-5, 7], H
C. trigyna L. [1a-d, 1f, 2-5, 7], H
Cyathula cylinderica Moq. [1f, 2-5, 7], H
C. uncinulata (Schrad.) Schinz [1f, 2-5, 7], H
Gompherena celosioides Mart. [1f, 2-5, 7], H
Pupalia lappacea (L.) A. Juss [1a-d, 1f, 2-5, 7], C
Sericostachys scandens Gilg & Lopr. [1a-d, 1f, 2-5, 7],C

ANACARDIACEAE Lindl.
Lannea welwitschii (Hiern) Engl. [1c-d], MT
Rhus natalensis Krauss [1-5], S
R. ruspolii Engl [1-5], S
R. quartiniana A. Rich. [1-5], S

ANNONACEAE Juss.
Annona senegalensis Pers. [1c-d], C
Artabotrys monteiroae Oliv. [1c-d, 2-4], C
Asteranthe asterias (S.Moore) Engl. & Diels
Monanthotaxis parvifolia (Oliv.)Verdc
M. ferruginea (Oliv.) Verdc. 1c-d, 2-4], C
Uvaria angolensis Oliv. 1c-d, 2-4], C
U. leptocladon Oliv. 1c-d, 2-4], C
U. schweinfurthii Engl. & Dieles1c-d, 2-4], C
Xylopia parviflora (A. Rich.) Benth1c-d, 2-4], MT

APIACEAE (UMBELLIFERAE Juss.)
Agrocharis incognita (Norman)Heyw.&Jury[1a-c,f, 2-7], H
Cryptotaenia africana (Hook.f.) Drude [1a-c, 1f, 2-7], H
Pimpinella heywoodii Abebe [1a-c, 1f, 2-7], H
Sanicula elata Buch.-Ham. ex D. Don [1a-f], H
Steganotaenia araliacea Hochst ex.A. Rich.[1a-c,1f, 2-7], H

APOCYNACEAE Juss.
Alstonia boonei De Wild. [1c-d], TT
Carissa spinarum L. [1a-f,2-7], C
Landolphia buchananii (Hall.f.) Stapf [1a-f], C
Oncinotis tenuiloba Stapf [1a-f], C
Saba comorensis (Boj.) Pichon [1c-d], C

AQUIFOLIACEAE Bartl.
Ilex mitis (L.) Radlk. [1a-b], MT

ARALIACEAE Juss.
Polyscias fulva (Hiern) Harms [1-5], MT
Schefflera abyssinica Forst. & Forst. f. [1a-b, 8], MT
S. myriantha (Bak.) Drake [1a], C

ASCLEPIDACEAE R. Br.
Ceropegia nilotica Kotschy [1a-d, 1f, 2-5], C
C. sankurensis Schltr. [1a-d, 1f, 2-5], C
C. sobolifera N.E.Br [1a-d, 1f, 2-5], C
Dregea schimperi (Decne.) Bullock [1a-d, 1f], C
Gomphocarpus semilunatus A. Rich. [1a-d, 1f, 2-5], H
G. fruticosus (L.) Ait.f. [1a-d, 1f, 2-5], H
Leptadenia hastata (Pers.) Decne. [1a-d, 1f, 2-5], C
Pentatropis nivalis D.V.Field & J.R.I.Wood [1a-d,1f,2-5], C
Pentarrhinum insipidum E. Mey. [1a-d, 1f, 2-5], C
Periploca linearifolia Quart-Dill. & A. Rich.[1a-d,1f,2-5], C
Secamone parvifolia (Oliv.) Bullock [1a-d, 1f, 2-5], C
S. punctulata Decne [1a-d, 1f, 2-5], C
Tacazzea apiculata Oliv. [1a-d, 1f, 2-5], C
T. conferta N.E.Br. [1a-d, 1f, 2-5], C
Tylophora sylvatica Decne. [1a-d, 1f, 2-5], C

ASTERACEAE L.
Adenostemma mauritianum DC [1a-d, 7], H
Ageratum conyzoides L. [1a-d, 7], H
Aspilia mossambicensis (Oliv.) Wild. [1a-c, 7], S
A. africana (Pers.) Adams [1a-c, 7], S
Bidens pachyloma (Oliv. & Hiern)Cufod. [1a-c, 7], H
B. prestinaria (Sch.Bip.)Fiori. [1a-c, 7], H
Botheriocline fusca Oliv. & Hiern [1a-d, 2-7], S
B. schimperi Oliv. & Hiern ex Benth [1a-d, 2-7], S
Carduus nyassanus (S. Moore) R.E.Fries [1a-d, 2-7], H
Conyza variegata Sch.Bip. ex A. Rich. [1a-b, 2-7], H
C. abyssinica Willd. [1a-b, 2-7], H
Crassocephalum montuosum (S. Moore)Milne-Redh.[1a-b,2,7] H
Dicrocephala integrifolia (L.f.) Kuntze [1a-d, 1f], H
Galinsoga parviflora Cav. [1a-d, 1f], H
Laggera crispata (D. Don) Oliv [1a-d, 1f, 2-7], H
L. pterodonta (DC.) Sch. Bip. ex Oli[1a-d, 1f, 2-7], H
L. tomentosa (Sch.Bip. ex A.Rich.)Oliv. & Hiern [1a-d, 1f, 2-7], H
Microglossa pyrifolia (Lam.) Kuntze (WL) [1a-d, 1f,2-7], C
Solanecio gigas (Vatke) C.Jeffrey [1a-d, 1f, 7], S
Sphaeranthus bullatus Mattf [1a-d, 1f, 2-7], H
Spilanthes costata Benth. [1a-c, 1f, 6-7], H
S. mauritiana Benth. [1a-c, 1f, 6-7], H
Tagetes minuta L. [1a-d, 1f, 2-7], H
Vernonia adoensis Sch. Bip. ex walp [1a-d, 1f, 2-7], S
V. amygdalina Del. [1a-d, 1f, 2-7], S
V. auriculifera Hiern. [1a-d, 1f, 2-7], S
V. biafrae Oliv. & Hiern [1a-d, 1f, 2-7], C
V. hochstetter Sch. Bip. ex walp[1a-d, 1f, 2-7], S
V. leopoldi (Sch. Bip. ex walp) Vatke[1a-d, 1f, 2-7], S
V. wollastonii S. Moore [1a-d, 1f, 2-7], C
BALANOPHORACEAE
Thonningia sanguinea Vahl [1c-d, 8],H

BALSAMINACEAE A. Rich.
Impatiens ethiopica Grey-Wilson [1a-c, 8], H
I. hochstetteri Warb. [1a-c, 8], H
I. rothii Hook.f. [1a-c, 8], H

BASELLACEAE Moq.
Basella alba L. [1a-c], C

BIGNONIACEAE Juss.
Stereospermum kanthianum Cham. [1a-c], ST

BORAGINACEAE Juss.
Cordia africana Lam. [1-7], MT
Cynoglossum coeruleum A.DC [1-7], H
Ehretia cymosa Thonn. [1-7], MT

BRASSICACEAE Burnett
Cardamine africana L. [1-7], H
C. trichocarpa A. Rich. [1-7], H

CACTACEAE Juss.
Rhipsalis baccifera (J. Miller) W.T. Stearn [1a-c,8], E

CAMPANULACEAE Juss.
Canarina abyssinica Engl. [1a-1b], E
C. eminii Schweinf[1a-1b], E

CANELLACEAE Mart.
Warburgia ugandensis Sprague [1a-1b], MT

CANNACEAE Juss.
Canna indica L. [Ia,1c], H

CAPPARIDACEAE Juss.
Capparis erythrocarpos Isert [1b-1c, 2-5], C
C. micrantha A. Rich
C. tomentosa Lam. [1b-1c, 2-5], C
Ritchiea albersii Gilg [11-c], ST

CARYOPHYLLACEAE Juss.
Drymaria cordata (L.) Schultes [1a-b], C
Stellaria mannii Hook.f. [1a-b], C
S. media (L.) Vill. [1a-b], C

CELASTRACEAE R. Br.
Catha edulis (Vahl) Forssk. ex Endl [1a-f], S
Elaeodendron buchananii (Loes) Loes. [1a-c], MT
Hippocratea africana (Willd.) Loes. [1a-c], C
H. goetzei Loes [1a-c], C
H. pallens Planchon. ex Oliver [1c-d], C
H. parvifolia Oliver [1c-d], C
Maytenus arbutifolia (A. Rich.) Wilczek[1a-c, 2-7], S
M. gracilipes (Welw. ex Oliv.) Exell [1a-c, 2-7], S
M. senegalensis (Lam.) Exell [1a-d, 2-7], S
M. undata (Thunb.) Blakelock [1a-b], S
Salacia congolensis De Wild & Th. Dur. [1c-d], C

CHENOPODIACEAE Vent.
Chenopodium procerum Moq. 1a-c, 2-7], H

COMBRETACEAE R. Br.
Combretum aculeatum Vent.[1c-d, 2-5], S
C. capituliflorum Steud. ex A. Rich. .[1c-d, 2-5], S
C. paniculatum Vent. .[1a-c, 2-5], C
Terminalia brownii Fresen. .[1c-d, 2-5], ST

CONVOLVULACEAE Juss.
Ipomoea carica (L.) Sweet [1a-c, 2-7], C
I. hochstetteri House [1a-c, 2-7], C
I. tenuirostris Steud. ex Choisy [1a-c, 2-7], C
Stiotocardia beraviensis (Vatke) Hall. F. [1a-c, 2-7], H

CRASSULACEAE DC.
Crassula alsinoides (Hook.f.) Engl. [1a-c, 2-7], H
C. schimperi Fisch. & Mey. [1a-c, 2-7], H
Kalanchoe densiflora Rolfe [1a-b,2,3,6], H
K. lanceolata (Forssk.)Pers [1a-c, 2-7], H
K. petitiana A. Rich. [1a-b], H

CUCURBITACEAE Juss.
Coccinia schliebenii Harms. [1a-d, 7], C
Cucumis ficifolius A. Rich. [1-8], C
Lagenaria abyssinica (Hook. f.) Jeffrey [1-8],C
Momordica foetida Schumach [1a-f, 7-8], C
Peponium vogelii (Hook.f.)Engl. [1a-f, 7-8], C
Sicyos polycanthus Cogn [1c-d, 4-5], C
Zehneria minutiflora (Cogn.) C. Jeffrey [1-8],C
Z. abyssinica (Hook.f.) Jeffery [1-8],C
Z. scabra (L.f.) Sond. [1-8], C

DILLENIACEAE Salisb.
Tetracera stulmanniana Gilg. [1c-d, 2-4], C

EBENACEAE Gürke
Diospyros abyssinica (Hiern) F. White [1a-e, 2-5], MT
D. mespiliformis Hochst. ex A.DC [1a-e, 2-5], MT
Euclea racemosa Murr. [1c-d, 1f, 2-5], S

ERYTHROXYLACEAE Kunth
Erythroxylum fischeri Engl. [1a-d], ST

EUPHORBIACEAE Juss.
Acalypha acrogyna Pax [1a-d], S
A. frutocosa Forssk. ([1a-d], S
A. ornata A. Rich. [1a-d], S
A. psilostachya Hochst. [1a-d], H
A. racemosa Baill. [1a-d], S
Alchornea laxiflora (Benth.) Pax & Hoffm. [1c-d], S
Argomuellera macrophylla Pax [1c-d], S
Bridelia atroviridis Mull. Arg. [1c-d], ST
B. cathartica Bertol. f. [1c-d, 2-5], ST
B. micrantha (Hochst.)Baill. [1a-d, 2-5], ST
B. scleroneura Mull. Arg. [1a-d, 2-5], ST
Croton macrostachyus Del. [1a-d, 1f, 2-7], MT
Erythrococca abyssinica Pax [1a-c], S
E. trichogyne (Muell. Arg.) Prain.[1a-d], S
Euphorbia ampliphylla Pax [1a-c], ST
E. omariana M. Gilbert [1a-d,6-7], H
E. schimperiana Sheele [1a-d, 6-7], H
Macaranga capensis (Baill.) Sim [1a-f, 4, 7], MT
Margaritaria discoidea (Baill.) Webster [1c-d,], ST
Phyllanthus fischeri Pax [1a-c], H
P. limmunis Cuf. [1a-c], S
P. mooneyi M. Gilbert [1a-c, 2-7], H
P. ovalifolius Forssk. [1a-c,2-7], S
P. sepialis Muell. Arg. [1a-c, 6-7], S
Ricinus communis L. [1a-c, 6-7], H
Sapium ellipticum (Krauss) Pax [1a-c], MT
Suregada procera (Prain) Croizat[1a-b], S
Tragia brevipes Pax[1a-c,2-7], C
T. crenata M. Gilbert[1a-c,2-7], S

FABACEAE Juss.
Acacia abyssinica Hochst. ex Benth [1a-b,6-7], MT
A. brevispica Harms. [1a-d], C
A. montigena Brenan & Exell. [1a-d], C
Aeschynomene elaphroxylon (Guill & Perr) Taub. [1e,8], S
Albizia grandibracteata Taub. [1a-f], MT
A. gummifera (J. F. Gmel.) C.A.Sm. [1a-c], MT
A. schimperiana Oliv. [1a-c], MT
Baphia abyssinica Brummitt [1c-d,], MT
Caesalpinia decapetala (Roth) Alston [1a-c], C
C. volkensii Harms [1a-b, 2-3], C
Calpurna aurea (Ait.) Benth [1a-c, 1f, 2-7], ST
Cassia arereh Del. [1a-c, 6-7], S
Crotalaria axillaris Ait. [1a-c, 6-7], S
C. karagwensis Taub [1a-c, 6-7], S
C. keniensis Bak.f. [1a-c], S
Dalbergia lactea Vatke [1a-d, 1f, 2-7], C
Desmodium hirtum Guill. & Perr [1a-c, 6-7], H
D. repandum (Vahl)DC [1a-c, 6-7], H
Dolichos sericeus E. Mey. [1a-c], C
Entada abyssinica Steud. ex A.Rich. [1a-d, 1f, 2-7], ST
Erythrina abyssinica Lam. ex DC [1a-c, 6-7], ST
E. brucei Schweinf. [1a-c, 6-7], ST
Lablab purpureus (L.)Sweet [1a-c, 6-7], C
Lotus discolor E. Mey [1a-c, 6-7], H
*Millettia ferrug*inea (Hochst.) Bak. [1a-c, 7], ST

Mimosa pigra L. [1c-d, 1f, 6-7], H
Pterolobium stellatum (Forssk.) Brenan [1-8], C
Senna occidentalis (L.) Link [1a-c, 2-7], S
S. petersiana (Bolle) Lock [1a-c, 2-7], S
Sesbania dummeri Phil. & Hutch.[1a-f, 7-8], S
Trifolium rueppellianum Fres [1a-c, 6-8], H

FLACOURTIACEAE DC.
Flacourtia indica (Burm.f.) Merr. [1a-c, 1f, 6-7], ST
Oncoba routledgei Sprague [1a-c, 6-7], ST

GERANIACEAE Juss.
Geranium aculeolatum Oliv. [1a-c, 1f, 6-8], H
G. arabicum Forssk. [1a-c, 1f, 6-8], H

GUTTIFERAE Juss.
Garcinia buchananii Baker [1c-d, 2-3], ST
G. livingstonei T. Anders. [1c-d, 2-3], ST
G. ovalifolia Oliver[1c-d, 2-3], ST
Hypericum peplidifolium A. Rich. [1a-c, 6-7], H
H. revolutum Vahl [1a-c, 6-7], ST

HAMAMELIDACEAE R. Br.
Trichocladus ellipticus Eckl. & Zeyh. [1c-d, 2-5], S

ICACINACEAE Miers
Apodytes dimidiata E. Mey. ex Arn. [1a-b], MT
Raphiostylis beninensis (Planch.) Benth [1c-d], C
Pyrenacantha sylvestris S. Moore [1c-d], C

LABIATAE Juss.(LAMIACEAE)
Ajuga bracteosa Wall. ex Benth. [1a-b], H
A. alba (Gurke) Robyns [1a-b], H
Achyrospermum schimperi (Hochst.exBriq)Perkins[1a-d], H
A. parviflorum S. Moore ([1a-b], H
Leucas urticifolia (Vahl)Sm. [1a-b], H
Nepeta azurea R. Br. ex Benth [1a-b], H
Ocimum urticifolium Roth [1a-c], S
O. lamiifolium Hochst. ex Benth. [1a-b], S
Plectranthus punctatus (L.F.) L´H´er [1a-b, 1f,7], H
P. sylvestris Gurke [1a-c, 1f,6-7] , H
P. laxiflorus Benth. [1a-c, 1f, 6-7], H
Satureja simensis (Benth.) Briq. [1a-b, 6-7], H
S. paradoxa (Vatke) Engl. ex Seybold [1a-b, 6-7], H
Salvia nilotica Jacq. [1a-b, 6-7], H
Stachys aculeolata Hook.f. [1a-b, 6-7], C

LAURACEAE Juss.
Ocotea kenyensis (Chiov.) Robyns & Wilczek [1a-b], MT
Cassytha filiformis L. [1a-c], H

LOBELIACEAE R. Br.
Lobelia giberroa Hemsl. [1a-b, 1f, 8], S
Monopsis stellorioides (Presl) Urban [1a-b, 1f, 6-8], H

LOGANIACEAE Mart.
Anthocleista schweinfurthii Gilg [1c-d, 1f], MT
Buddleja polystachya Fresen. [1a-b, 6-7], S
Nuxia congesta R. Br. ex Fresen [1a-b, 2-4], ST
Strychnos henningsii Gilg [1c-d], ST
S. innocua Del. [1c-d], ST
S. mitis S. Moore [1a, 1c-d], MT H

MALVACEAE Juss.
Abutilon cecilii N.E.Br. [1a-c, 2-5], H
A. longicuspe Hochst. ex Garcke [1a-c, 2-5], S
Hibiscus calyphyllus Cavan. [1a-c, 2-5], H
H. diversifolius A. Rich. [1a-c, 2-5], S
H. ludwigii Eckl. & Zeyh [1a-c, 2-5], 5
Pavonia urens Cav. [1a-c, 2-5], H
Sida acuta Burm.f. [1a-c, 2-5], H
S. collina Schlechtend. [1a-c, 2-5], S
S. ovata Forssk. [1a-c, 2-5], S
S. rhombifolia L. [1a-c, 2-5], S
S. ternata L. [1a-c, 2-5], S
Wissadula rostrata (Schumach &Thonn.)Ho.f.[1a-c, 2-5], H

MELASTOMATACEAE Juss.
Dissotis decumbens (P. Beauv.) Triana [1a-b, 2-8], H
Tristemma mauritianum J.F.Gmel. [1a-c, 2-8], H

MELIACEAE Juss.
Ekebergia capensis Sparrm. [1a-c], MT
Lepidotrichilia volkensii (Gurke) Leroy [1a-c],ST
Pseudocedrela kotschyi (Schweinf.) Harms [1c-d], ST
Trichilia dregeana Sond. [1a, 1c-d], MT
T. emetica Vahl. [1c-d], MT
T. prieuriana A. Juss. [1c-d, 2], MT
Turraea holstii Gurke [1a-1c], ST

MELIANTHACEAE Link
Bersama abyssinica Fresen [1a-c, 1f, 2-7], ST

MENISPERMACEAE Juss.
Cissampelos pareira L. [1a-c], C
C.owariensis Beauv. Ex DC. [1a-d], C
Tiliacora funifera Oliv. [1c-d], C
T. troupinii Cufod. [1a-c], C

Tinospora caffra (Miers) Troupin [1a-c], C
Stephania abyssinica (Dillon & A. Rich.)Walp.[1a-c,2-7], C
S. cyanantha Welw. ex Hiern [1a-c, 2-5], C

MORACEAE Link
*Antiaris toxica*ria Lesch [1c-d], TT
Dorstenia soerensenii Friis [1a-c, 1e, 8], H
D. barnimiana Schweinf. [1a-c, 1e, 8], H
Ficus asperifolia Miq. [1c-d, 2-6], ST
F.capreaefolia Del [1c-d, 2-6], ST
F. exasperata Vahl. [1c-d, 2-6], ST
F. lutea Vahl [1a, 1c-e, 2-6], ST
F. mucuso Ficalho [1c-e, 2-6], MT
F. ovata Vahl [1a, 1c-d, 2-6], ST
F. palmata Forssk. [1a, 1c-d, 2-6], ST
F. sur Forssk. [1a-e, 2-6], MT
F. sycomorus L. [1a-e, 2-6], MT
F. thonningii Blume [1a-f, 2-6], ST
F. umbellata Vahl [1a-e, 2-6], ST
F. vallis-choudae Del. [1a-e, 2-6], ST
F. vasta Forssk. [1a-e, 2-6], MT
Milicia excelsa (Welw.) C. C. Berg [1c-d], TT
Morus mesozygia Stapf [1c-d], MT
Trilepisium madagascariense DC. [1c-d], MT

MYRSINACEAE R. Br.
Embelia schimperi Vatke [1a-c, 2-6], C
Maesa lanceolata Forssk. [1a-f, 2-6], ST
Myrsine africana L. [1a-b, 2-6], S

MYRTACEAE Juss.
Eugenia bukobensis Engl. [1c-d], ST
Syzygium guineense ssp. afromontanum F.White [1a-c], MT
S. guineense ssp. guineense (Willd.)DC [1a-c], MT
S. guineense ssp. macrocarpum F. White [1c-d, 2-6], ST

NYCTAGINACEAE Juss.
Pisonia aculeata L. [1c-d], C

OLEACEAE Hoffsgg. & Link
Jasminum dichotomum Vahl [1c-d, 2-5], C
J. abyssinicum Hochst. ex Dc [1a-b], C
Olea europaea L. ssp. cuspidata (Wall. ex G. Don) Cif. L'Olivicoltore [1a-b, 3-6], ST
O. capensis L.ssp. macrocarpa (C.H.Wright)Verdc.[1a], MT
O. welwitschii (Knobl.) Gilg & Schellenb. [1a-c], TT
Chionanthus mildbraedii (Gilg&Schellenb.) Stearn [1a-c], S
Schrebera alata (Hochst.) Welw. [1a-c, 2-5], ST

OLINIACEAE Sond.
Olinia rochetiana A. Juss. [1a-b], ST

OPILIACEAE Valeton
Opilia amentacea Roxb. [1c-d], C

OXALIDACEAE R. Br.
Oxalis corniculata L. [1a-c, 7], H
O. radicosa A. Rich. [1a-c, 7], H
O. procumbens Steud. ex A. Rich. [1a-c, 7], H

PASSIFLORACEAE Kunth
Adenia rumicifolia Engl. [1a-b], C
Passiflora edulis Sims [1a-b], C

PHYTOLACCACEAE R. Br.
Hilleria latifolia (Lam.) H. Walter [1c-d], H
Phytolacca dodecandra L´Herit. [1a-c,3-7], C

PIPERACEAE J. Agardh
Piper capense L.f. [1a, 1c-f], H
P. guineense Schum. & Thonn. [1a, 1c-f], C
P. umbellatum L. [1a, 1c-f, 8], H
Peperomia abyssinica Miq. [1a-e, 8], H
P. fernandopoiana C. DC. [1a-e, 8], H
P. molleri C. DC. [1a-e, 8], H
P. retusa (L.f.) A.Dietr. [1a-e, 8], H
P. rotundifolia (L.) Kunth [1a-e, 8], H
P. tetraphylla (Forster) Hook & Arn. [1a-e, 8], H

PITTOSPORACEAE R. Br.
Pittosporum viridiflorum Sims [1a-c. 2-5], ST

PLUMBAGINACEAE Juss.
Plumbago zeylanica L. [1a-d], C

POLYGONACEAE Juss.
Rumex abyssinicus Jacq. [1a-b, 3-4], S
Persicaria decipiens (R. Br.) K.L. Wilson [1a-b, 7-8], H
P. nepalensis (Meisn.)Miyabe [1a-b, 7-8], H
P. senegalensis (Meisn.) Sojak [1a-b, 7-8], H

PRIMULACEAE Vent.
Ardisiandra sibthorpioides Hook. F. [1a-c,8], H

RANUNCULACEAE Juss.
Clematis longicauda Steud. ex A. Rich. [1a-c], C
C. hirsuta Perr. & Guill. [1a-c], C
C. simensis Fresen. [1a-c], C

Thalictrum rhynchocarpum Dill. & A. Rich. [1a-c], H
Ranunculus multifidus Forssk. [1a-c], H

RHAMNACEAE Juss.
Gouania longispicata Engl. [1a-c],C
Helinus mystacinus (Ait.) E. Mey.ex Steud. [1a-c], C
Rhamnus prinoides L´Herit. [1a-c], C
R. staddo A. Rich. [1a-b], S
Sagetia thea (Osbeck) M.C.Johnston [1a-c], C
Scutia myrtina (Burm.f.) Kurz [1a-c],C
Ventilago diffusa (G.Don) Exell [1c-d],C

RHIZOPHORACEAE R. Br.
Cassipourea malosana (Baker) Alston [1a-b],MT

ROSACEAE Juss.
Alchemilla fischeri Engl. [1a-c],H
A. ellenbeckii Engl. [1a-c], H
*Hagenia abyssinic*a (Bruce) J.F.Gmel. [1a-b], ST
Prunus africana (Hook.f.) Kalkm. [1a-c], TT
Rosa abyssinica Lindley [1a-b, 2-6], S
Rubus apetalus Poir. [1a-c, 7], C
R. rosifolius Sm. [1a-b,7], C
R. steudneri Schweinf. [1a-c, 7], C

RUBIACEAE Juss.
Breonadia salicina (Vahl) Hepper & Wood [1d-e],MT
Canthium oligocarpum Hiern [1a-c], ST
Coffea arabica L. [1a,1c], ST
Craterispermum schweinfurthii Hiern [1c-d], S
Crossopteryx febrifuga (Hochst.) Bridson [1c-d, 2-5], ST
Hallea rubrostipulata (K. Schum.) J.F.Leroy [1c-d, 2-5], ST
Hymenodictyon floribundum (Hochst. & Steud.) Robinson [1c-d, 2-5], ST
Galiniera saxifraga (Hochst.) Bridson [1a-d], ST
Gardenia ternifolia Schumach. & Thonn. [1c-d], ST
Geophila repens (L.)J. M. Johnston [1a-c, 8], H
Keetia gueinzii (Sond.) Bridson [1c-d], C
K. zanzibarica (Klozsch) Bridson [1c-d], C
Mussaenda arcuata Poir. [1c-d, 2-5], C
Oxyanthus speciosus ssp. globosus DC [1a-e], ST
O. speciosus ssp. stenocarpus DC. [1c-d], ST
Pavetta oliveriana Hiern [1c-d], S
P. abyyssinica Fresen. [1a-c], S
*Pentas schim*periana (A. Rich.) vatke [1a-c], H
P. lanceolata (Forssk.) Defl. [1a-c], H
Polysphaeria parvifolia Hiern [1c-d], S
Psychotria orophila Petit [1a-c], S
P. peduncularis (Salisb.) Steyerm [1c-e], H
Psydrax parviflora (Afz.) Bridson [1a, 1c], ST
P. schimperiana Spermacoce L. [1a, 1c], ST
Rothmannia urceliformis (Hiern) Robyns [1a, 1c-d], ST
Rubia cordifolia L. [1a-d], H
Rytigynia neglecta (Hiern) Robyns [1a-1c], S
Sarcocephalus latifolius (Smith) Bruce [1a-c], ST
Spermacoce mauritiana Gideon [1a-d], S
Uncaria africana G. Don [1c-d], C
Vangueria apiculata K. Schum. [1a,1c],ST
Wendlandia arabica Defl. [1c-d], S

RUTACEAE Juss.   .
Citrus aurantium L. [1a-b], S
Clausena anisata (Willd.) Benth. [1a-c], ST
Fagaropsis angolensis (Engl.) Milne [1a-c],MT
Teclea nobilis Del. [1a-c], ST
T. simplicifolia (Engl.) Verdoon [1a-c],ST
Toddalia asiatica (L.) Lam. [1a-c], C
Vepris dainellii (Pichi-Serm.) Kokwaro [1a-c],ST
Vepris sp. [1c-d],ST
Zanthoxylum leprieurii Guill. & Perr. [1c-d],ST

SAPINDACEAE Juss.
Allophylus abyssinicus (Hochst.) Radlkofer [1a-c], ST
A. macrobotrys Gilg [1a-c], S
Blighia unijugata Bak. [1c-d],MT
Cardiospermum halicacabun L. [1c-d],C
Deinbollia kilimandscharica Taub [1a-c], ST
Dodonaea angustifolia L.f. [1a-b],ST
Filicium decipiens (Wight & Am.) Thw. [1a, 1c], MT
Lecaniodiscus fraxinifolius Bak. [1c-d],MT
Lepisanthes senegalensis (Juss. ex Poir.) Leenh. [1c-d],ST
Pappea capensis Eckl. & Zeyh. [1c-d],ST
Paullinia pinnata L. [1a-d],C
Zanha golungensis Hiern [1c-d],MT

SAPOTACEAE Juss.
Manilkara butugi Chiov. [1c-d], TT
Mimusops kummel A. DC. [11a, c-d], MT
Pouteria adolfi-friederici (Engl.) Baehni[1a, 1c-d], TT
P. alnifolia (Bak.) Roberty[1c-d], MT
P. altissima (A.Chev.) Baehni[1c-d], TT

SCROPHULARIACEAE Juss.
Halleria lucida L. [1a-b], S
Veronica abyssinica Fresen [1a-b], H

SIMAROUBACEAE DC.
Brucea antidysenterica J.F.Mill. [1a-d], ST

SOLANACEAE Juss.
Capsicum frutescens L. [1c-d], H
Datura stramonium L [1a-c], H
Discopodium penninervium Hochst. [1a-c], H
Physalis peruviana L. [1a-c], H
Solanum benderianum L [1c-d], C
S. giganteum L. [1a-c], S
S. incanum L [1a-c], S
S. indicum L. [1a-c], S
S. nigrum [1a-c], H

STERCULIACEAE Bartling
Dombeya torrida (J.F.Gmel.) P. Bamps [1a-c], ST

TACCACEAE L.
Tacca leontopetaloides (L.) O. Ktze. [1c-d], H

TILIACEAE Juss.
Grewia ferruginea Hochst. Ex A. Rich. [1a-c], S
G. Mollis A. Juss. [1a-c], S
Triumfetta rhomboidea Jacq. [1a-c], S

ULMACEAE Mirbel
Celtis africana Burm.f. [1a-f], MT
C. gomphophylla Bak. [11a, 1c-d], MT
C. philippensis Blanco [1c-d], MT
C. toka (Forssk.) Hepper & Wood [1c-d], MT
C. zenkeri Engl [1c-d], MT
Trema orientalis (L.) Bl. [1a-d], ST

URTICACEAE Juss.
Boehmeria macrophylla Homemann [1a-d], H
Droguetia iners (Forssk.) Schweinf. [1a-c], H
Elatostema monticolum Hook.f. [1a-b], H
Girardinia diversifolia (Link) Friis [1a-b], H
*Pilea tetrap*hylla 8Steudel) Blume [1a-c], H
P. rivularis Wedd.H [1a-c], H
P. bambuseti Engl. [1a-b], H
Urera hypselodendron (A. Rich.) Wedd. [1a-b],C
U. trinervis (Hochst.) Friis & Immelman [1c-d], C
Urtica simensis Steudel [1a-b], H

VERBENACEAE J.St. Hil.
Clerodendrum alatum L. [1a-b], S
C. myricoides (Hochst.) Vatke [1a-b], S
Premna schimperi Engl. [1a-b], S

VIOLACEAE Batsch
Rinorea friisii M.Gilbert [1c-d], ST
R. ilicifolia (Oliv.)Kuntze [1c-d], S

VITACEAE Juss.
Ampelocissus abyssinica (Hochst.exA.Rich.)Planch[1a-c], C
Cayratia gracilis (Guill. & Perr.) Suesseng. [1a-c], C
Cissus arguta Hook.f. [1a, 1c-d], C
C. petiolata Hook.f. [1a, 1c-d], C
C. quadrangulanis L. [1a, 1c-d], C
C. rotundifolia (Forssk.) Vahl [1a, 1c-d], C
Cyphostemma adenocaule (Steud. ex A. Rich.) Descoings ex Wild & Drummond [1a, 1c-d], C
C. kilimandscharica (Gilg) Descoings ex Wild & Drummond [1a, 1c-d], C
Rhoicissius tridentata (L.f.)Wild & Drummond [1a, 1c-d], C

D.ANGIOSPERMAE-MONOCOTYLEDONAE

AMARYLLIDACEAE J. St. Hil.
Scadoxus multiflorus (Martyn) Raf. [1a-c], H
S. nutans (Friis & I. Bjørnstad) Friis & Nordal [1a-c], E
S. puniceus (L.) Friis & Nordal [1a-c], H

ANTHERICAEAE J. Agardh
Chlorophytum comosum (Thunb.)Jacq. [1a-c], H
C. gallabatense Schweinf. ex Baker [1a-c], H
C. macrophyllum (A. Rich.) Aschers [1a-c], H

ARACEAE Juss.
Culcasia falcifolia Engl. [1a,1c-d], C
Arisaema schimperannum Schott [1a-c,8], H
A. flavum (Forssk.) Schott [1a-c, 8], H
Amorphophallus abyssinicus (A. Rich.) N.E. Br. [1a-b, 8], H
A. gallaensis (Engl.) N.E. Br [1a-b, 8], H

ARECACEAE Juss
P*hoenix reclinata* Jacq. [1a-d, 2-5], RT

ASPARAGACEAE Juss.
Asparagus africanus Lam. [1a-d], C
A. racemosus Willd. [1a-d], C
A. officinalis L. [1a-d], C

COLCHICACEAE DC:
Gloriosa superba L. [1a-b], H

COMMELINACEAE R. Br.
Aneilema beniniense (P. Beauv.) Kunth [1a-c], H
Commelina cemosa Chiov. [1a,1c-d], H

C. foliacea Chiov. [1a, 1c-d], H
C. latifolia Hochst. ex A. Rich. [1a,1c-d], H
C. peterisii Hassk. [1a-d], H
C. diffusa Burm.f. [1a-d], H
Pollia condensata C. B. Clarke[1c-d], H
P. mannii C. B. Clarke [1c-d], H

COSTACEAE (K. Schum.) Nak.
Costus afer Ker-Gawl [1c-d], H
C. lucanusianus J. Braun & K. Schum [1c-d], H

CYPERACEAE Juss.
Carex echinochloe Kunze [1a-b], G
Coleochloa abyssinica (Hochst. ex A.Rich.)Gilly [1a], G
Cyperus esculentus L. [1a-b], G
C. fischerianus A. Rich. [1a-c], G
C. aterrimus A. Rich. [1a-c], G
C. longibracteatus (Cherm.) Kuk [1a-c], G
C. plateilma (Steud.) Kuk [1a-c], G

DIOSCOREACEAE R. Br.
Dioscorea bulbifera L. [1c-d], C
D. praehensilis Benth. [1c-d], C
D. sagittifolia Pax[1c-d], C
D. schimperiana Kunth [1c-d, 2-3], C

DRACAENACEAE Salisb.
*Dracaena afromont*ana Mildbr. [1a-b], RT
D. fragrans (L.) Ker-Gawl [1a-c], RT
D. steudneri Engler [1a-b, 8], RT

POACEAE Juss. (GRAMINEAE)
Arundo donax L. [1a-c], S
Digitaria abyssinica (Hochst. Ex A. Rich.) Stapf. [1a-c], G
Hyparrhenia cymbaria (L.) Stapf [1a-c], G
Leptaspis zeylanica Nees ex Steud. [1c-d], G
Olyra latifolia L. [1c-d], G
Oplismenus compositus (L.) P. Beauv. [1a-c], G
O. hirtellus (L.) P. Beauv. [1a-c], G
O. undulatifolius (Ard.) Roem. & Schult. [1a-c], G
Panicum calvum Stapf [1a-c, 2-6], G
P. repens L. [1a-c,2-6], G
P. ruspolii Chiov. [1a-c,2-6], G
P. hochstetteri Steud. [1a-c, 2-6], G
P. monticola Hook.f. [1a-c, 2-6], G
P. maximum Jacq. [1a-b, 2-6], G
P. porphyrrhizos Steud. [1a-b, 2-6], G
*Pseudechinolaena polystachy*a *(*Kunth) Stapf. [1a-b, 2-6], G
Poecilostachys oplismenoides(Hack.)W.D.Clayt[1ab,2-6], G
Acritochaete volkensii Pilg. [1a-c, 2-6], G
Pennisetum clandestinum Chiov. [1a-c, 2-6], G
P. ramosum (Hochst.) Schweinf [1a-c, 2-6], G
Poa leptoclada Hochst. ex A. Rich. [1a-c, 2-6], G
Setaria atrata Hack. [1a-c, 2-6], G
S. megaphylla (Steud.)Th. Dur. [1a-c, 2-6], G
S. sphacelata (Schumach.) Moss [1a-c, 2-6], G

HYACINTHACEAE Lindl.
Drimiopsis ?botryoides Baker. [1c-d,5],H

MARANTACEAE Petersen
Marantochloa leucantha (K. schum.) Milne-Redh. [1c-d], H
M. mannii (Bentham) Milne-Redh. [1c-d], H

MUSACEAE Juss.
Ensete ventricosum (Welw.) Cheesman [1a-c], RT

ORCHIDACEAE Juss.
Aerangis brachyarpa (A. Rich.) Th.Dur.& Schinz [1a-c], E
A.luteoalba (Kraenzl.)Schltr.var.rhodostica (Kraenzl.) J.Stewart [1a-c], E
A. thomsonii (Rolfe) Schltr [1a-c], E
Ancistrorhynchus metteniae (Kraenzl.) Summerh [1a-c], E
Angraecum minus Summerh [1a-c], E
Bulbophyllum intertextum Lindl. [1a-b], E
B. josephii (Kuntze) Summerh. [1a-c], E
B. lupulinum Lindl. [1a-c], E
B. scaberulum (Rolfe) Bolus [1a-c], E
Corymborkis corymbis Thouars [1c-d], H
Diaphananthe adoxa F. Rasm [1a-b], E
D.?fragrantissima (Rchb. f.)Schltr. [1a-b], E
D. tenuicalcar Summerh. [1a-b], E
Eulophia guineensis Lindl. [1c-d], H
Graphorkis lurida (Sw.) Kuntze [1c-d], H
Habenaria cornuta Lindl. [1a-c], H
H. humilior Rchb.f. [1a-c], H
H. malacophylla A.Rich. [1a-c], H
H. peristyloides A. Rich. [1a-c], H
H. schimperiana A. Rich. [1a-c], H
Liparis abyssinica A. Rich. [1a-b], H
L. deistelii Schltr. [1a-b], H
Malaxis weberbaueriana (Kraenzl.) Summerh [1a-b], H
Microcoelia globulosa (Hochst.) L. Johsson. [1a-c], H
Nervilia bicarinata (Bl.)Schltr. [1a-c], H
Oeceoclades ugande (Rolfe) Garay & Taylor[1a-b], H
Polystachya bennettiana Rchb. f. [1a-c], E
P. caduca Rchb.f [1a-c], E
P. cultriformis (Thouars)Spreng. [1a-c], E

P. lindblomii Schltr. [1a-c], E

P. paniculata (Sw.) Rolfe [1a-c], E

P. rivae Schweinf. [1a-c], E

P. tessellata Lindl. [1a-c], E

Satyrium schimperi A.rich. [1a-b], H

Stanfieldiella imperforata (C.B.Clarke)Brenan [1a-c], E

Stolzia repens (Rolfe) Summerh [1a-c], E

Tridactyle bicaudata (Lindl.) Schltr.

T. filifolia (Schltr.) Schltr [1c-d], E

Vanilla imperialis Kränzl. [1c], C

SMILACACEAE Vent.

Smilax anceps Willd. [´1c-d], C

S. aspera L. [1c-d], C

ZINGIBERACEAE Lindl.

Aframomum corrorima (Braun) Jansen [1a-c], H

A. zambesiacum (Baker) K. Schum.[1c-d], H

Curcuma domestica Valeton [1c], H

Zingiber officinale Roscoe [1c], H

Appendix 2. Distribution of 155 trees and shrubs in the Afromontane rainforests of Ethiopia. BO = Bonga; HA = Harenna; BK = Berhane-Kontir; YA = Yayu; MA = Maji; AFM = Afromontane species; GC-Guineo-Congolian flora element; lin = Linking species

Species	Family	Distribution type	BO	HA	BK	YA	MA
Alangium chinense	Alangiaceae	lin	+	+			
Albizia grandibracteata	Fabaceae	AFM	+		+	+	
Albizia gummifera	Fabaceae	AFM	+		+	+	
Albizia schimperiana	Fabaceae	AFM	+		+	+	
Alchornea laxiflora	Euphorbiaceae	lin			+		
Allophylus macrobotrys	Sapindaceae	lin			+		+
Allophylus abyssinicus	Sapindaceae	AFM	+	+		+	
Alstonia boonei	Apocynaceae	GC			+		
Anthocleista schweinfurthii	Loganiaceae	GC			+	+	
Antiaris toxicaria	Moraceae	lin			+	+	
Apodytes dimidiata	Icacinaceae	AFM	+	+	+	+	+
Argomuellera macrophylla	Euphorbiaceae	GC			+	+	+
Baphia abyssinica	Fabaceae	GC			+	+	
Bersama abyssinica	Melianthaceae	AFM	+	+		+	+
Blighia unijugata	Sapindaceae	lin			+	+	+
Breonadia salicina	Rubiaceae	lin		+		+	
Bridelia atroviridis	Euphorbiaceae	GC			+	+	
Bridelia cathartica	Euphorbiaceae	GC			+		
Bridelia micrantha	Euphorbiaceae	lin	+		+	+	
Bridelia scleroneura	Euphorbiaceae	lin			+		
Brucea antidysenterica	Simaroubaceae	AFM	+	+	+	+	+
Buddlea polystachya	Loganiaceae	AFM	+	+			
Calpurnia aurea	Fabaceae	AFM	+	+	+	+	+
Canthium oligocarpum	Rubiaceae	AFM	+	+	+	+	+
Capparis erythrocarpos	Capparidaceae	GC			+	+	
Cassipourea malosana	Rhizophoraceae	AFM	+	+	+	+	+
Celtis gomphophylla	Ulmaceae	lin	+	+	+	+	+
Celtis philippensis	Ulmaceae	lin			+	+	
Celtis toka	Ulmaceae	GC			+	+	
Celtis zenkeri	Ulmaceae	lin			+	+	
Celtis africana	Ulmaceae	lin	+	+	+	+	+
Chionanthus mildbraedii	Oleaceae	lin	+	+	+	+	+
Clausena anisata	Rutaceae	lin	+	+	+	+	+
Coffea arabica	Rubiaceae	AFM	+	+	+	+	+
Cordia africana	Boraginaceae	lin	+	+	+	+	+
Craterispermum schweinfurthii	Rubiaceae	lin			+		

Appendix 2. Continued

Species	Family	Distribution type	BO	HA	BK	YA	MA
Crossopteryx febrifuga	Rubiaceae	lin			+	+	
Croton macrostachyus	Euphorbiaceae	lin	+	+	+	+	+
Cyathea manniana	Cyatheaceae	AFM	+	+	+	+	+
Dalbergia lactea	Fabaceae	AFM	+	+	+	+	+
Deinbollia kilimandscharica	Sapindaceae	AFM	+	+	+	+	+
Diospyros abyssinica	Ebenaceae	lin	+	+	+	+	+
Diospyros mespiliformis	Ebenaceae	lin	+	+	+		
Dodonea angustifolia	Sapindaceae	lin	+	+			
Dombeya torrida	Sterculiaceae	AFM			+		
Dracaena afromontana	Dracaenaceae	AFM	+	+		+	
Dracaena fragrans	Dracaenaceae	lin	+	+	+	+	+
Dracaena steudneri	Dracaenaceae	AFM	+	+	+	+	+
Ehretia cymosa	Boraginaceae	lin	+	+	+	+	+
Ekebergia capensis	Meliaceae	AFM	+	+	+	+	+
Elaeodendron buchananii	Celastraceae	AFM	+	+	+	+	+
Erythroxylum fischeri	Erythroxylaceae	lin			+		
Euclea racemosa	Ebenaceae	lin					+
Eugenia bukobensis	Myrtaceae	lin			+	+	
Euphorbia ampliphylla	Euphorbiaceae	AFM	+		+		
Fagaropsis angolensis	Rutaceae	AFM	+	+	+	+	+
Ficus asperifolia	Moraceae	GC			+		
Ficus exasperata	Moraceae	lin			+	+	+
Ficus lutea	Moraceae	lin			+	+	
Ficus mucuso	Moraceae	GC			+	+	
Ficus ovata	Moraceae	lin	+		+		
Ficus palmata	Moraceae	lin			+		
Ficus sur	Moraceae	lin	+	+	+	+	+
Ficus sycomorus	Moraceae	lin		+	+		
Ficus thonningii	Moraceae	lin	+	+	+	+	+
Ficus umbellata	Moraceae	GC			+		
Ficus vallis-choudae	Moraceae	lin			+	+	
Ficus vasta	Moraceae	lin			+	+	
Filicium decipiens	Sapindaceae	lin		+			
Flacourtia indica	Flacourtiaceae	lin	+	+	+	+	+
Galiniera saxifraga	Rubiaceae	AFM	+	+	+	+	+
Garcinia buchananii	Guttiferae	lin			+		
Garcinia livingstonei	Guttiferae	lin			+		
Garcinia ovalifolia	Guttiferae	GC			+	+	
Hagenia abyssinica	Rosaceae	AFM		+			
Hallea rubrostipulata	Rubiaceae	lin			+		
Halleria lucida	Scrophulariaceae	AFM		+			

Appendix 2. Continued

Species	Family	Distribution type	BO	HA	BK	YA	MA
Hymenodictyon floribundum	Rubiaceae	lin			+		
Hypericum revolutum	Guttiferae	AFM	+	+			
Ilex mitis	Aquifoliaceae	AFM	+				
Juniperus excelsa	Cupressaceae	AFM		+			
Lannea welwitschii	Anacardiaceae	Lin			+		
Lecaniodiscus. fraxinifolius	Sapindaceae	Lin			+		
Lepidotrichilia volkensii	Meliaceae	AFM	+	+	+	+	+
Lepisanthes senegalensis	Sapindaceae	Lin			+		
Macaranga capensis	Euphorbiaceae	lin	+	+	+	+	+
Maesa lanceolata	Myrsinaceae	lin	+	+	+	+	+
Manilkara butugi	Sapotaceae	AFM			+	+	+
Margaritaria discoidea	Euphorbiaceae	lin		+			
Maytenus arbutifolia	Celastraceae	AFM	+	+		+	
Maytenus gracilipes	Celastraceae	AFM	+		+	+	
Maytenus senegalensis	Celastraceae	lin	+	+			
Maytenus undata	Celastraceae	lin		+			
Milicia excelsa	Moraceae	lin			+	+	
Millettia ferruginea	Fabaceae	AFM	+	+	+	+	+
Mimusops kummel	Sapotaceae	lin		+	+	+	+
Morus mesozygia	Moraceae	lin			+	+	
Myrsine africana	Myrsinaceae	AFM		+			
Nuxia congesta	Loganiaceae	AFM	+	+			
Ocotea kenyensis	Luraceae	AFM	+	+			
Olea capensis L. ssp. macrocarpa	Oleaceae	AFM		+			
Olea welwitschii	Oleaceae	AFM	+	+	+	+	+
Olinia rochetiana	Oliniaceae	AFM		+			
Oncoba routledgei	Flacourtaiceae	AFM		+			
Oxyanthus speciosus	Rubiaceae	AFM	+	+	+	+	+
Pappea capensis	Sapindaceae	lin			+		
Phoenix reclinata	Arecaceae	lin	+			+	
Pittosporum viridiflorum	Pittosporaceae	lin	+	+	+	+	+
Podocarpus falcatus	Podocarpaceae	AFM	+	+			
Polyscia fulva	Araliaceae	AFM	+	+	+	+	+
Pouteria adolfi-friederici	Sapotaceae	AFM	+	+	+		
Pouteria alnifolia	Sapotaceae	lin			+		
Pouteria altissima	Sapotaceae	GC			+	+	+
Prunus africana	Rosaceae	AFM	+	+	+	+	+
Pseudocdrela kotschyi	Meliaceae	GC			+		
Psychotria orophila	Rubiaceae	AFM	+	+	+	+	+
Psydrax parviflora	Rubiaceae	lin			+	+	
Psydrax schimperiana	Rubiaceae	lin		+			

Appendix 2. Continued

Species	Family	Distribution type	BO	HA	BK	YA	MA
Rinorea friisii	Violaceae	GC			+		
Rinorea ilicifolia	Violaceae	AFM			+		
Ritchiea albersii	Cappardiaceae	AFM	+	+	+	+	+
Rothmannia urceliformis	Rubiaceae	lin	+	+	+	+	+
Rytigynia neglecta	Rubiaceae	AFM	+	+	+	+	+
Salacia congolensis	Celastraceae	GC			+	+	
Sapium ellipticum	Euphorbiaceae	lin	+		+	+	+
Schefflera abyssinica	Araliaceae	AFM	+	+			
Schefflera myriantha	Araliaceae	AFM	+				
Schrebera alata	Oleaceae	AFM	+	+			
Senna petersiana	Fabaceae	AFM			+		
Solanecio gigas	Asteraceae	AFM	+	+	+		
Strychnos henningsii	Loganiaceae	GC			+		
Strychnos innocua	Loganiaceae	GC			+		
Strychnos mitis	Loganiaceae	lin		+	+		
Suregada procera	Euphorbiaceae	lin		+			
Syzygium guineense ssp. afromontanum	Myrtaceae	AFM	+	+			
Syzygium guineense ssp. guineense	Myrtaceae	lin	+	+			
Syzygium guineense ssp. macrocarpum	Myrtaceae	lin	+	+			
Teclea nobilis	Rutaceae	AFM	+	+	+	+	+
Teclea simplicifolia	Rutaceae	AFM		+	+	+	+
Tetracera stulmanniana	Dilleniaceae	GC			+		
Trema orientalis	Ulmaceae	AFM	+		+	+	+
Trichilia dregeana	Meliaceae	lin	+		+	+	+
Trichilia emetica	Meliaceae	lin			+		
Trichilia prieuriana	Meliaceae	GC			+	+	
Trilepisium madagascariense	Moraceae	lin	+		+	+	+
Uncaria africana	Rubiaceae	GC			+		
Vepris dainellii	Rutaceae	AFM	+	+	+	+	+
Vernonia amygdalina	Asteraceae	lin	+	+	+	+	+
Vernonia auriculifera	Asteraceae	lin	+	+	+	+	+
Warburgia ugandensis	Canellaceae	AFM		+			
Wendlandia arabica	Rubiaceae	lin		+			
Whitfieldia elongata	Acanthaceae	GC			+	+	
Xylopia parviflora	Annonaceae	lin			+		
Zanha golungensis	Sapindaceae	lin			+		
Zanthoxylum leprieurii	Rutaceae	GC			+		

Appendix 3. Useful plant species recorded in the Afromontane rainforests of Ethiopia. BO = Bonga; HA = Harenna; BK = Berhane-Kontir; YA = Yayu; MA = Maji; Uses (T = Timber; F = Food; M = Medicine; S = Spice; BH = Beehives/honey); + = indicate presence; ✓ = indicate use type

Family	Species	BO	BK	YA	MA	HA	T	F	M	S	BH
Apocynaceae	*Carissa spinarum*	+	+	+	+	+		✓			
Apocynaceae	*Landolphia buchananii*	+	+	+	+	+					
Araliaceae	*Polyscia fulva*	+	+	+	+	+					✓
Araliaceae	*Schefflera abyssinica*	+				+					✓
Arecaceae	*Phoenix reclinata*	+	+	+	+	+		✓			
Asteraceae	*Vernonia amygdalina*	+		+		+			✓		
Boraginaceae	*Cordia africana*	+	+	+	+	+	✓	✓			
Canellaceae	*Warburgia ugandensis*					+	✓		✓		
Celastraceae	*Hippocratea africana*	+	+	+	+	+					✓
Celastraceae	*Hippocratea goetzei*	+	+			+					✓
Cupressaceae	*Juniperus* ***excelsa***					+	✓				
Dioscoreaceae	*Dioscorea bulbifera*		+					✓			
Dioscoreaceae	*Dioscorea praehensilis*		+					✓			
Dioscoreaceae	*Dioscorea sagittifolia*		+					✓			
Euphorbiaceae	*Croton macrostachyus*	+	+	+	+	+	✓		✓		
Euphorbiaceae	*Ricinus communis*	+	+	+	+	+			✓		
Fabaceae	*Albizia grandibracteata*	+	+	+	+						
Fabaceae	*Albizia gummifera*	+		+	+						✓
Fabaceae	*Albizia schimperiana*	+		+	+						✓
Fabaceae	*Millettia ferruginea*	+	+	+	+	+			✓		
Flacourtiaceae	*Flacourtia indica*	+	+	+	+	+		✓			
Icacinaceae	*Apodytes dimidiata*	+	+	+		+	✓				
Labiatae	*Ocimum urticifolium*	+							✓		
Lauraceae	*Ocotea kenyensis*	+		+		+	✓			✓	
Loganiaceae	*Strychnos henningsii*		+					✓			
Loganiaceae	*Strychnos innocua*		+					✓			
Loganiaceae	*Strychnos mitis*		+			+		✓			
Meliaceae	*Ekebergia capensis*	+	+	+	+	+	✓				
Meliaceae	*Trichilia dregeana*	+	+	+	+		✓	✓			
Moraceae	*Antiaris toxicaria*		+	+			✓				
Moraceae	*Ficus mucuso*		+	+				✓			
Moraceae	*Ficus sur*	+	+	+		+		✓			
Moraceae	*Milicia excelsa*		+				✓				
Moraceae	*Morus mesozygia*		+	+			✓	✓			
Moraceae	*Trilepisium madagascariense*	+	+	+	+		✓	✓			
Myrsinaceae	*Embelia schimperi*	+	+		+	+			✓		
Myrsinaceae	*Myrsine africana*					+			✓		

Appendix 3. Continued

Family	Species	BO	BK	YA	MA	HA	T	F	M	S	BH
Myrtaceae	*Eugenia bukobensis*		+	+				✓			
Myrtaceae	*Syzygium guineense*	+				+		✓			
Oleaceae	*Olea welwitschii*	+	+	+	+	+	✓				
Passifloraceae	*Passiflora edulis*	+						✓			
Phytolaccaceae	*Phytolacca dodecandra*	+	+	+	+	+			✓		
Piperaceae	*Piper capense*	+	+		+					✓	
Piperaceae	*Piper guineense*		+							✓	
Podocarpaceae	*Podocarpus falcatus*	+				+	✓				
Ranunculaceae	*Clematis simensis*	+	+	+		+			✓		
Rhamnaceae	*Rhamnus prinoides*	+	+	+		+		✓			
Rhamnaceae	*Rhamnus staddo*					+		✓			
Rosaceae	*Hagenia abyssinica*					+	✓		✓		
Rosaceae	*Prunus africana*	+		+	+	+	✓				
Rosaceae	*Rosa abyssinica*					+		✓			
Rosaceae	*Rubus apetalus*	+	+	+	+	+		✓			
Rosaceae	*Rubus rosifolius*	+						✓			
Rosaceae	*Rubus steudneri*	+	+	+	+	+		✓			
Rubiaceae	*Coffea arabica*	+	+	+	+	+		✓			
Rutaceae	*Citrus aurantium*					+		✓			
Rutaceae	*Clausena anisata*	+	+	+	+	+			✓		
Sapindaceae	*Dodonea angustifolia*					+			✓		
Sapotaceae	*Manilkara butugi*		+		+		✓	✓			
Sapotaceae	*Mimusops Kummel*	+	+		+	+	✓	✓			
Sapotaceae	*Pouteria adolfi-friederici*	+	+	+	+	+	✓				
Sapotaceae	*Pouteria altissima*		+	+			✓	✓			
Simaroubaceae	*Brucea antidysenterica*	+	+	+	+	+			✓		
Solanaceae	*Capsicum frutescens*		+					✓			
Solanaceae	*Solanum nigrum*		+			+		✓			
Urticaceae	*Urtica simensis*					+		✓			
Zingiberaceae	*Aframomum corrorima*	+	+	+						✓	
Zingiberaceae	*Curcuma domestica*		+							✓	
Zingiberaceae	*Zingiber officinale*		+							✓	

Appendix 4 Soil chemical analysis of samples from three studied Afromontane rainforests of Ethiopia

Sites	Altitude	Horizon	Soil depth (cm)	pH.1.25 (H$_2$0)	OM (%)	C (%)	Total N (%)	C/N	Available P (ppm)	Exch. K (meq/100g)
Maji	1600	Ah	0-15	5.60	6.74	3.91	0.40	9.77	1.10	2.10
		AB	15-60	4.27	3.61	2.09	0.17	12.32	0.95	1.00
		BC	60-95	4.37	2.08	1.21	0.12	10.05	1.02	0.81
		BC	95+	4.28	1.54	0.89	0.09	9.93	0.86	0.75
	1640	Ah	0-30	5.20	7.46	4.33	0.34	12.73	3.59	2.96
		AB	30-100	5.40	3.78	2.19	0.17	12.90	1.28	1.42
		B	100+	4.65	1.97	1.14	0.12	9.52	1.25	1.40
	1590	Ah	0-30	5.10	6.08	3.53	0.28	12.60	6.97	2.44
		BC	30+	5.22	1.96	1.14	0.12	9.47	0.86	1.76
Bonga	1900	Ah	0-45	4.61	5.19	3.01	0.31	9.71	0.35	0.24
		Bw	45-75	5.10	1.14	0.66	0.09	7.35	0.23	0.13
	2050	Ah	0-25	-	9.92	5.75	0.60	9.59	0.55	0.73
		C	25+	-	1.78	1.03	0.12	8.60	0.77	0.20
	1970	Ah	0-22	4.61	6.86	3.98	0.49	8.12	0.64	0.34
		A1	22-47	4.74	2.91	1.69	0.23	7.34	0.21	0.13
		Bt	47-140	4.95	1.38	0.80	0.11	7.28	0.31	0.05
		C	140+	4.93	0.37	0.21	0.05	4.29	0.34	0.04
	1950	Ah	0-22	5.03	6.66	3.86	0.47	8.22	0.65	0.40
		AC	22-53	4.94	2.12	1.23	0.14	8.78	0.22	0.07
	1900	Ah	0-30	5.91	6.72	3.90	0.43	9.06	0.67	0.44
		Bw	30-95	4.95	2.91	1.69	0.23	7.34	0.27	0.14
	1935	Ah	0-20	5.51	6.89	4.00	0.46	8.69	0.52	0.41
		A1	20-50	4.91	2.02	1.17	0.19	6.17	0.19	0.22
		Bt	50+	5.23	1.14	0.66	0.12	5.51	0.21	0.18
	1975	Ah	0-25	4.21	5.13	2.98	0.35	8.50	0.31	0.16
		A1	25-47	4.43	2.57	1.49	0.21	7.10	0.14	0.08
		Bt	47^{+}	4.73	2.89	1.68	0.12	13.97	1.05	0.09
Berhane-Kontir	1800	Ah	0-30	7.06	3.38		0.24	-	0.82	0.34
		Bw	30-80	6.02	0.91	-	0.07	-	0.88	0.15
		Bt	80^{+}	5.86	0.59	-	0.05	-	1.72	0.13
	1400	Ah	0-30	5.63	3.41	-	0.22	-	1.32	0.48
			30^{+}	5.96	0.50	-	0.06	-	0.22	0.56
	1000	Ah	0-20	6.07	4.84	-	0.34	-	63.86	1.29
		Bw	20-50	6.27	1.26	-	0.12	-	55.58	0.84
		Bt	50^{+}	6.43	0.60	-	0.06	-	54.90	0.50

Appendix 5 Soil profile description for three soil pits in the Bonga and Berhane-Kontir forests, southwest Ethiopia

A. **RHODIC NITOSOLS**: SOIL PIT BONGA1-LT2P5

Altitude 1935 m; date 30/10/2003

Ref: 0176996 N & 0810196 E (UTM)

I. GENERAL SITE DESCRIPTION

1. Soil moisture regime : *Udic /moist/*
2. Soil temperature regime: -
3. Diagnostic horizon: *Agric* or *Argellic*
4. Diagnostic criteria: *ferralic property*
5. Local classification: *Chelo (red soil)*
6. Climatic classification: *Kopen; Tropical* wet climate
    a. Max rainfall: *1800 mm/yr*
    b. Temperature of rainfall: *hot/ warm*
    c. Station: *Kuma*
    d. Altitude:*1935* m
7. Exposition: *WNW*
8. Parent material: *Not observed*
    a. Assumed: *volcanic ejecta*
    b. High weatherable material
    c. Deep soil
9. Effect depth: *> 170 cm; weathered*
10. Geomorphology: *Mountainous area*
11. Topography: *Undulating to mountainous*
12. Position of the site: *Middle slope*
13. Micro relief:
    a. Pattern of slope*: Linear*
    b. Rock out crop*: none*
14. *Hydrology:*
    a. Water table*: not observed*
    b. Permeability*: high permeable, but seasonal run off*
    c. Run off: *Slow, fresh water*
15. Drainage class*:*
    a. Erosion: *none*
    b. Erosion degree*: none*
16. Slope stability*: Stable environment*
17. Land utilization type*:*
    a. Natural vegetation
    b. Closed forest
    c. Primary forest (?)
    d. Deciduous forest

II. PROFILE DESCRIPTION

1. **Soil type**: *RHODIC NITOSOLS*
    a. Nitric- *high contain of Na*
    b. Rhodic- *red dusky*
    c. *No variation in clay distribution in all horizons*
2. **Ah Horizon**
    a. Depth: *0-20 cm*
    b. Boundary: *diffused and smooth*
    c. Color: *5 YR 3/3/moist: Dark-reddish brown*
    d. Texture: *clay*
    e. Organic matter: *Root and fragments of wood*
    f. Decomposition rate: *Slightly decomposed*
    g. Structure:
        i. Grade: *moderately strong*
        ii. *Size: fine to medium*
        iii. *Form: crab*
    h. *Consistency:*
        i. When moist*: friable*
        ii. When wet*: stick and plastic*
    i. Pores:
        i. Quantity: *common*
        ii. Size: *very fine*
        iii. Shape: *irregular*
        iv. Orientation: *horizontal*
        v. Continuity: *continuous*
        vi. Location: *on the surface*
        vii. Distribution: *impede and expede*
        viii. Total porosity: *highly porous*
    j. Root
        i. Quantity: *many*
        ii. Size: *very fine to coarse*
        iii. Location: *on the surface*

- iv. Distribution: *throughout the horizon*

- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 5.51
- n. Cutans: *none*
- o. Inclusion: *none*
- p. Rock: *none*
- q. Pan: *none*
- r. Biological activity: *few worm channel*

3. A1 Horizon

- a. Depth: 20-50 cm
- *b.* Boundary: *diffused and smooth*
- c. Color: 10R 3/4/*moist: Dusky-red*
- d. Texture: *clay*
- *e.* Organic matter: *none*
- *f.* Decomposition rate:---
- *g.* Structure:
  - *i.* Grade: *weak*
  - *ii.* Size*: medium*
  - *iii.* Form*: sub-angular block- break into granular*
- *h.* Consistency*:*
  - *i.* When moist*: friable*
  - *ii.* When wet*: stick and plastic*
- i. Pores:
  - i. Quantity: *many*
  - ii. Size: *micro pores*
  - iii. Shape: *tubular*
  - iv. Orientation: *random*
  - v. Continuity: *continuous*
  - *vi.* Distribution: *impede and expede*
  - *vii.* Total porosity: *highly porous*
- j. Root
  - i. Quantity: *common*
  - ii. Size: *very fine to coarse*
  - iii. Location: *on the surface*
  - iv. Distribution: *throughout the horizon*
- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 4.91
- n. Cutans: *none*
- o. Inclusion: *none*
- p. Rock: *none*
- q. Pan: *none*
- r. Biological activity: *none*

4. Bt Horizon

- a. Depth: > 120 cm
- *b.* Boundary: *not clear*
- c. Color: 10R 3/4/*moist: Dusky-red*
- d. Texture: *clay*
- *e.* Organic matter: *none*
- *f.* Decomposition rate. *none*
- *g.* Structure:
  - *i.* Grade: *weak*
  - *ii.* Size*: fine to medium*
  - *iii.* Form*: sub-angular block- break into smaller fine angular block*
- *h.* Consistency*:*
  - *i.* When moist*: friable*
  - *ii.* When wet*: stick and plastic*
- i. Pores:
  - i. Quantity: *many*
  - ii. Size: *micro-pores*
  - iii. Shape: tubular
  - iv. Orientation: *random*
  - v. Continuity: *continuous*
  - *vi.* Distribution: *impede and expede*
  - *vii.* Total porosity: *highly porous*
- j. Root
  - i. Quantity: *few*
  - ii. Size: *very fine to coarse*
  - iii. Distribution: *throughout -horizon*
- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 5.23
- n. Cutans:
  - i. Quantity: *Common*
  - ii. Thickness: *thin*
  - iii. Kind: *clay*
- o. Inclusion: *none*
- p. Rock: *none*
- q. Pan: *none*
- r. Biological activity: *none*

B. **DYSTRIC REGOSOLS**: SOIL PIT BONGA 3.LT2P3

Altitude 1950 m; Date 30/10/2003

Ref: 0176997 N & 0809596 E (UTM)

I. GENERAL SITE DESCRIPTION

1. Soil moisture regime : *Udic /moist/*
2. Soil temperature regime: -
3. Diagnostic horizon: *Umbric*
4. Diagnostic criteria: *weatherable minerals*
5. Local classification: *Aishew (Black soil)*
6. Climatic classification: *Kopen; Tropical wet climate*
   - *a.* Max rainfall*:1800 mm/yr*
   - *b.* Temperature of rainfall*: hot/ warm*
   - *c.* Station*: Kuma*
   - *d.* Altitude*:1950m*
7. Exposition: *ridge*
8. Parent material: *observed*
   - *a.* Colluvial (sedimentary) materials
   - *b.* Weathering: highly weathered;
   - *c.* Resistant to weathering*:* low
9. Effect depth: 0-50 *cm; weathered*
10. Geomorphology: *Mountainous area*
11. Topography: *Undulating to mountainous*
12. Position of the site: *Middle slope*
13. Micro relief:
    - *a.* Pattern of slope*: Linear*
    - *b.* Rock out crop*: none*
14. *Hydrology:*
    - *a.* Water table*: not observed*
    - *b.* Permeability*: high permeable, but seasonal run off*
    - *c.* Run off: *Slow, fresh water*
15. Drainage class*:*
    - *a.* Well drained
    - *b.* 0-50 cm*: moist*
    - *c.* degree of erosion: *none*
16. Slope stability*: Stable environment*
17. Land utilization type*:*
    - *a.* Natural vegetation
    - *b.* Closed forest
    - *c.* Primary forest (?)
    - *d.* Deciduous forest

II. PROFILE DESCRIPTION

1. **Soil type**: *DYSTRIC REGOSOLS*
   - *a.* Cambic
   - *b.* Umbric
2. **Ah Horizon**
   - a. Depth: 0-22 cm
   - *b.* Boundary: diffuse and smooth
   - c. Color: *5 YR 3/3/moist: Dark-reddish brown*
   - d. Texture: *clay*
   - *e.* Organic matter: *leaves and fragmented wood*
   - *f.* Decomposition rate: slightly decomposed
   - *g.* Structure:
     - *i.* Grade: moderate
     - *ii.* Size*: fine to medium*
     - *iii.* Form*: crabi*
   - *h.* Consistency*:*
     - *i.* When moist*: friable*
     - *ii.* When wet*: stick and plastic*
   - i. Pores:
     - i. Quantity: *common*
     - ii. Size: very *fine to medium*
     - iii. Shape: *irregular*
     - iv. Orientation: *random*
     - v. Continuity: *continuous*
     - *vi.* Distribution: *impede*
     - *vii.* Total porosity: *highly porous*
   - j. Root
     - i. Quantity: *common*
     - ii. Size: *very fine to coarse*
     - iii. Distribution: *throughout the horizon*
   - k. Mottle: *none*
   - l. $CaCO_3$: *none*
   - m. pH: 5.03
   - n. Cutans: none
   - o. Inclusion: very few rocks
   - p. Rock:
     - i. Quantity: *very few*
     - ii. Size: very fine

            iii. Weathering: *strongly weathered*
    q. Pan: *none*
    r. Biological activity: *few worm channel*

3. **AC horizon**
    a. Depth: 22-53 cm
    b. Boundary: *clear and wave*
    c. Color: 2*.5 YR 3/6/moist: Dark-red*
    d. Texture: *clay*
    e. Organic matter: none
    f. Structure:
        i. Grade: *weak*
        ii. Size*: fine to coarse*
        iii. Form*: massive, but weak*
    g. Consistency*:*
        i. When moist*: friable*
        ii. When wet*: stick and plastic*
    h. Pores:
        i. Quantity: *common*
        ii. Size: fine to medium
        iii. Shape: *tubular*
        iv. Orientation: *random*
        v. Continuity: *continuous*
        vi. Distribution: *impede*
    i. Root:
        i. Quantity: *few*
        ii. Size: *fine to coarse*
        iii. Distribution: *throughout the horizon*
    j. Mottle: *none*
    k. $CaCO_3$: *none*
    l. pH: 4.94
    m. Cutans: *none*
    n. Inclusion: *very few rocks*
    o. Rock:
        i. Quantity: *few*
        ii. Size: *medium to coarse*
        iii. Weathering: *fresh to* slightly *weathered*
    p. Pan: *none*
    q. Biological activity: *few worm channel*

4. C horizon

- *Highly weathered*

C. **HUMIC CAMBSOLS**: SOIL PIT BERHANE-KONTIR1

Altitude 1800 m ; Date 20/06/2004

Ref: 7° 05`333 N & 35°24`783 E

I. GENERAL SITE DESCRIPTION

1. Soil moisture regime : *Udic /moist/*
2. Soil temperature regime:----------
3. Diagnostic horizon: *Argellic*
4. Diagnostic criteria: ferralic (reddish)
5. Local classification: ------------------
6. Climatic classification: *Kopen; Tropical wet climate*
    - *a.* Max rainfall: *2200 mm/yr*
    - *b. Temperature of rainfall: hot/ warm*
    - *c.* Station*: Kontir*
    - d. Altitude: *1800 m*
7. Exposition: *S*
8. Parent material: *not observed*
9. Effect depth: *1.5 m+; weathered and root*
10. Geomorphology: *Mountainous area*
11. Topography: *Undulating to mountainous*
12. Position of the site: *ridge slope*
13. Micro relief:
    - *a.* Pattern of slope*: Linear*
    - *b.* Rock out crop*: none*
14. *Hydrology:*
    - *a.* Water table: *not observed*
    - *b.* Permeability*: high permeable, but seasonal run off*
    - *c.* Run off*: Slow, fresh water*
15. Drainage class*:*
    - *a.* Well drained soil
    - *b.* degree of erosion: *none*
16. Slope stability*: Stable environment*
17. Land utilization type*:*
    - *a.* Natural vegetation
    - *b.* Closed forest
    - *c.* Primary forest
    - *d.* Deciduous forest

II. PROFILE DESCRIPTION

1. **Soil type**: *HUMIC CAMBSOLS*
    - *a.* Cambic
    - b. Umbric

2. **Ah Horizon**

- a. Depth: *0-30 cm*
- *b.* Boundary: *diffused*
- c. Color: *dark reddish brown*
- d. Texture: *slightly clay*
- e. Organic matter: *leaves and fragmented wood*
- f. Decomposition rate: *highly decomposed*
- g. Structure:
    - *i.* Grade: *moderately strong*
    - *ii.* Size*: fine to medium*
    - *iii.* Form*: crabi*
- h...Consistency*:*
    - *iv.* When moist*: friable*
    - *v.* When wet*: stick and slightly plastic*
- i. Pores:
    - vi. Quantity: *common*
    - vii. Size: micro to *fine*
    - viii. Shape: *irregular*
    - ix. Orientation: *random*
    - x. Continuity: *continuous*
    - *xi.* Distribution: *impede*
    - *xii.* Total porosity: *highly porous*
- j..Root
    - i. Quantity: *many*
    - ii. Size: *fine to coarse*
    - iii. Distribution: *throughout the horizon*
- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 7.06
- n. Cutans: *none*
- o. Inclusion: *very few rocks*Rock:
    - i. Quantity: *few*
        - i. Size: *fine*
        - ii. Weathering: *weathered*
    - b. Pan: *none*
    - c. Biological activity: *few worm channel*

3. **Bw Horizon**
    - a. Depth: 30-80 cm
    - *b.* Boundary: *diffused*

- c. Color: *strong brown*
- d. Texture: *clay*
- *e.* Organic matter: *few*
- *f.* Decomposition rate: -
- *g.* Structure:
  - *i.* Grade: *moderate*
  - *ii.* Size*: fine to medium*
  - *iii.* Form*: sub-angular block*
- *h.* Consistency*:*
  - *i.* When moist*: friable*
  - *ii.* When wet*: stick and slightly plastic*
- i. Pores:
  - i. Quantity: *many*
  - ii. Size: *micro to fine*
  - iii. Shape: *irregular*
  - iv. Orientation: *horizontal*
  - v. Continuity: *continuous*
  - *vi.* Distribution: *impede*
  - *vii.* Total porosity: *highly porous*
- j. Root
  - i. Quantity: *few*
  - ii. Size: *fine to medium*
  - iii. Distribution: *throughout the horizon*
- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 6.02
- n. Cutans:
  - i. few
  - ii. Thickness: thin
  - iii. Kind: humus
- o. Inclusion: *very few rocks*
- p. Rock:
  - i. Quantity: *few*
  - ii. Size: *coarse*
  - iii. Weathering: *highly weathered*
- q. Pan: *none*
- r. Biological activity: *no*

4. Bt Horizon

- a. Depth: 80 cm +
- *b.* Boundary: *diffused*
- c. Color: *reddish brown*
- d. Texture: *clay*
- *e.* Organic matter: none
- *f.* Decomposition rate: -
- *g.* Structure:
  - *i.* Grade: moderate
  - *ii.* Size*: fine to medium*
  - *iii.* Form*: sub-angular block*
- *h.* Consistency*:*
  - *i.* When moist*: friable*
  - *ii.* When wet*: stick and slightly plastic*
- i. Pores:
  - i. Quantity: *few*
  - ii. Size: micro to *fine*
  - iii. Shape: irregular
  - iv. Orientation: *horizontal*
  - v. Continuity: *continuous*
  - *vi.* Distribution: *impede*
  - *vii.* Total porosity: *highly porous*
- j. Root
  - i. Quantity: *few*
  - ii. Size: *fine to medium*
  - iii. Distribution: *throughout the horizon*
- k. Mottle: *none*
- l. $CaCO_3$: *none*
- m. pH: 5.86
- n. Cutans: patchy
  - i. few
  - ii. Thickness: thin
  - iii. Kind: humus
- o. Inclusion: very few rocks
- p. Rock: -
- q. Pan: *none*
- r. Biological activity: *no*

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