Ecology and Development Series No. 10, 2003

Tadesse Woldemariam Gole

Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for *in situ* conservation of wild *Coffea arabica* L. populations

Cuvillier Verlag Göttingen

Abstract

This study provides the first detailed analysis of the vegetation of a rain forest area with wild populations of *Coffea arabica* and the impacts of human use on the ecosystem. Wild *C. arabica* is restricted to the montane rain forests of southwestern and southeastern parts of Ethiopia. Threat to these wild populations and to the montane rain forests due to deforestation warrants the need to take *in situ* conservation measures and to establish gene reserves. The present study was carried out on Yayu forest (Illubabor Zone of Oromiya State, southwestern Ethiopia), which represents the largest (ca. 10,000 ha) undisturbed forest fragment currently existing for the conservation of wild *C. arabica* populations, and which earlier has been identified as a potential coffee gene reserve.

Yayu forest has a very high plant species diversity and abundance of the coffee trees compared to other similar forest areas in the country. About 220 species of vascular plants were recorded from the forest, 160 of which occurred in 58 sample plots of 400 m^2 each. A cluster analysis, coupled with the indicator species analysis following Dufrêne and Legendre's method revealed three groups, with *Coffea arabica*, *Argomuellera macrophylla* and *Dracaena fragrans* as indicators, respectively. The three indicator species are the most dominant species in the small trees and shrubs stratum. These groups also form distinct clusters in PCA based species-plots biplots. The *C. arabica* group represents vegetation at higher altitudes and on gentle slopes. The *A. macrophylla* group occurs on steep slopes at low altitudes along the Geba river which dissects the forest, and the *D. fragrans* group on steep slopes at higher altitudes. *Coffea arabica* is one of the most abundant and frequent species in the forest. However, its abundance decreases with an increase in slope. Floristically, Yayu forest is a transitional rain forest between the Afromontane rain forest of higher altitudes and the Guineo-Congolian forest of the lowlands.

To assess the impacts of human use, different forest categories reflecting the traditional forest management types were compared to undisturbed forest stands. These categories are the "Semi-Forest Coffee Systems" (new- and old) and "Semi-Forest-Plantation Systems". The number of woody plant species in the managed forests decreased by up to 40%, as compared to the undisturbed forests. Within the managed forests, diversity decreases with duration and intensity of management, the lowest being in the Semi-Forest-Plantation Systems. Frequent clearing of small trees, shrubs and climbers in the managed forests has negative effects on the regeneration of tree species, including *Coffea*. The vegetation structure in the managed forests is simplified to two distinguishable layers: the shade trees in the canopy layer and the coffee stand in the lower stratum.

Networks of forest reserves are perceived as the best options for conservation and sustainable use of coffee genetic resources. The Geographic Information System (GIS) based ordered weighted averaging (OWA) method was used to classify the forest and surrounding farmlands in Yayu into zones like core zone, buffer zone-I, buffer zone-II and transition zone to be used in future reserve management. The total area included in this analysis was 36,586 ha, out of which 23% was classified as core zone, 5% as buffer zone-I, 26% as buffer zone-II and 46% as transition zone. Protection in the core zone is strict, in buffer zone-I with very limited use, in buffer zone II with sustainable use of resources including coffee; and the transition zone allows agricultural practices for crop production. Furthermore, the impacts of human use and the implications for conservation are discussed, and relevant recommendations for management of the forest and further research forwarded.

Die Vegetation des Yayu-Waldes in SW Äthiopien: Auswirkungen anthropogener Nutzung und Implikationen für den in-situ-Schutz der Wildpopulationen von *Coffea arabica* L.

Kurzfassung

Die vorliegende Studie bietet die erste detaillierte Analyse der Vegetation eines Bergregenwaldgebietes mit Wildpopulationen von *Coffea arabica* und untersucht die Auswirkungen anthropogener Nutzung auf das Waldökosystem. Die Vorkommen des wilden *C. arabica* beschränken sich auf die montanen Regenwälder im südwestlichen und südöstlichen Äthiopien. Die Bedrohung dieser Wildpopulationen sowie der montanen Regenwälder durch Abholzung macht *in situ* Schutzmaßnahmen und Einrichtung populationsgenetischer Schutzgebiete notwendig. Die vorliegende Studie wurde im Yahu-Wald (Illubabor Zone des Staates Oromiya, Südwest-Äthiopien) durchgeführt, welches das größte (ca. 10.000 ha) unberührte Waldfragment darstellt, das für den Schutz der wilden *C. arabica*-Populationen zur Verfügung steht, und bereits als potenzielles kaffeegenetisches Schutzgebiet ausgewiesen worden ist.

Der Yayu-Wald hat eine sehr hohe Pflanzenartenvielfalt wie auch eine hohe Abundanz von Kaffeebäumen im Vergleich zu ähnlichen Waldgebieten des Landes. Ungefähr 220 Gefäßpflanzenarten wurden erfasst, wovon 160 in 58 Probeflächen von je 400 m^2 vorkamen. Eine Clusteranalyse zusammen mit der Indikatorenartenanalyse nach Dufrêne and Legendre ergab drei Gruppen mit *C. arabica*, *Argomuellera macrophylla* bzw. *Dracaena fragrans* als Indikatorenarten. Diese drei Indikatorenarten sind die dominantesten Arten innerhalb der Schicht der kleinen Bäume und Sträucher. Diese Gruppen ergeben auch deutliche Clusters in auf einer Hauptkomponentenanalyse basierenden Arten-Probeflächen-Biplot. Die *C. arabica*-Gruppe bildet die Vegetation in größeren Höhenlagen und auf sanften Abhängen. Die *A. macrophyll*-Gruppe kommt an steilen Abhängen in niedrigen Höhenlagen entlang des Geba-Flusses, der den Wald durchschneidet, vor und die *D. fragrans*-Gruppe stellt die Vegetation auf steilen Hängen in wiederum größeren Höhenlagen. *Coffea arabica* ist durchweg eine der Arten mit der höchsten Abundanz, jedoch nimmt diese mit zunehmender Hangneigung ab. Floristisch gesehen ist der Wald ein Übergangsregenwald zwischen dem afromontanen Regenwald der höheren Lagen und dem Guineo-Kongolesischen Tieflandwald.

Um die Auswirkungen der anthropogenen Nutzung auf den Wald zu ermitteln, wurden verschiedene Waldkategorien, die die traditionellen Waldnutzungstypen repräsentieren, mit ungestörten Beständen verglichen. Die Kategorien sind "Semi-Forest"-Kaffeesysteme (neu und alt) und "Semi-Forest Plantation"-Systeme. Verglichen mit den ungestörten Waldbereichen nahm die Anzahl der holzigen Pflanzenarten in den genutzten Wäldern bis zu 40 % ab. Innerhalb der genutzten Wäldern nimmt die Artenvielfalt mit der Dauer und Intensität der Nutzung ab, wobei die Artenvielfalt am niedrigsten in den "Semi-Forest"-Kaffeesystemen ist. Die häufige Rodung von kleinen Bäumen, Sträuchern und Kletterpflanzen in den genutzten Wäldern hat negative Auswirkungen auf die Regeneration der Baumarten, einschließlich *C. arabica*. Die Vegetationsstruktur in den genutzten

Wäldern weist im Wesentlichen zwei Schichten auf: die Schattenbäumen in der Kronenschicht und der Kaffeebestand in der unteren Schicht.

Netzwerke von Waldschutzgebieten werden als die beste Option für den Schutz und die nachhaltige Nutzung der kaffeegenetischen Ressourcen erachtet. Die auf einem geografischen Informationssystems (GIS) basierende "ordered weighted averaging (OWA)"-Methode wurde verwendet, um den Yayu-Wald und die umgebenden Farmflächen für ein zukünftiges Schutzgebietsmanagement in Kernzone, Pufferzone I, Pufferzone II und Übergangszone zu gliedern. Die gesamte analysierte Fläche betrug 36.586 ha wovon 23 % als Kernzone, 5 % als Pufferzone I, 26 % als Pufferzone II und 46 % als Übergangszone klassifiziert wurden. Die Schutzbestimmungen in der Kernzone sind streng, in der Pufferzone I ist eine beschränkte Nutzung und in Pufferzone II eine nachhaltige Nutzung der Ressourcen einschließlich Kaffee erlaubt; in der Übergangszone ist landwirtschaftlicher Anbau zugelassen. Es werden die Auswirkungen der anthropogenen Nutzung und deren Folgen für die Schutzmaßnahmen diskutiert. Empfehlungen für das zukünftige Management des Yayu-Waldes sowie für weitere Forschungen werden gegeben.

TABLE OF CONTENTS

1 GENERAL INTRODUCTION 1
1.1 Background and problem statement 1
1.2 Aims and scope of the study 6
1.3 Structure of the dissertation 7

2 STATE OF KNOWLEDGE OF THE FOREST VEGETATION, BIOLOGY AND THE CONSERVATION STATUS OF *COFFEA ARABICA* L. 9
2.1 The forest vegetation of southwest Ethiopia 9
2.2 Taxonomy, genetic diversity and reproductive biology of Coffea arabica 15
2.2.1 Taxonomy 15
2.2.2 Genetic diversity 16
2.2.3 Reproductive biology 18
2.3 Geographical distribution of wild populations of Coffea arabica 19
2.4 Approaches in plant genetic conservation 20
2.4.1 *Ex situ* conservation methods 21
2.4.2 *In situ* conservation methods 24
2.4.3 Complementary conservation strategies 26

3 DESCRIPTION OF THE STUDY AREA AND SAMPLING DESIGN 28
3.1 The study area 28
3.1.1 Geographic location 28
3.1.2 Geology and soils 29
3.1.3 Topography and drainage systems 29
3.1.4 Climate 29
3.1.5 Human population and means of subsistence 31
3.1.6 Land tenure and land-use types 31
3.2 Sampling design and location of plots 32

4 FLORISTIC ANALYSIS OF THE UNDISTURBED FOREST VEGETATION AT YAYU: A POTENTIAL GENE RESERVE FOR *COFFEA ARABICA* 35
4.1 Introduction 35
4.2 Materials and Methods 37
4.2.1 The data set 37
4.2.2 Classification and indicator species analysis 38
4.2.3 Ordination of vegetation data 39
4.2.4 Environmental variables and community type relationships 40
4.3 Results 41
4.3.1 Floristic composition 41
4.3.2 Classification and indicator species 46
4.3.3 Ordination 52
4.3.4 Relationships between environmental variables and community type 56

4.4 Discussion 57
4.4.1 Floristic composition 57
4.4.2 The plant community types and differences in environmental variables 59
4.4.3 Implications for the conservation of the Yayu forest 62

5 IMPACTS OF HUMAN USE ON THE STRUCTURE AND SPECIES COMPOSITION OF THE YAYU FOREST 67
5.1 Introduction 67
5.2 Material and methods 69
5.2.1 Vegetation categories and datasets 69
5.2.2 Analysis of differences in species composition 71
5.2.3 Ordination 73
5.2.4 Vegetation structure and basal area 73
5.3 Results 74
5.3.1 Impacts on species diversity and composition 74
5.3.2 Ordination 80
5.3.3 Population structure of trees 85
5.3.4 Differences in abundances and vegetation structure 88
5.3.5 Changes in basal area 89
5.4 Discussion 90
5.4.1 Differences in species diversity and composition 91
5.4.2 Population structure of trees 93
5.4.3 The forest structure 93
5.4.4 Implications for conservation 95

6 THE *IN SITU* CONSERVATION OF WILD *COFFEA ARABICA* POPULATIONS IN THE YAYU FOREST: SUITABILITY ANALYSIS AND RESERVE ZONING 98
6.1 Introduction 98
6.2 Materials and methods 101
6.2.1 Data sources 101
6.2.2 Digital elevation model development 102
6.2.3 Regression analysis and criteria map layers development 103
6.2.4 Input criteria and pre-processing 104
6.2.5 Reserve zoning: the multi-criteria evaluation method 106
6.3 Results 112
6.3.1 Digital terrain data 112
6.3.2 Relationship of coffee occurrence and species diversity index with the environmental variables 114
6.3.3 Reserve suitability and zones 117
6.4 Discussion 121
6.4.1 Evaluation criteria 121
6.4.2 Reserve zones 122
6.4.3 Implications for conservation 123

7 CONCLUSIONS AND RECOMMENDATIONS 125
7.1 Conclusions 125
7.2 Recommendations 126

8 REFERENCES 128

9 APPENDICES 143

ACKNOWLEDGEMENTS 163

1 GENERAL INTRODUCTION

1.1 Background and problem statement

Biological diversity (or biodiversity) is defined in Article number 2 of the Convention on Biological Diversity (CBD) as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (UNCED 1992). This definition recognizes three distinct levels of biodiversity: genetic, species and ecosystem. Today, the conservation of biological diversity is one of the major concerns of the human society.

Biodiversity is not evenly distributed over the globe (Barthlott 1998). Some regions of the world, especially those in the tropics, have an extremely high level of diversity. Unfortunately, most biodiversity-rich countries of the tropics have poor economies, which is one of the main challenges when attempting to conserve the world’s biodiversity. Ethiopia is one of the top 25 richest countries in terms of biodiversity (WCMC 1994). Above all, Ethiopia is well known for its high level of crop genetic diversity, and hence is one of the seven Vavilov’s centers of crop origin (Vavilov 1951; Harlan 1969). More than 38 species of crop plants important for food and agriculture have their centers of origin and diversification in Ethiopia. Coffee (*Coffea arabica* L.) is one of the most important crop plants originated from Ethiopia. As a crop, *C. arabica* is the most widely distributed and cultivated of all the species in the genus. It is grown as a major cash crop in many countries of Africa, Latin America and Asia. The other economically important cultivated coffee species are *C. canephora* and *C. liberica* (Purseglove 1968)

The CBD also defines genetic resources as “genetic materials of actual or potential value” (UNCED 1992). Such genetic resources are found both in wild and in cultivated plants. Wild relatives of cultivated plants might harbor rich genetic resources for tolerance against abiotic (e.g., drought, cold, heat, salt, solar radiation, herbicides), and biotic (pathogens, parasites, competitors) stresses, which can be used for crop improvement (Nevo 1998; Schoen and Brown 1993). Some examples can be cited to indicate how genetic diversity is important with regard to *C. arabica:* the importance of Ethiopian coffee germplasm in breeding programs concerning resistance to diseases like coffee leaf rust, coffee berry disease and nematode, and for high-yielding commercial cultivars. Hence, conservation of the genetic resources of both the wild and the cultivated plants is vital for the future of agriculture.

Coffee production failed in Sri Lanka in the 19th century mainly due to coffee leaf rust (Demel 1999), which forced the county to totally abandon coffee production in 1869 and shift to tea production. The coffee plantations in Sri Lanka at that time were derived from very few individual trees introduced from the Amsterdam Botanic Garden, so that the genetic diversity of the material in the plantations was very low. In Ethiopia, coffee production was sustained for centuries even though coffee leaf rust is endemic to the country. In Brazil, the major Arabica coffee producer, coffee production was threatened by coffee leaf rust in the early 1970s. The Ethiopian coffee germplasm was used to develop cultivars that are resistant or have partial resistance to the disease through breeding (Van der Vossen 1985; Carvalho 1988) Another example is the damage caused to coffee production in Eastern Africa by the outbreak of the coffee berry disease in the 1970s and 1980s. In Ethiopia, the disease does not affect coffee production significantly, mainly due the availability of high genetic diversity. Ethiopian coffee breeders were able to develop cultivars resistant to the disease in a very short time using materials from the wild coffee gene pool (Mesfin and Bayetta 1984; Tewolde 1990; Mesfin 1991a).

Recent research findings show the importance of the Ethiopian coffee genetic materials in breeding programs for high productivity and disease resistance (Bertrand et al. 1997; Anzueto et al. 2001). Ethiopian *C. arabica* accessions were used as parents and crossed with commercial varieties to obtain strong hybrid vigor, resulting in over 30% higher productivity of the F1 hybrids in Central America (Bertrand et al. 1997). Similarly, the Ethiopian coffee collections were used to widen the genetic base of the cultivated coffee varieties and increased resistance to the nematode *Meloidogyne incognita,* a destructive, widespread pathogen of *C. arabica* in Guatemala and other coffee growing countries (Anzueto et al. 2001). Hence, there is no doubt that the existence of a gene pool with wide genetic variability can safeguard coffee production from dangers posed by possible disease outbreaks and environmental stresses. This warrants the need to conserve the diverse coffee gene pools in Ethiopia.

Several studies have shown that the populations of *C. arabica* from the southwestern part of Ethiopia have high genetic variability, and the forests there are thus suitable for *in situ* conservation of the species. For example, Sylvian (1955, 1958) and Meyer (1968) observed a high diversity of several phenotypic characters among the Ethiopian coffee populations. Montagnon and Bouharmont (1996) also found higher phenotypic diversity among the populations of *C. arabica* collected from Ethiopia as compared to cultivated populations of the species from around the world. Recent analyses of *C. arabica* genetic diversity using molecular markers (Lashermes et al. 1996; Anthony et al. 2002; Steiger et al. 2002) revealed the presence of high genetic variability among the Ethiopian coffee populations. The investigators used the accessions collected by the FAO and ORSTOM, which they described as 'subspontaneous-derived accessions', since their identity is not known for certain. However, the majority of the collections of FAO and ORSTOM in the 1960s from southwestern Ethiopia were from wild populations and some from naturalized populations (Meyer 1968; Charrier and Berthaud 1988). The latter might have originated from cultivars. It is assumed that most of the 'subspontaneous-derived accessions' are of wild origin. However, it is not clear how many originate from cultivars and how many from the wild plants, as both the wild and cultivated plants occur in southwestern Ethiopia. What is certain is that the populations from southwestern Ethiopia have a higher level of genetic diversity compared to the widely grown cultivars throughout the world. The cultivated coffee growing outside Ethiopia originates from two main lines of cultivars: *C. arabica* var. *typica* Cramer and *C. arabica* var. *bourbon* (B. Rodr.) Choussy (Lashermes et al. 1996; Anthony et al. 2002). Many researchers have confirmed that Ethiopia is definitely the center of origin for *C. arabica* (Vavilov 1951; Harlan 1969; Engels and Hawkes 1991). The presence of the coffee plants of different stages of domestication and the availability of high genetic variability in southwestern Ethiopia lead to the hypothesis that the montane rain forest in this region is the center of origin where *C. arabica* first evolved within Ethiopia. Wild populations of the species still occur in several montane forests in SW Ethiopia, which are isolated from each other due to deforestation.

Early travelers in the region at the beginning of the 20th century described the presence of vast expanses of montane rain forest. Notable examples are O. Neumann, a German naturalist and member of the Count von Erlanger Expeditions (Engler 1906 cited in Friis 1992) and F. J. Bieber, an Austrian traveler (Cofodontis 1948 cited in Friis 1992). It is assumed that the montane rain forest in SW Ethiopia has existed for long period of time as studies on the climate of Eastern Africa based on pollen data indicate that about 8000 years ago, the regions north of 3°S were wetter than they are today (Peyron et al. 2000). It appears that the highland areas became wetter and warmer, since older pollen data of ca. 20,000 years show that tropical highlands currently characterized by evergreen forest were dominated by steppe and/or xerophytic vegetation (Elenga et al. 2000).

Stohlgren et al. (1997a,b) introduced the term 'keystone ecosystem' in conservation biology. According to Stohlgren and co-workers, a keystone ecosystem is a portion of a landscape which is particularly important for a given ecological or management question. It can be an ecosystem that contains high plant-species richness, distinctive species compositions, or distinctive ecological processes. Hence, the forest ecosystems with wild *C. arabica* populations in SW Ethiopia can be keystone ecosystems for the conservation of this species together with other plant species. Any effort to conserve the genetic resources of *C. arabica* in situ should, therefore, focus on these forests as a priority.

The keystone forest ecosystems for the conservation of wild *C. arabica* populations are currently highly threatened by deforestation (Tadesse et al. 2002). During the last 30 years, the highland plateau of SW Ethiopia has lost more than 60% of its forest cover. The major cause of deforestation is conversion of the forest to farmland. This in turn is caused by the high level of dependency of the local communities on agriculture (up to 90% of the population) and high rate of population growth due to immigration from other parts of the country (Alemneh 1990; Tadesse and Denich 2001). Loss of the genetic resources of coffee and other forest biodiversity as a result of deforestation, is presumed to be enormous. Though loss of genetic diversity is not easy and straightforward to quantify like changes in forest cover, it is a well-founded fact that deforestation causes genetic erosion (O'Neill et al. 2001). Genetic erosion is the loss of genetic diversity, including an unfavorable change in the frequency of adaptive or commercially important alleles. Deforestation may result in loss of the wild populations or isolation of populations, which consequently leads to a loss of genetic diversity unique to the lost population or to a reduced gene flow among populations then isolated.

Most of the montane rain forest areas in SW Ethiopia have been deforested, and the remaining forest areas are highly fragmented. Hence, there is an urgent need to conserve the wild coffee and its forest habitat in the remnant forest areas. This can be achieved by establishing coffee gene reserves. A gene reserve is an *in situ* conservation method to preserve the genetic resources within the natural habitat (Maxted et al. 1997). The Man and Biosphere reserve of UNSECO is considered to be a good conservation strategy for sustainable use and conservation of plant genetic resources (UNESCO-UNEP 1984; Maxted et al. 1997). This approach enables the classification of the forest landscape in which the target genetic resources are found into different management zones, and the allocation of non-damaging uses by human beings in some parts while protecting core parts of the reserve in order to meet the conservation objectives (IUCN 1994; Hepcan 2000).

In order to establish a gene reserve for *in situ* conservation of coffee in the mountain rain forests of SW Ethiopia, it is essential to identify the location and distribution patterns of the wild coffee populations and other associated plant species. To achieve this, one has to answer questions such as: What species of plants occur along with coffee and how abundant are these species? What does the structure of the forest look like? Is there any kind of relationship or association among plant species in the forest ecosystem, i.e., formation of communities? Which plant communities are important for conservation? What is the distribution pattern of coffee, plant communities and overall diversity within the forest landscape with respect to different topographic features or environmental gradients of the forest ecosystem? How does human use of the forest ecosystem affect the composition and structure of the forest? What is the implication of this disturbance due to human use on the forest ecosystem, on the coffee population and on the population of other plant species? These are the leading questions for the present study.

Vegetation analysis has evolved from a mere descriptive analysis of the list of major plant species occurring in particular localities (Clements 1916) to a more rigorous statistical analysis of quantitative vegetation data (Jongman et al. 1995), which allows the classification of sites or species into community types that can be identified by a specific indicator species (McCune and Grace 2002). By doing so, it is possible to identify plant community types and forest areas important for the conservation of the wild coffee population and other plant species within the forest landscape. Vegetation analysis enables the understanding of the pattern of distribution of the target species or species groups within the landscape and helps to identify parts of the landscape that are of high priority for the conservation of such species. Developments in numerical ecology, GIS and landscape modeling provide great opportunities to refine and support conservation and management decisions.

However, there is a lack of such ecological information regarding the mountain rain forests of SW Ethiopia. This study was, therefore, carried out to generate first-hand ecological data, and to use such data for coffee gene reserve planning, by focusing on one forest area as a case study.

1.2 Aims and scope of the study

Based on the existing data on coffee distribution, information from the offices of the district department of agriculture, exploratory surveys, and socio-economic feasibility studies, Demel et al. (1998) proposed the establishment of coffee gene reserves at three sites: the Geba-Dogi, Berhane-Kontir and Boginda-Yeba forest areas. However, not enough is known about the vegetation ecology of these forests in order to develop management plans for gene reserves. Hence, a vegetation study was carried out in one of the forest areas proposed for a *C. arabica* gene reserve: the Geba-Dogi, which is referred to as Yayu forest hereafter. The objectives of this study are:

1) To assess the floristic composition and plant community types of the forest ecosystem. The main objective of conserving genetic resources *in situ* is to ensure continuation of the normal evolutionary processes by keeping both the biotic and abiotic environment as close to the natural conditions as possible. To do so, it is important to know the status of the natural forest, by analyzing the plant community types within the forest

and their pattern of distribution. Besides, it is possible that other plant species that require urgent conservation action could be discovered during the vegetation survey.

2) To assess the impacts of human use on floristic composition and vegetation structure in the forest coffee systems. People modify the natural ecosystem to rip the maximum utility or services from the system. Modification of the forest in the traditional coffee production systems may affect both the composition and structure of the forest vegetation. Studying such systems will provide information on how people modify the forest ecosystem, the species and species groups that are affected by human activities, and help to develop a management alternative in which as many species and species groups as possible can be maintained.

3) To assess the spatial patterns of coffee and plant species diversity in the forest. The spatial patterns of coffee populations and species diversity may vary within the forest landscape due to different topographic and environmental factors. Parts of the forest are more important than others for conservation of the wild coffee population, species diversity or unique landscape features.

4) To develop a plan for the gene reserve by classifying the forest area into different management zones for conservation and use of the wild coffee populations or other elements of forest biodiversity. In order to zone the forest landscape, continuous spatial criteria in the form of maps are required. Such criteria can be developed from analysis of the spatial patterns of the vegetation data and the topographic features of the forest landscape. The criteria can then be combined to produce a suitability map for conservation and use.

1.3 Structure of the dissertation

This dissertation has seven chapters, including the introductory chapter. The second chapter reviews the current state of knowledge about the ecology, biology and conservation of *Coffea arabica*. This includes the forest vegetation of southwest Ethiopia, the taxonomy, genetic diversity, reproductive biology, and geographical distribution ranges of *C. arabica* as well as the different conservation approaches currently in use.

The third chapter deals description of the study area and sampling design. Only the methods used for field data collection, data compilation and pre-processing are presented. Detailed data analysis methods are presented separately in the respective chapters.

The analysis of the undisturbed forest is presented in Chapter 4. In this chapter, the results of the analysis of the forest vegetation, indicator species of the plant community types, and the gradients in vegetation distribution are presented.

The fifth chapter presents the analysis of the impact of human use on the structure, species composition and diversity of the forest vegetation. The results of the comparison among five forest categories under different intensities of human use/ disturbance, and the implications of such management for conservation are presented.

The sixth chapter focuses on the development of a tentative reserve design and management plan. Methods for categorizing the forest area and its surroundings into different management zones of the reserve such as core, buffer and transition zones are presented. Appropriate management and monitoring strategies for each zone are also forwarded here. The final chapter of the dissertation contains conclusions and recommendations.

2 STATE OF KNOWLEDGE OF THE FOREST VEGETATION, BIOLOGY AND THE CONSERVATION STATUS OF *COFFEA ARABICA* L.

Conservation of a species, habitat, or ecosystem requires careful design based on detailed scientific knowledge (Wilson and Perlman 2000). No single discipline can provide adequate scientific knowledge for designing a conservation program, which results in a need for cooperation among different professions. In planning plant genetic resource conservation, conservationists use the available knowledge in the fields of ecology, geography, taxonomy and genetics of the target species. In this chapter, the current state of knowledge of the ecology of the forest vegetation in which *Coffea arabica* occurs as well as the ecogeographic distribution, taxonomy, genetic diversity and reproductive biology of the species are discussed. Besides, the different conservation approaches relevant for coffee plant genetic resources are reviewed.

2.1 The forest vegetation of southwest Ethiopia

The flora of southwestern Ethiopia has been among the least known in the tropical Africa until recent years, mainly due to lack of access. Until the mid 20th century, surveys and descriptions of the forest vegetation were based on the observations of a few foreign travelers. O. Neumann and F. Bieber, a German and an Austrian traveler, respectively, reported the existence of rain forests in the region for the first time in 1906 (Friis et al. 1982). The plant specimens collected by Bieber in 1906 were not identified until Cufodontis performed this task in 1948 (Friis et al. 1982). Some Italian foresters also visited the forests of SW Ethiopia around the late 1930s and early 1940s (e.g., Cufodontis 1939, 1940; Giordano 1939, 1940 cited in Friis et al. 1982). The opening up of access roads in the 1960s has facilitated botanical collection from the forests of the area. Among the many botanical expeditions, the intensive collections and field surveys by Professor Ib Friis from the Institute of Systematic Botany, University of Copenhagen, during the last three decades are the most important contribution to the knowledge of the forests of this region (Friis et al. 1982; Friis 1983, 1986a, 1986b, 1992; Friis and Sebsebe 2001). Other recent and more specific studies on the forests in the SW include regeneration ecology by Abayneh (1998) and plant community ecology by Kumelachew and Tamrat (2002).

Broader attempts to understand the country's forest vegetation and its classification were made during the second half of the 20th century. Some researchers assessed the vegetation classes subjectively based on the similarities in geographical distribution to the other East African countries (e.g., Hedberg 1951; Coetzee 1978), while others (Hamilton 1982) based their classification on altitude and moisture distribution. The most significant early contributions to the classification of the vegetation of Ethiopia were those of Pichi-Sermolli (1957) and von Breitenbach (1963). Pichi-Sermolli's work was the earliest and most detailed map of the vegetation types of Ethiopia (Friis 1992), covering also Djibouti, Eritrea and Somalia. He recognized 24 vegetation units. Most of the vegetation units are physiognomic. This system was used to compile the first AETFAT vegetation map of Africa (Keay 1959). Later, von Breitenbach (1963) published a more detailed vegetation map of Ethiopia, building upon the same system. The boundaries of the vegetation maps of von Breitenbach are quite similar to those of Pichi-Sermolli, except for the differences in the terminologies for naming the vegetation types (Friis and Sebsebe 2001). The main difference between this classification and that of Pichi-Sermolli is that it is a much more detailed and rigid classification, based on physiognomy in relation to altitude, humidity and presumed stage of succession (Friis and Sebsebe 2001). Von Breitenbach used seven vegetation categories for mapping, which he further classified into 82, providing complex and detailed vegetation types, mainly based on "associations". Classification of vegetation into "association" based on presumed stage of succession at certain altitudes and degrees of humidity, differs in concept and methodology from the 'association' commonly used by the Zurich-Montpelier School of phytosciologists (Braun-Blanquet 1932; Westhoff and Van der Maarel 1978). The system of Von Breitenbach is poorly documented and lacks essential information on locations and distribution (Friis et al. 1982).

The most widely accepted system of vegetation types for Africa is that of Greenway (1973), which was adopted for the vegetation map of southwestern Ethiopia (Friis et al. 1982). This system is physiognomic, and can also easily accommodate a more detailed system based on "associations". It was also used as a basis to produce the second vegetation map of Africa and the accompanying descriptive memoir (White 1983).

The studies of Friis (1992) are the latest in the series of developments towards a comprehensive classification and mapping of the forest vegetation of Ethiopia. According to these, seven vegetation types occur in Ethiopia, namely: Dry peripheral semi-deciduous Guino-Congolian forest, transitional rain forest, Afromontane rain forest, undifferentiated Afromontane forest of the Ethiopian Highlands, dry single-dominant Afromontane forest of the Ethiopian highlands, dry single-dominant Afromontane forest of the escarpments and riverine forest. Four forest vegetation types among these occur in SW Ethiopia. More detailed descriptions of these forests, namely: (A) dry peripheral semi-deciduous Guineo-Congolian forest, (B) transitional rain forest, (C) Afromontane rain forest, and (D) riverine forest, are given below.

2.1.1 Dry peripheral semi-deciduous Guineo-Congolian forest

The dry peripheral semi-deciduous Guineo-Congolian forests are restricted to the Baro lowlands, in Gambella State (formerly western part of the Illubabor administrative region). Chaffey (1979) was the first to make an inventory of such a forest. In the 1980s and later, several botanists and ecologists studied the forest. It occurs in a rather flat area with an altitudinal range of 450-600 m. The mean temperature is high, with a mean annual maximum of 35-38^{0}C and a mean annual minimum of 18-20^{0}C. The mean annual rainfall is between 1300 mm and 1800 mm, and the wettest period is between May and September.

The forest occurs mainly on rocky or sandy and well-drained soils, and is semi-deciduous, with a 15-20 m tall continuous canopy of *Baphia abyssinica* (which is endemic to southwestern Ethiopia and adjacent areas of the Sudan), mixed with less common species such as *Celtis toka*, *Diospyros abyssinica, Lecaniodiscus fraxinifolius, Malacantha alnifolia, Trichilia prieureana, Zanha golungensis,* and *Zanthozylum leprieurii*. Some species which emerge high above the main canopy are: *Alstonia boonei, Antiaris toxicaria, Celtis gomphophylla,* and *Milicia excelsa*. Small trees such as *Acalypha neptunica, Erythroxylum fischeri, Tapura fischeri, Ziziphus pubescens,* and *Xylopia parviflora* form a continuous stratum below the canopy. The shrub layer is composed of *Alchornea laxiflora, Argomuellera macrophylla, Mimulopsis solmisii, Oncoba spinosa, Oxyanthus speciosus, Rinorea ilicifolia*, and *Whitfieldia elongata.*

Lianas are not common. However, the lower strata of the forest are often densely populated with woody climbers. There is no record of any epiphytic species. The ground is mostly covered with thick litter, and there are apparently very few species of forest floor herbs except *Streptogyna crinita*.

2.1.2 Transitional rain forest

The transitional rain forest is found on the escarpments of the southwestern highlands in Welling, Illubabor and Kufa, between the dry peripheral semi-deciduous Guineo-Congolian forest and the Afromontane rain forest. These forests occur at altitudes between 500 and 1500 m, partly in river valleys, and partly in areas with a high water table. The annual temperature ranges from 20-25^{0}C. The mean annual rainfall is about 2000 mm, with rain falling all year round, the highest amounts falling in September. More detailed information about such forests is found in some Italian sources (Friis 1992) and Chaffey (1979). The transitional rain forests are similar in physiognomy and composition to the humid broad-leaved Afromontane rain forest of southwestern Ethiopia described below, with additional species from the lowland forest described above. However, a few species of forest trees or shrubs known in neither of these two forests appear to be restricted to the transitional forest. A list of these species includes: *Aningeria altissima, Anthocleista schweinfurthii, Campylospermum bukobense, Celtis philippensis, Celtis zenkeri, Croton sylvaticus, Dracaena fragrans, Elaeodendron buchananii, Eugenia bukobensis, Ficus exasperata, Garcinia huillensis, Manilkara butugi, Morus mesozygia, Phoenix reclinata, Strychnos mitis, Trichilia dregeana, Trilepisium madagascariense* and *Vepris dainellii.* Friis (1992) noted that this forest type may contain Guineo-Congolian forest species, which are not yet recorded in Ethiopia. This forest type, therefore, deserves further studies.

2.1.3 Afromontane rain forest

These forests occur in the SW highlands and on the Bale Mountains in the SE highlands of Ethiopia. They characteristically contain a mixture of *Podocarpus* and broad-leaved angiosperm species in the canopy, but *Podocarpus* becomes gradually more infrequent towards the southwest of Kafa and Illubabor, while *Aningeria adolfi-friederici* becomes more prominent in the same direction. The Afromontane rain forest of SW Ethiopia occurs in Wellega, Illubabor, and western Kafa. It is found between 1500 and 2500 m, with average annual temperatures of 18-20^{0}C, and an annual rainfall between 1500 mm and 2000 mm, sometimes even more than 2000 mm, with rain all the year round, but a maximum in April-October. The highest mean rainfall recorded in the region is about 2600 at Tepi (Asfaw Fanta 1981). Such forests were studied by Logan (1946), Chaffey (1979), Friis et al. (1982), and Friis (1992).

Aningeria adolfi-friederici is the most emergent species in the 20-30-m-high canopy layer. The main canopy trees of 10-30 m height include: *Albizia gummifera, A. schimperiana, A. grandibracteata, Blighia unijugata, Cassipourea malosana, Celtis africana, Croton macrostachyus, Ekebergia capensis, Euphorbia ampliphylla, Ficus sur, F. ovata, F. thonningii, Hallea rubrostipulata, Ilex mitis, Macaranga capensis, Ocotea kenyensis, Olea capensis* ssp. *welwitschii, Polyscias fulva, Schefflera abyssinica, Prunus africana, Sapium ellipticum,* and *Syzygium guineense* ssp. *afromontanum*. A discontinuous lower canopy of small trees (less than 10 m high) includes *Allophylus abyssinicus, Apodytes dimidiata, Bersama abyssinica, Brucea antidysentrica, Calpurnia aurea, Canthium oligocarpum, Chionanthus mildbraedii, Clausena anisata, Coffea arabica, Cyathea manniana, Deinbollia kilimandscharica, Dracaena afromontana, D. fragrans, D. steudneri, Ehretia cymosa, Ensete ventricosa, Erythrina brucei, Galiniera saxifraga*, *Lepidotrichilia volkensii, Lobelia giberroa, Millettia ferruginea, Nuxia congesta, Oncoba routledgei, Oxyanthus speciosus* ssp. *stenocarpus*, *Phoenix reclinata, Pittosporum viridiflorum 'ripicola', Psychotria orophila, Ritchiea albertsii, Rothmannia urcelliformis, Solanecio gigas, Solanecio mannii, Teclea nobilis, Trema orientalis, Turraea holstii,* and *Vepris dainellii.* Lianas are common, and about 25 species have been recorded. Epiphytes are also numerous, and include ferns, lycopods, orchids, *Peperomia spp.* and *Scadoxus nutans.* The ground cover is very rich in herbs in areas where light is sufficient. More than 110 species have been recorded from such a forest (Friis 1992).

2.1.4 Riverine forest

The riverine and riparian forest vegetation of the study area is very variable, the floristic composition being dependent on altitude and geographical location. Riverine forest in the Ethiopian Highlands can in general, include the following species: *Breonadia salicifolia, Ficus capreaefolia, Ficus vallis-choudae, Phoenix reclinata, Salix mucronata, Tamarindus indica,* and *Trichilia emetica* (Friis 1992).

Carr (1998) studied the Lower Omo River and found that forests are predominant in the meandering segment of the river. *Ficus sycomorus*, *Tapura fischeri*, *Melanodiscus oblongus*, *Celtis toka* and *Trichilia emetica* were most significant in upstream forest sites, whereas *Cordia sinensis*, *Acacia mellifera*, *Ziziphus mauritiana* and *Ficus sycomorus* were more common in communities nearer to Lake Turkana, where the river terminates.

The riverine forest along Baro River above Gambella (Baro Lowlands) includes the following species: *Baphia abyssinica, Celtis toka, Lecaniodiscus fraxinifolius, Lepisanthes senegalensis, Malacantha alnifolia, Mallotus sp., Tapura fischeri, Trichilia retusta,* and *Ziziphus pubescens.* The shrubs include: *Grewia trichocarpa.* The climbers include: *Acridocarpus ugandensis, Cissus petiolata,* and *Tiliacora funifera* (Friis 1992).

The riverine forest along the Didessa River at about 1300 m consists of *Ficus lutea, Ficus vallis-choudae, Cordia africana, Mimusops kummel, Trichilia emetica* and *Phoenix reclinata* in the canopy layer, which is 10-15 m high. The lower strata include: *Trichocladus ellipticus, Garcinia huillensis, Sapium ellipticum, Suregada procera, Dracaena,* etc. Climbers are: *Artabotrys monteiroae, Landolphia buchananii, Saba comorensis, Paullinia pinnata,* and *Pisonia* (Friis 1992).

As indicated above, coffee (*Coffea arabica*) is one of the common trees in the lower stratum of small trees and shrubs below 10 m both in the Afromontane and the transitional rain forests. In the current study, *C. arabica* was recorded in the riverine forests along the Geba river in Yayu. However, the abundance of coffee is lower in riverine forests compared to upland forests. Details of the distribution pattern of coffee and the overall forest vegetation of Yayu can be found in Chapter 4 of this study.

2.2 Taxonomy, genetic diversity and reproductive biology of *Coffea arabica*

2.2.1 Taxonomy

The genus *Coffea* belongs to the family Rubiaceae, which has around 500 genera and over 6000 species. Rubiaceae is one of the largest families of flowering plants, mostly trees and shrubs, and more rarely herbs. Most species of the family occur in the tropics, particularly in the lower story of tropical rain forests.

New species of the genus *Coffea* are continually being discovered. Many new species have been discovered in recent years in the forests of Eastern Africa (Bridson 1982) and Madagascar (Davis 2001; Davis and Rakotonasolo 2000, 2001a, 2001b). In total, around 92 species of *Coffea* are currently recognized, of which 45 species occur in Madagascar, 44 in Africa, and three in the Mascarenes (Dulloo 1998; Davis and Rakotonasolo 2001a).

Leroy (1980) recognized three subgenera of *Coffea*. These are: subgen. *Coffea* (ca. 90 spp.), subgen. *Baracoffea* (Leroy) Leroy (ca. 4 spp.), and a monotypic subgen. *Psilanthopsis* (A. Chev.) Leroy. According to Bridson (1994), however, it is not worthy to consider *Psilanthopsis* as a subgenus, and recommended it to be placed in subgen. *Coffea. C. arabica* is the type species for the genus and belongs to the subgen. *Coffea*.

Several phenotypically deviating populations and lines of cultivars have been formally recognized as varieties of *C. arabica (*var. *bourbon* Choussy, var. *typica* Cramer,) but there has been no clear distinction between cultivars (including land races) and the wild populations (Bridson and Verdcourt 1988). The naming of botanical varieties of *C. arabica* in literature is confounded due to mix up with cultivars. Cultivars are actually to be named under a different system, the code for cultivated plants (Trehane et al. 1995) and are to be treated separate from naturally occurring infraspecific variation. Hence, further research is necessary to clarify these issues.

Sylvain (1955, 1958) attempted to systematically classify the coffee cultivars growing in Ethiopia. In his classification, he recognized 12 major types based on tree habit, leaf color and size, calyx characteristics, size and shape of fruits and seeds, and the yielding ability. For naming, he used the names of the locality where the coffee types were found. The 12 Ethiopian coffee types of Sylvain (1955, 1958) are the Enarea, Jimma or Kaffa, Agaro, Chochie, Zeghie, Wolkitie, Wallamo, Irgalem, Dilla, Arba Gougou, Harar and Loulo. He also admitted that his list of the distinct cultivars was not complete due to the inability to cover all coffee growing regions. Over 130 traditional landraces or farmers' cultivars have recently been recorded from different coffee growing regions of Ethiopia (Admasu et al. 1989; Demel and Assefa 1994; Tadesse et al. 2001). The distinctness of these cultivars needs further investigation. Known cultivars of *C. arabica* growing outside of Ethiopia include 'Blue Mountain' in Jamaica, 'French Mission' in Kenya and Tanzania, 'Kent's' in India, 'Mundo Novo' in Brazil, 'San Ramon' and its segregate 'Villalobos' in Costa Rica to mention a few, which are derived from two main lines of cultivars (van der Vossen 1985; Anthony et al. 2002).

2.2.2 Genetic diversity

Coffea arabica differs from other species in the genus in that it is the only tetraploid (2n=44) and self-fertile species. All others are diploid (2n=22) and self-infertile (Carvalho 1952; Charrier and Berthaud 1985). Morphologically, *C. eugenioides* and *C. congensis* are more similar to *C. arabica* (Friis 1979). Carvalho (1952) observed that *C. arabica* exhibits the cytogenetical behavior of allotetraploid plants, indicating that it has evolved from a cross between two wild diploid species. Based on morphological characteristics of hybrids of diploid coffee species and the haploid progenies of *C. arabica,* it has been suggested that *C. eugenioides* and *C. congensis* (or *C. canephora* or *C. liberica*) are the putative diploid progenitors of *C. arabica* (Carvalho 1952; Narasimhaswamy 1962; Charrier and Berthaud 1985). On the other hand, Monaco (1968) argued that *Coffea arabica* could also be an autotetraploid species and suggested investigating other chromosome races in the wild populations of the species in Ethiopia.

A definite conclusion on the origin of the diploid species parenting *C. arabica* has not yet been reached. However, recent analysis of the phylogenetic relationships of *Coffea* species using internal transcribed spacer (ITS) sequences of nuclear ribosomal DNA placed *C. arabica* in a group which encompasses diploid species originating from West and Central Africa (Lashermes et al. 1997). The diploid species in this group (also called canephoroid group) include *C. canephora, C. brevipes, C. congensis, C. humilis, C.*

kapakata, C. liberica and C. stenophylla. On the other hand, Raina et al. (1998), using genomic in-situ hybridization (GISH) and fluorescent in-situ hybridization (FISH), confirmed the allopolyploid nature of *C. arabica* and suggested that it originates from two diploid species: *C. congensis* and *C. eugenioides*. A more recent study using *trn*L-*trn*F sequence of chloroplast DNA revealed that *C. eugenoides* is the maternal progenitor species of *C. arabica* (Cros et al. 1998). Lashermes et al. (1999) applied restriction fragment markers (RFLP) in combination with GISH and reached the conclusion that *C. arabica* is an amphidiploid formed by hybridization between *C. eugenioides* and *C. canephora,* or ecotypes related to these diploid species.

It has been suggested that the search for the origin of *C. arabica* should include a diploid 'race' *C. arabica* in the rain forests of Ethiopia (Meyer 1965) and the intergeneric level relationships between *Coffea* and *Psilanthus* (Charrier and Berthaud 1985). From the studies reported to date, it seems that more research work needs to be done to gain knowledge on the putative diploid progenitors of *C. arabica.* Further investigation based on the materials from the wild populations in SW Ethiopia and the relationship of *C. arabica* with closely related taxa can be of great help in this regard. As Meyer (1965) speculated, *C. arabica* may also have been derived as a result of allotetraploid hybrid from parents now extinct.

Although *C. arabica* is economically very important, few investigations have been carried out on its genetics (Raina et al. 1998). This is especially true when it comes to the populations of the species in Ethiopia. Botanists and genetists who visited Ethiopia in the 1960s and before observed the presence of high phenotypic variability among the wild coffee populations and landraces (Sylvain 1955, 1958; Meyer 1965; Monaco 1968). Recent studies using modern molecular techniques indicate that there is higher genetic diversity among wild populations of *Coffea arabica* than among its cultivars (Lashermes et al. 1996, 1999; Montagnon and Bouharmont 1996; Anthony et al. 2001, 2002; Esayas et al. submitted). These studies indicate high levels of polymorphism especially among the populations from the southwestern part of Ethiopia. However, these studies were based on a limited number of accessions collected in the 1960s during the FAO (FAO 1968) and the OSTROM (now IDR) coffee missions (Charrier and Berthaud 1988). In most cases, no distinction was made between whether the plant material was collected from wild populations in forests and landraces. To avoid this problem, authors have usually used the term "subspontaneous" to described the origin of plant material (e.g., Lashermes et al. 1996; Anthony et al. 2002).

2.2.3 Reproductive biology

Several authors have dealt with the reproductive biology of *C. arabica* (e.g., Carvalho 1988; Carvalho and Monaco 1969; Charrier and Berthaud 1985; Meyer 1965; van der Vossen 1985; Purseglove 1968). Coffee flowers first appear when the young plant attains an age of two to three years. Flowering remarkably coincides with the onset of a rainy season. A rain shower of a minimum of 20 mm following an extended dry season is required to break the dormancy of flower buds. Flowering may occur once or twice a year depending on whether the rainfall is uni- or bi-modal. Buds that will develop into flowers are usually induced four to five months before anthesis. The time between breaking of the dormancy and anthesis may vary from 4 to 10 days depending on temperature and atmospheric humidity. Flower buds open on sunny days in the early morning, and begin to wither after 2 days. A few days later all floral parts drop away except the ovaries.

Flowers have a short corolla tube, long style and exerted stamens. Although such flowers morphologically permit natural cross pollination, *C. arabica* is largely autogamous. Double fertilization occurs on the day the flower opens. The outer cells of the integument multiply actively giving rise to the perisperm. The first division of the endosperm occurs from 21 to 27 days after flower opening, and the first division in the zygote occurs 60 to 70 days after anthesis, when the endosperm is already multinucleated (Carvalho and Monaco1969; Carvalho1988).

Studies on the cultivars of *Coffea arabica* Brazil (Carvalho and Krug 1949) and Kenya (Van der Vossen 1974) show that on average about 11.9% of pollination takes place through natural cross-pollination (also in Carvalho 1988). The percentage of cross-pollination is influenced by environmental conditions, which may affect the main cross-pollinating agents, namely insects and wind. The rate of out-crossing may vary in the range of 7-15%. The rate of out-crossing is expected to be higher in its center of origin than in the cultivars growing elsewhere, since the natural pollinating agents that evolved with the species are found in the natural habitats. Meyer (1965) observed 40-60% self-fertility in the wild coffee plants in SW Ethiopia, which indicates the possibility of a higher out-crossing rate.

It takes 7-9 months for coffee fruits to mature. A matured fruit is about 1.5 cm long, oval-elliptic in shape, and has a short pedicel. Immature fruits are green and turn yellow on ripening, and then red when fully ripened. The fruit consists of a smooth, tough outer-skin or exocarp, soft yellowish pulp or mesocarp and greyish-green, fibrous endocarp (= parchment) surrounding the two seeds. The seeds are 8.5-12.5 mm long at maturity; ellipsoidal in shape, pressed together with a flattened surface on the inside that has a deep groove, and a convex outer surface. A thin, silvery testa (= silver skin) follows the outline of the endosperm, so that fragments are often found in the ventral groove after preparation. Seeds consist mainly of green corneous endosperm, folded in a peculiar manner, and a small embryo near the base. Polyembryony has been recorded (Purseglove 1968).

The main means of propagation of cultivated coffee in commercial plantations is planting seedlings raised from seeds. There is no seed dormancy, but the seeds are short-lived and their viability decreases rapidly after six months when stored at ambient temperatures. It is advisable to plant within 2 months of harvesting (Purseglove 1968). Vegetative propagation is sometimes used for multiplying clones and for top-working inferior plantations. Top-working is the process of changing the top of an established tree from one cultivar to another, or to multiple cultivars, by budding or grafting (Purseglove 1968).

2.3 Geographical distribution of wild populations of *Coffea arabica*

The genus *Coffea* occurs in the tropical regions of the African continent and the surrounding islands in the Indian Ocean. All economically important species of the genus, i.e., *C. arabica, C. canephora,* and *C. liberica* are restricted to African continent. The diploid taxa occur mostly in the rain forest areas of Uganda, Kenya, Tanzania, Congo and West Africa and as far north as Sierra Leone (Meyer 1968). Moreover, the diploid coffee species often have overlapping ecological distribution in eastern and central Africa, and

Madagascar. However, the single tetraploid species of the genus, *C. arabica*, is geographically disjunct from all other coffee species and is confined to the Ethiopian highland plateau. There are two records of occurrence of *C. arabica* in forests outside Ethiopia: Mount Marsabit in northern Kenya and Mount Boma in southeast Sudan (Friis 1979). However, these areas and the respective coffee populations have not been sufficiently investigated to confirm whether these are natural populations or escapes from cultivation. A recent study using RAPD markers shows that the population on Mount Marsabit is more similar to a widely grown cultivar of the species in plantations of Kenya than to the wild population, and its truly wild origin is questionable (Lashermes et al. 1996).

The wild populations of *C. arabica* occur in the humid forests of southwest and southeast Ethiopia, separated from each other by the Great Rift Valley (GRV), at altitudes ranging between 1000 and 2000 m. The southwestern forests constitute the main ecoregion of the species. Specifically, it occurs in the Illubabor, Jimma, West Wellega and Bale zones of Oromia State, and in the Kaffa, Sheka, Bench and Maji zones of the Southern Nations and Nationalities People (SNNP) state. Localities known for their high abundance of coffee trees, and hence important for conservation and sustainable use of wild populations of the species are the Amora-Gedel, Berhane-Kontir, Boginda-Yeba, Dawo-Tobi, Geba-Dogi (Yayu), Harenna (Bale mountains), Maji, and Mankera forests. All are on the southwestern plateau except the Harenna forest, which is located east of the GRV. In its natural range, coffee is one of the dominant plant species in the shrub or small tree layer.

2.4 Approaches in plant genetic conservation

Approaches in plant genetic conservation can be broadly categorized into two: *Ex situ* and *in situ*. *In situ* conservation is defined in Article 2 of the Convention on Biological Diversity (CBD) as the conservation of ecosystems and natural habitats & the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties (UNCED 1992). This is a broad definition and recognizes the conservation of plants in both their natural habitats and man-made habitats like farms and homegardens, covering all forms of diversity from wild relatives of crops to cultivated plants, their cultivars, land races and weedy forms (Dulloo et al. 1998). *Ex situ* conservation is defined as the conservation of components of biological diversity outside their natural habitats (UNCED 1992). The fundamental difference between these two approaches is that *ex situ* conservation involves the sampling, transfer and storage of target organisms from the target area, whereas *in situ* conservation involves designation, management and monitoring of target organisms where they are encountered (Maxted et al. 1997).

There is a growing appreciation for *in situ* conservation over *ex situ*, as *in situ* conservation entails conservation of populations of the target taxon in its natural habitat. Therefore, it is a holistic approach that also provides protection for other species sharing the same habitat, and of the natural evolutionary processes leading to adaptation of the species to changes in the biophysical environment over time. Like in any other process of biological evolution, there are two fundamental steps in crop evolution: the creation of the diversity through mutations and selection (Harris and Hillman 1989; Brush 2000). Two types of selection distinguish crop evolution from evolution under natural conditions: natural selection and artificial (or conscious) selection. Natural selection involves the accumulation of random variations by nature and the genes eventually become widespread in the population. Artificial selection is selection by man, through which cultivars of specific agronomic qualities are selected and promoted from one generation to the other. These two evolutionary processes must continue to maintain a viable agricultural production. The availability of genetic diversity is, therefore, an essential part of crop evolution. This can be best achieved by maintaining diversity *in situ.*

2.4.1 *Ex situ* conservation methods

Several authors have reviewed *ex situ* conservation techniques for conservation of plant genetic resources (Damaina 1996; Maxted et al. 1997; Dulloo et al. 1998). Damaina (1996) and Maxted et al. (1997) provided an overview of the available methods while Dulloo et al. (1998) made an extensive review of the techniques applied to conserve the genetic resources of the economically most important coffee species. There are six major techniques of *ex situ* conservation: seed storage, *in vitro* storage, DNA storage, pollen storage, and "storage" of living plants in field gene banks and botanical gardens. Among these, two methods, namely *in vitro* conservation and field gene banks, are the only relevant methods for conservation of coffee genetic resources.

***In vitro* conservation**

Basically, *in vitro* conservation involves the maintenance of explants in a sterile, pathogen-free environment and is widely used for vegetatively propagated and recalcitrant-seeded species. It offers an alternative to field gene banks. Recently, numerous *in vitro* techniques for short-term (slow growth) and long-term storage (cryopreservation) of coffee germplasm have been developed (Dussert et al. 1997a; Engelmann 1997). For long-term storage, cryopreservation is the only method with great promise. Research on the development of cryopreservation techniques has been performed with seeds, zygotic embryos, apices, and somatic embryos (Dussert et al. 1997a).

Dussert et al. (1997b, 1998) show that partially desiccated seeds of *C. arabica* can be cryopreserved if they are slowly precooled down to – 50^{0}C prior to their immersion into liquid nitrogen. This is the optimal temperature for transfer of *C. arabica* seeds to liquid nitrogen (Dussert et al. 2002). Until recently, the number of seeds that developed into normal seedlings remained low, even when cryopreserved under optimal conditions (Dussert et al. 2000a). It was found, however, that seed osmo-conditioning, i.e., controlled rehydration of seeds in a solution with low osmotic potential could have an extremely beneficial effect on seedling recovery after cryopreservation (Dussert et al. 2000b). The first cryopreserved *C. arabica* gene bank was established at CATIE (Dussert et al. 2002). Currently, duplicates of CATIE's *C. arabica* core collection accessions are being successfully cryopreserved. This is the first *ex situ* conservation method which enable storage of coffee seeds in gene banks.

Field gene banks

Conservation in field gene banks, like any other kind of *ex situ* conservation, involves collection of materials from different geographical locations and planting at one location. They are mainly established to conserve the genetic resources of recalcitrant species, sterile seeded plants and clonal material (Maxted et al., 1997). Field gene banks are commonly used for such plants as coffee, cocoa, rubber, coconut, mango, banana, cassava, sweet potato, and yam. The advantages of field gene banks are that the material is easily accessible for utilization, and that evaluations can be undertaken while the material is being conserved. The disadvantages are that the material is restricted in terms of genetic diversity, is susceptible to pests, disease and vandalism, and involves large areas of land.

Since the early 1960s, several individuals and organizations have made efforts to collect, conserve and utilize coffee germplasm (Meyer 1965; FAO 1968; IAR 1986; Berthaud and Charrier 1988). The FAO Coffee Mission collected germplasm from most of the coffee-growing areas of Ethiopia, while Meyer's collections were only from southwest and central Ethiopia. ORSTOM also collected coffee germplasms from wild populations in the forests of SW Ethiopia (Berthaud and Charrier 1988), following the FAO mission. The Ethiopian National Coffee Collection Program (ENCCP) continued to collect coffee germplasm from all over the country, including areas that were not covered by other germplasm collection missions (IAR 1986). Accessions of germplasm collected up to now are found in different field gene banks around the world and within Ethiopia (Table 2.1).

Table 2.1. Major *Coffea arabica* field genebank collections

Country	**Institute**	**Total number of accessions**
Brazil[a]	Centro Nacional de Recursos Geneticos	275
Colombia[a]	Centro Nationale de Investigaciones de Cafe´ Pedro Uribe Mejia	886
Costa Rica[a]	Centro Agronomico Tropicale de Investigacion y Enseñanza	1498
Côte d'Ivoire[a]	ORSTOM-Institut français de recherché scientifique pour le development en coopération (CATIE)	1787
Ethiopia[b]	Institute of Biodiversity Conservation and Research	4500
Ethiopia[c]	Jimma Research Station	679
India[a]	Central Coffee Research Institute, Kamataka	329
Kenya[a]	Coffee Research Foundation	592
Madagascar[a]	Recherche Agricole a Madagascar	329
Tanzania[a]	Tanzanian Agricultural Research Organization	42
USA[a]	US Department of Agriculture	292

Sources: a: Dulloo *et al.* 1998; b: IBCR database until February 2001; c: IAR 1986

The largest collection of coffee accessions is found in Ethiopia under the auspices of the Institute of Biodiversity Conservation and Research (IBCR). The current number of stored accessions is about 4,500 and more are added every year. In addition, the Jimma Agricultural Research Center of the Ethiopian Agricultural Research Organization (EARO) maintains about 600 coffee types and 700 random selections of lines that show varying resistance to the coffee berry disease (IAR 1986; Demel *et al.* 1998).

2.4.2 *In situ* conservation methods

Very little progress has been made in the development of the scientific principles needed to evaluate *in situ* genetic conservation and to monitor respective activities, despite its growing popularity and relative importance. This conservation method is still at its infancy and much more has to be done for success. However, given the nature of occurrence of plant genetic diversity, three main methods of *in situ* conservation can be recognized (Maxted et al. 1997): conservation in "gene reserves", on-farm and in homegardens.

Gene reserve conservation

This involves the location, designation, management and monitoring of genetic diversity in a particular, natural habitat. This method is the most appropriate for the bulk of wild species, whether closely or distantly related to crop plants. It permits multiple species conservation in a single reserve. The disadvantages are that the conserved material is not immediately available for agricultural exploitation and, if the management regime is minimal, little characterization or evaluation data may be available. In the latter case, the reserve management may often be unaware of the genetic diversity of species that should be conserved or even of the complete floristic composition of the reserve.

Despite the development of the *ex situ* conservation methods described above, *in situ* conservation still remains an important element of the overall strategy for the long-term conservation of the *Coffea* gene pool. However, no gene reserves exist that have been set up specifically for the conservation of the wild gene pool of *Coffea* (Dulloo et al. 1998). There was a plan to establish ‘natural parks’ in three administrative regions of Ethiopia for the *in situ* conservation of *Coffea arabica*, namely: Kaffa, Illubabor and Bale (Melaku and

Hailu, undated, unpublished proposal). Accordingly, Yayu forest was one of the candidate sites proposed for conservation. However, these efforts have not gone far beyond the proposal stage. In 1998, the Coffee Improvement Project of Ethiopia proposed the establishment of three *C. arabica* gene reserves in southwest Ethiopia (Demel et al. 1998; Paulos and Demel 2000). The sites selected were the Berhane-Kontir (ca. 9,000 ha), Boginda-Yeba (ca. 3,000 ha), and Yayu (ca. 10,000 ha) forests. Complementary, *ex situ* conservation in different agro-ecological zones was also proposed. However, little was done to practically implement these proposals.

The three forest areas proposed as gene reserves were selected based solely on their accessibility and consideration of financial constraints regarding the conservation of more sites. There are about five forest areas with known occurrences of wild coffee populations, which could be equally important for conservation. Additional sites known to have wild coffee populations include: Amora-Gedel, Dawo-Tobi, Bale mountains, Mankera, and Maji.

On-farm and/or homegarden conservation

Farm-based conservation involves the maintenance of traditional crop varieties or cropping systems by farmers within the traditional agricultural systems. On the traditional farms and homegardens, the land races are sown and harvested. Each season, the farmers keep a proportion of the harvested seed for re-sowing. Thus, the land race is highly adapted to the local environment and is likely to contain locally adapted alleles that may prove useful for specific breeding programs.

The overall advantage of this method is that it ensures the maintenance of ancient land races and those wild species dependent on traditional agriculture. However, the land races may yield less than modern cultivars and the farmers may require subsidizing and possibly monitoring to ensure continued cultivation. Contemporary economic forces tend to act against the continued cultivation of ancient land races, which are undoubtedly suffering rapid genetic erosion, if not facing extinction (Dulloo et al. 1998). However, the rate of genetic erosion in coffee compared to annual crops is presumed to be lower, since coffee is a perennial species and can last for some decades. Hence, there is a better chance of maintaining ancient landraces of coffee than of annual or short-lived crops.

Homegarden and on-farm conservation methods are similar, especially when it comes to coffee. But homegarden conservation involves a smaller scale and more species-diverse management than on-farm conservation. This form of *in situ* conservation focuses mainly on medicinal, flavoring and vegetable species (Maxted 1997). The Ethiopian homegardens have a very diverse species composition. Zemede and Ayele (1995) recorded 162 species in 111 homegardens. In the southern, eastern and southeastern parts of Ethiopia, coffee is the main species in the multi-storied perennial crops planted in the homegarden system. In fact, homegardens are the main source of coffee produced in Ethiopia, accounting for 64% of the total production. Hence, most of the locally adapted, genetically diverse traditional land races are found in homegardens. Farmers are the sole caretakers and conservationists maintaining the diversity of homegarden coffee genetic resources to date. Melaku and Hailu, (undated, unpublished proposal) identified six administrative regions that are important for the conservation of *C. arabica* on-farms and in homegardens. The regions include Kefa, Illubabor, Sidamo, Wellega, Gamo Gofa and Hararge. However, the proposal was not implemented. Hence, there is a need for developing mechanisms to ensure and encourage farmers to continue maintaining the traditional land races of coffee for the long-term conservation *in situ* in homegardens, as the global coffee market currently does not favor small-scale coffee production.

2.4.3 Complementary conservation strategies

Scientifically, the two main conservation approaches, *ex situ* and *in situ*, should not be seen as alternatives or in opposition to one another, but rather as complementary (UNCED 1992; Damaina 1996; Maxted et al. 1997; Dulloo et al. 1998). One conservation strategy or technique will act as a back up to another. *Ex situ* has the advantage of easy access and good documentation that can be used by breeders for crop improvement. Continued collection from *in situ* conservation areas can enrich the genetic resources in *ex situ* conservation and enhance use of the genetic resource for breeding. *Ex situ* can also back up *in situ* conservation by reintroducing the seeds in cases when the original adapted land races are lost due to natural or human-induced calamities (e.g., drought in Ethiopia, civil war in Rwanda, etc.). Hence, for a successful conservation of genetic resources, applying a combination of different techniques of both *in situ* and *ex situ* techniques is advantageous.

3 DESCRIPTION OF THE STUDY AREA AND SAMPLING DESIGN

3.1 The study area

3.1.1 Geographic location

The Ethiopian Highlands are divided into two massifs by the Great Rift Valley: the northwestern and the southeastern highland plateaus. Yayu forest is located in the southwestern part of the northwestern highlands, in the Illubabor Zone of Oromia State (Figure 3.1). The study area lies between 8^{o}21'-8^{o}26' N and 35^{o}45'-36^{o}03'E along the rivers Geba and Dogi.

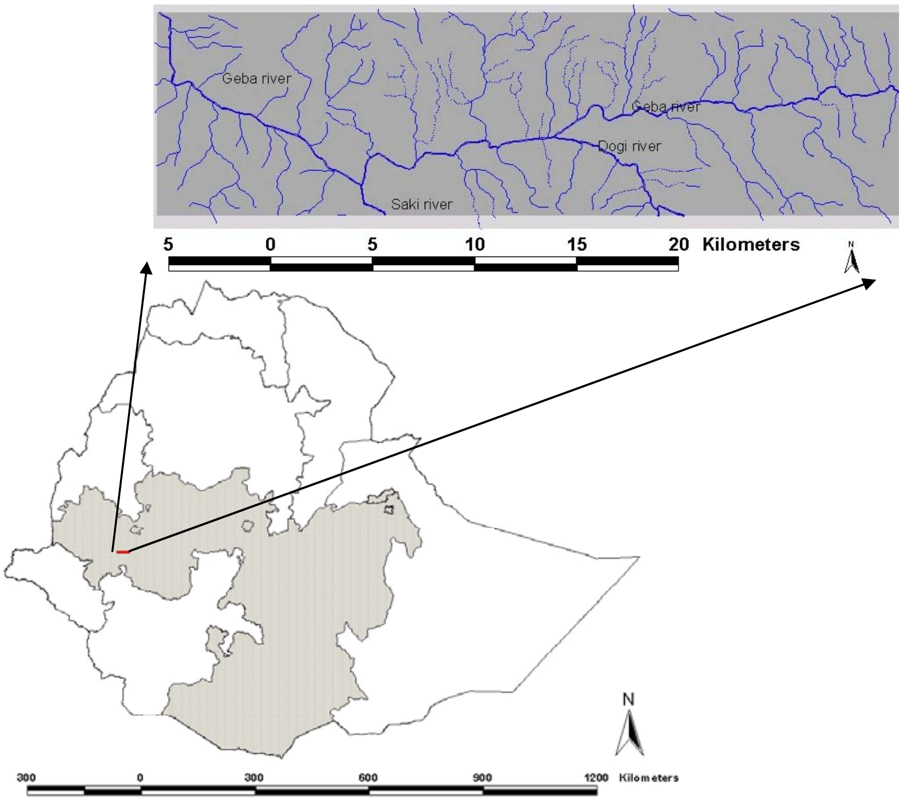


Figure 3.1. Map of Ethiopia with the Oromia State and the study area. The study area is marked red. The detail shows the drainage systems (Geba and Dogi rivers, and their tributaries, blue)

3.1.2 Geology and soils

Ethiopia is part of a large regional geological structure, the Horn of Africa. The underlying basement rock in this region consists of intensively folded and faulted Precambrian rocks, overlain by Mesozoic marine strata and Tertiary basalt traps (Westphal 1975). The Tertiary volcanic rocks include rhyolites, trachytes, tuffs, ignimbrites, agglomerates, and basalt. These rocks form the substrates of most of the Afromontane forests (Friis 1992).

Generally, the soils of the area are red or brownish ferrisols derived from volcanic parent material. The prevalence of high rainfall has masked other soil forming-factors and hence, very similar soils have developed on a variety of parent materials. Other soil groups in the area include nitosols, acrisols, vertisols, and cambisols (Tafesse 1996).

3.1.3 Topography and drainage systems

The forest area is characterized by a rolling topography, and is highly dissected by small streams and two major rivers, Geba and Dogi. The landform frequently changes from flat surfaces on the top of plateaux to very steep slopes and valley bottoms within short distances. The altitudes in the study area range between ca. 1200 m at lower river valleys to ca. 2000 m a.s.l. The study plots are located between 1250 and 1700 m.

The Dogi River drains into the Geba, which flows southwest ending in the Baro River, one of the main tributaries to the Nile, and drains most areas of the forested areas in the southwestern part of the country.

3.1.4 Climate

Generally, the forest area is hot and humid. The mean annual temperature is about 20^{o}C, ranging from a mean minimum of 12.7^{o}C to mean maximum of 26.1^{o}C. There is only a slight difference in temperature throughout the year, with the hottest months in February to April (maximum 29^{o}C) and the coldest months during July to September (minimum 12^{o}C). The mean annual rainfall is 2100 mm year^{-1}, with high variation from year to year, ranging from about 1400 to 3000 mm year^{-1}. The rainfall pattern is uni-modal, with low rainfall in January and February, gradually increasing to the peak period between May and October, and then decreasing in November and December (Figure 3.2).

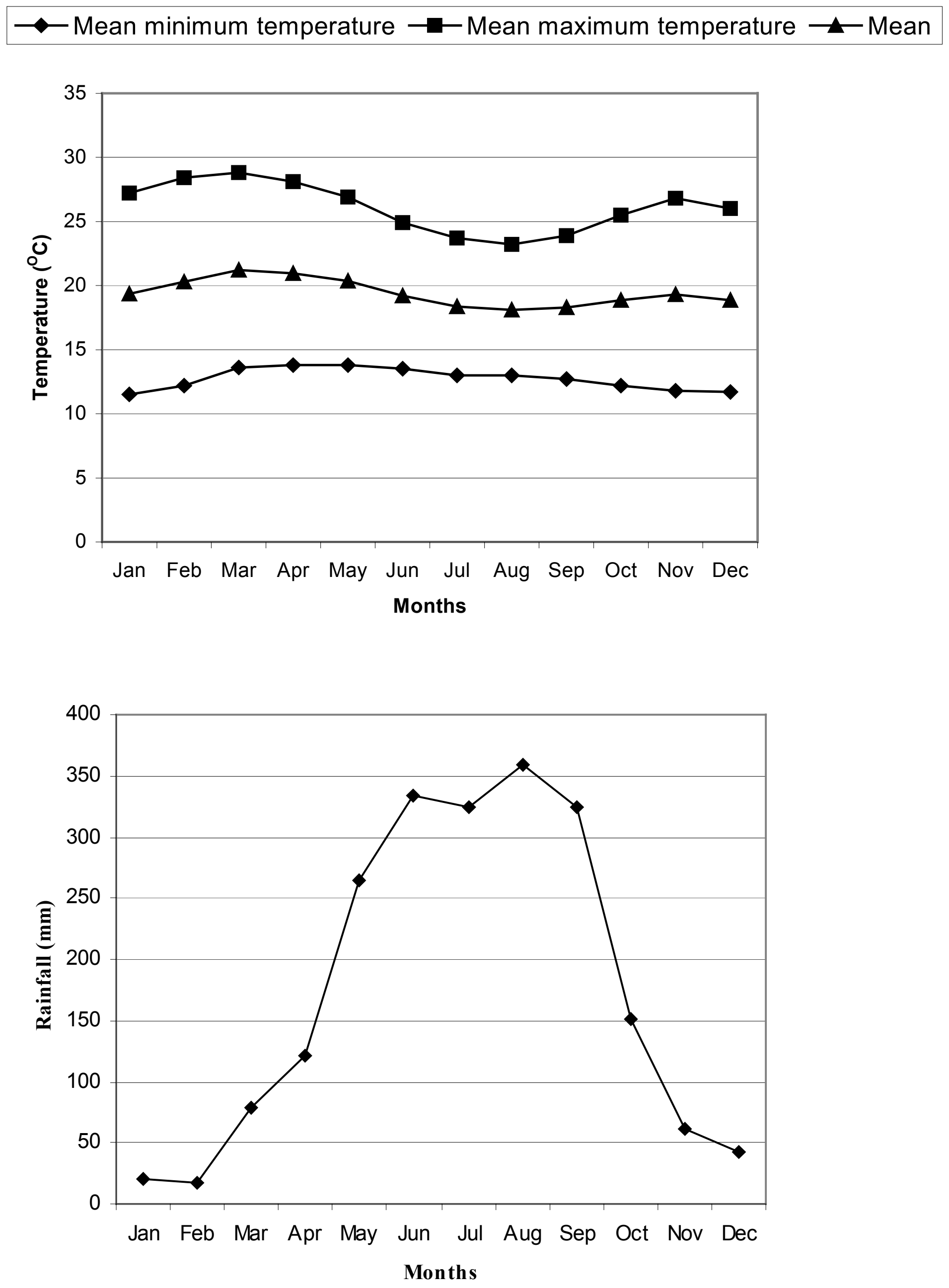


Figure 3.2. Annual rainfall and temperature distribution patterns (Source: Ethiopian Meteorological Service).

3.1.5 Human population and means of subsistence

According to the 1994 census, the population density of Illubabor is 80.3 persons per km^2. The population growth rate is one of the highest in the country, with an annual growth rate of 3.2% (Tafesse 1996). The major town in the area is Mettu, 40 km southwest of the study area; other important towns are Yayu, Hurumu and Cora. The Oromo is the major ethnic group of the population in this area. Other ethnic groups are mostly immigrants from the northern part of Ethiopia, like the Amhara and the Tigre. In the nearest towns such as Yayu and Hurumu, there are also Arabs, Gurages and Kambatas.

The major occupation in the area is agriculture, which employs over 90% of the labor force (Tafesse 1996; Tadesse and Denich 2001). The agricultural practice in the region is mainly smallholder subsistence farming. For more than 60% of the population, coffee production, processing and marketing are the major sources of employment (MCTD 1989). In towns, the major employment sources are services and government sectors. Until now there has been no industry or mining activity in the area. However, a fertilizer factory in Yayu and coal mining in some parts of the Geba river valley are soon to be in operation, which in future can provide some off-farm employment.

3.1.6 Land tenure and land-use types

In Ethiopia, the government is the sole owner of land. Landholders have only a use right, which can be revoked at any time. On average, the area of land held per family or household is between 1.25 to 2.0 hectares.

Land-use types in the Yayu district can be categorized into five major types: forest (55.8%), agriculture (35.7%), grazing land (4.4%), wetland (2.3%), and settlement and others (2.7%). Yayu district has the highest percentage forest cover compared to other districts in Ethiopia, which by far above the percent forest cover for the SW parts of Ethiopia (18%) and that of the country as a whole (2.7%) (Tafesse 1996; Tadesse et al. 2002). Most forest areas are demarcated as National Forest Priority areas. However, the local community heavily depends on the forest (Tadesse and Denich 2001), mainly for coffee, spices and honey production. The traditional method of hanging beehives on trees in the forest is used for honey production. Spices from two herbaceous plant species, *Aframomum corrorima* and *Piper capense,* are collected from naturally growing plants on the forest floors. The main food crops are maize, sorghum and teff. Coffee is the major cash crop growing in the area, followed by chat (*Catha edulis*).

3.2 Sampling design and location of plots

A systematic sampling design was used in this study to collect data on vegetation and environmental variables (Figure 3.3). In the natural high forest, sampling plots were laid in a north-south compass direction, which also coincides with the steepest altitudinal gradients from a higher altitude down to the Geba river valley, on both the northern and southern sides of the rivers. The plots were spaced 300 m along the transect lines. The distance between two neighboring transect lines was 500 m. Nested plot design was used to sample plants of different sizes and different environmental variables (Figure 3.4).

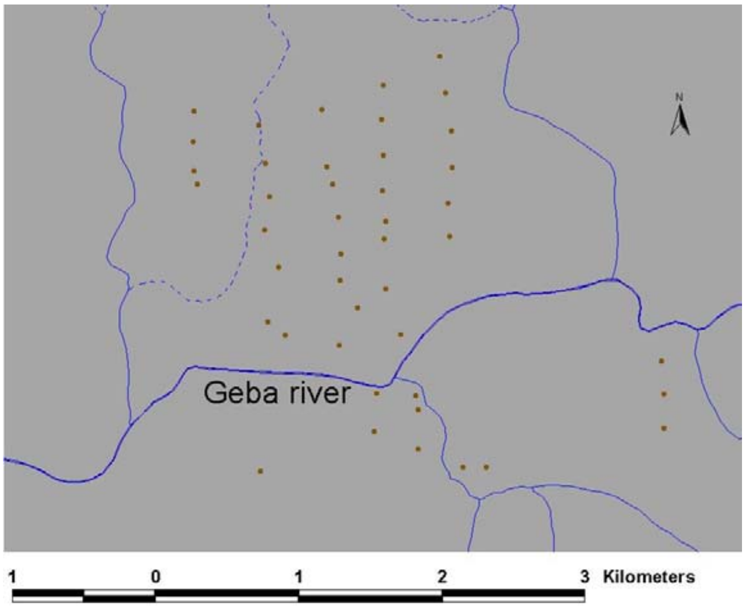


Figure 3.3. Partial view of the layout of the study plots within the forest landscape. Dots represent the study plots.

The size of the major plot was 20 m x 20 m. In the major plot, all trees with diameter at breast height (dbh) $\geq$ 5 cm were recorded. Each plant was identified to species level, and its diameter at breast height (dbh), total height and number of individuals recorded.

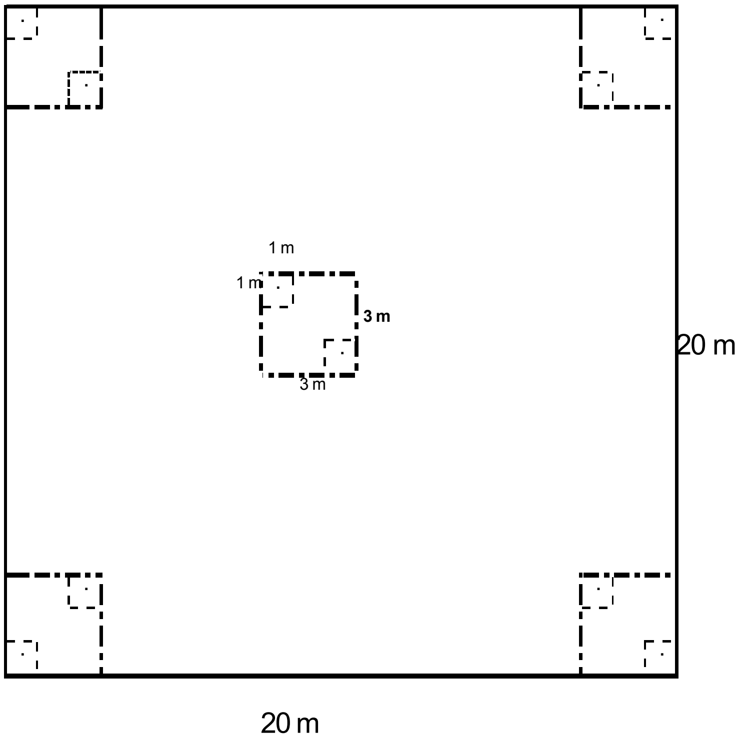


Figure 3.4. Layout of the study plot

Within the major plots, five 3 m x 3 m subplots (9 m^2) were set up, as shown in Figure 3.4. These plots were used to collect two sets of vegetation data: (1) saplings and shrubs with dbh < 5 cm and > 1.5 m in height, and (2) number of stems and species of the seedlings of all trees, shrubs and climbers. In addition, foliage density (canopy cover) was estimated at the center of these subplots using a forest densiometer (Lemmon 1956, 1957). Within each 9 m^2 subplot, two 1 m^2 subplots were used to collect data on the species and abundance of herbaceous plants. Finally, the percent cover of all plant species found within the major plot (400 m^2) was visually estimated.

From these data, the plant community structure, including the coffee population structure, was analyzed. Voucher specimens of plant species difficult to identify in the field and all plants that had fruits and flowers during the survey were collected, identified and deposited at the National Herbarium of Ethiopia (ETH), Addis Ababa University. The list of voucher specimens can be found in Appendix 8. The nomenclature of plant names in this study follows the Flora of Ethiopia (Edwards et al. 1997, 2000; Hedberg and Edwards 1989, 1995) and Cufodontis (1953-1972).

Altitude, slope and aspect were recorded in the major plots. Geographical positions were also recorded in degrees and UTM at all major plots. Soil samples were collected from the top 20 cm in each of the 9 m^2 subplots and mixed to obtain a representative sample for each plot. The samples were air-dried and passed through a 2 mm sieve prior to chemical and physical analysis, which were performed at the Water Works Design and Construction Enterprise (WWDCE) Soils lab, Ethiopia and the Institute for Plant Nutrition (IPN), the University of Bonn, following standard procedures (Allen 1989). At WWDCE, all soil samples were assayed for particle size distribution, percent moisture, CEC, available P, available K and pH and at IPN for C and N ratio. For the C-N ratio analysis, an automated C-N analyzer (EURO EA Elemental Analyzer) was used.

Abundance and frequency of all tree, shrub and climber species encountered in the study plots were compiled on a plot basis. Abundance is the number of stems per plot. Two sets of the abundance values were calculated, i.e., average abundance per plot was calculated by dividing the sum of the number of stems of a species from all plots through the total number of plots (maximum frequency). Local abundance was calculated as the ratio of the total number of stems of a species divided by its absolute frequency (as in Grace et al. 2000). Absolute frequency of a species is the number of plots in which the species was recorded. Relative frequency of a species is the ratio of absolute frequency of the species to the total number of study plots (which is equal to maximum frequency).

The basal area (BA) was calculated for all species from diameter (D) at breast height, using the formula $BA = \pi (D/2)^2$. Average canopy cover was taken for each plot as a simple mean for the canopy cover estimate in each 9 m^2 subplot using a densiometer. Aspect, or the direction that a slope faces, was measured in degrees and transformed geometrically to eastness (sin(aspect)) and northness (cos(aspect)) sensu Roberts (1986) and Palmer (1993).

4 FLORISTIC ANALYSIS OF THE UNDISTURBED FOREST VEGETATION AT YAYU: A POTENTIAL GENE RESERVE FOR *COFFEA ARABICA*

4.1 Introduction

Ethiopia has very diverse climatic conditions varying from hot and dry deserts in the lowland areas, parts of which are as deep as 116 m below sea level, to cold and humid alpine habitats in highlands, which rise to over 4000 m above sea level. Such diverse climatic conditions and habitats partly contributed to the presence of high species diversity in plants and animals, making Ethiopia one of the top 20 richest countries of the world in biodiversity (WCMC 1992). Forest is among the diverse ecosystems in Ethiopia, varying from broadleaved deciduous woodlands in the lowlands to montane rain forests in the highlands. Most of the montane rain forests occur in at altitudes ranging from 1500-2600 m in the southwestern part of the country (Friis 1992). The montane rain forests of Ethiopia are home to various endemic and indigenous plants (Mesfin 1991b). They also contain the wild gene pools of some important plants for food and agriculture such as *Aframomum corrorima, Coffea arabica* and *Piper capense*.

FAO (1981) estimates that about 40% of the land surface of Ethiopia were under forest cover about a century ago. By 1960, the forest cover of Ethiopia had dwindled to about 3.4% (Aklog 1990). The highlands of Ethiopia in fact have been highly deforested in the past 100 years, and even today, deforestation continues to be the major threat to the remaining forest areas in the southwestern part of Ethiopia. In the early 1970s, about 40% of the SW highland plateau was covered by forest (Reusing 1998). Thirty years later, the region has lost about 60% of its forest cover (Tadesse et al. 2002). This has also threatened the wild coffee populations and many other species. Nowadays, the forests with wild coffee populations are highly fragmented and isolated from each other.

Such fragmented forest areas in the highlands of SW Ethiopia are the remaining localities for the conservation of the wild gene pool of the widely distributed and cultivated Arabica Coffee (*Coffea arabica)* and other plant species (Tewolde 1990; Tadesse et al. 2002). The forests are also sources of livelihood for the local community who mainly depend on the production of coffee from the wild trees (Tadesse and Denich 2001; Tadesse et al. 2001). Hence, conservation and sustainable utilization of the forest and coffee genetic resources are currently the management priorities for the forests in the region. Demel et al. (1998) identified three forest areas, namely Yayu (also called Geba-Dogi, after the rivers draining it), Berhane-Kontir and Boginda-Yeba as potential conservation areas for the wild *C. arabica* populations. These forests were selected based on three criteria: presence of wild coffee populations, relative accessibility for research and management, and size of the forest area. Yayu forest (which is located between 793870-830490 m E and 923320-934340 m N, Zone 36) is the most accessible and the largest of the three areas. However, very little is known about the forest vegetation of Yayu and the other areas mentioned. Previous studies of the flora of the southwestern Ethiopia include those of Logan (1946), Chaffey (1979), Friis et al. (1982), Friis (1992) and Kumlachew and Tamrat (2002). Among these, Kumlachew and Tamrat (2002) classified the forest vegetation into communities based on the analysis of cover abundance of both woody and herbaceous species, and analyzed the distribution patterns of the plant communities with regard to environmental gradients. However, the scale of their analysis is too broad and not of specific locality to be of any use in management decisions and conservation planning. Other than suggesting the forest as a potential gene reserve, the previous studies by Demel et al. (1998) also did not investigate the status of the wild coffee population in the forest. However, they suggested several issues the need further investigation, which diversity of the forest flora and impacts of human use on the forest vegetation. It is known that the forest used by the local people for coffee production (Tafesse 1996; Demel 1999). The local community has traditional management systems of the forest to produce coffee. The impact of such human use of the forest on species composition, diversity and vegetation was not investigated before. Addressing such issues is important to develop a concept for conservation and sustainable use. The aims of this study are, therefore, (1) to analyze the floristic composition and identify plant community types; (2) to identify indicators for the plant communities, and (3) to assess the distribution patterns of species and plant communities with respect to environmental gradients at one specific forest area, the Yayu forest.

There is no common understanding on the nature of plant communities among ecologists (Callaway 1997; Looijen and Van Andel 1999) and the debate continues even to date. The two most polarized positions of the debate revolve around the ‘supper-organism’ concept of Clements (1916; 1936) and the ‘individualistic’ concept of Gleason (1917; 1926). Clements viewed communities as holistic and interdependent, whereas the "Gleasonians" saw plant communities as random assemblages of species with similar adaptations to the abiotic environment. There are, however, direct and indirect positive interactions within plant communities, and hence plant species in communities are more interdependent (Callaway 1997) than some current theories (Whittaker 1951; Wilson et al. 1996; Ter Braak and Prentice 1998), which regarding plant communities as random assemblages would allow. The issue of interdependence has a far-reaching implication on how we conserve and use resources in the natural world (Callaway 1997). A community is the product of several ecological processes, which include competition and facilitation (Callaway 1997). In this study the term "plant community" is simply used in the sense of describing a group of the individuals of different plant species occupying the area under study. In order to make a sound management decision in nature conservation, it is important to know which species occur together, since the loss of seemingly insignificant species may have important effects on the other species (Ehrlich 1990; Ehrlich and Wilson 1991; Noss and Cooperrider 1994). Hence, the different groups or community types identified in this study represent groups of sites that have certain internal homogeneity in their species composition, and can be considered as distinct units in which specific management or conservation measures relevant for the major species comprising the assemblage can be made.

4.2 Materials and Methods

4.2.1 The data set

Vegetation survey data from 58 study plots in the undisturbed forest were used for the analysis. Details of the sampling design are described in chapter 3.2.1 of this dissertation. Systematic sampling design was used for data collection, in which sample plots were laid along transects. The major sample plot is 20 m by 20 m, with subplots of 3 m x 3 m and 1 m x 1 m for smaller size plants in order to sample different size classes in different sized plots. Several vegetation and environmental data were collected from the plots (Chapter

3.2.1). For the analysis in this chapter, only the abundance data of trees, shrubs and climbers, and the environmental data (soils, slope altitude aspects) were used. Herbs were excluded since data from different plots were collected during different seasons, wet and dry. Most annual herbs die during the dry season, making data on herbs collected in wet and dry seasons not comparable. In the quantitative data analysis, rare species (i.e., with less than 5% relative frequency) were excluded to avoid noise, since cluster analysis is sensitive to rare species that occur in few plots, while in Principal Component Analysis (PCA) a rare species has no significant contribution (Ter Braak 1995; Grace *et al*. 2000).

4.2.2 Classification and indicator species analysis

Cluster analysis using Euclidean distances and Ward's method of hierarchical grouping was performed to identify community types (McCune & Mefford 1999). Ward's method was used since it minimizes the total within group mean sum of squares or residual sum of squares (Van Tongeren 1995). In ecology, cluster analysis is used to classify sites[*], species or variables into groups based on their similarities (Van Tongeren 1995; McCune & Mefford 1999). It helps to identify structure in the data by explicitly identifying groups in the raw data.

Statistical validity of the identified groups was evaluated using the multi-response permutation procedure (MRPP) (Biondini et al. 1985; Mielke and Berry 2001, McCune and Grace 2002). The Euclidean distance was used as a distance measure in the MRPP test. The MRPP is a nonparametric procedure for testing the hypothesis of 'no difference' between two or more groups of entities (McCune & Mefford 1999). It does not require multivariate normality or homogeneity of variances. Both cluster analysis and MRPP were performed using PC-ORD software (McCune & Mefford 1999).

A very common goal in vegetation analysis is to detect and describe the value of different species for indicating environmental conditions (McCune & Mefford 1999). In this study, the new alternative method of indicator species analysis proposed by Dufrêne & Legendre (1997) was used. This method provides a simple and intuitive solution for identifying indicator species (McCune & Mefford 1999). 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. It provides indicator values for each species in each group and tests for statistical significance using a Monte Carlo technique (McCune & Mefford 1999).

Dufrêne & Legendre's indicator species analysis is done in two steps. The first step is to obtain a classification of sites. Groups identified by any traditional classification technique or any other appropriate technique can be used. In this study, the groups identified with cluster analysis were used. The second step is to identify indicator species corresponding for the identified groups. Dufrêne & Legendre (1997) defined indicator species as the most characteristic species of each group, found mostly in a single group of the typology, and present in the majority of the sites belonging to that group. The indicator values range from 0 (no indication) to 100 (perfect indication). The novelty of this approach is that the indicator value of species is based only on within species-abundance and frequency comparisons, without any comparison among species. The analysis procedure provided in PC-ORD software (McCune & Mefford 1999) was used to perform the indicator species analysis. The statistical significance of the indicator values was tested using the Monte Carlo permutation technique, running a total of 1000 permutations.

4.2.3 Ordination of vegetation data

In ordination or gradient analysis, there are two models in use: the linear response model (Principal Component Analysis-PCA or Redundancy Analysis-RDA) and the unimodal response model (Detrended Correspondence Analysis-DCA, Correspondence Analysis-CA, or Canonical Correspondence Analysis-CCA). The choice of either of the two model types depends on the property of the data set. Performing a preliminary analysis using DCA can help to detect the appropriate model for the analysis. If the value of the longest gradient is larger than 4.0, the unimodal method should be used for analysis, since it shows that the data are very heterogeneous, and too many species deviate from the linear response model. On the other hand, if the longest gradient is shorter than 3.0, the linear method is the

[*] Note that 'sites' and 'plots' are used interchangeably in the ordination and cluster analysis of this study

preferred analysis method (Ter Braak 1995; Ter Braak and Šmilauer 1998). In this data set, the longest gradient was shorter than 3.0. (=2.141), and hence, the linear model was chosen.

Among the linear methods, PCA is more suitable to detect the differences underlying the data structure (Ter Braak 1995), because it preserves the Euclidean distance among sites (Legendre and Gallagher 2001). However, community ecologists argue that Euclidean distance (and thus PCA) is inappropriate for raw species abundance data (Legendre and Legendre 1998), leading most researchers to use the CCA method. Legendre and Gallagher (2001) propose different types of data transformations for ordinating species data, like the Chord distance (Orlóci 1967), the Chi-square, and the Hellinger distance (Rao 1995) methods. Transforming the raw data enables the use of linear models, even on a data set that has long gradients (Legendre and Gallagher 2001). Therefore, the species abundance data was transformed using the Chord-distance before running the ordination analysis. The Chord distance was chosen since it gives low weights to rare species, preserves the Euclidean distances in the gradients, produces only minor horseshoe effects in ordination, and allows the representation of species and sites in biplots (Legendre and Gallagher 2001). The PCA of the transformed data was performed using CANOCO version 4.0 (Ter Braak and Šmilauer 1998), choosing the standardized (or species-centered) PCA procedure. Then, the CanoDraw 3.1 program was used to make the PCA biplots. Ordination allows ordering objects (species and plots in this case) along axes according to their resemblance (Ter Braak 1995; McCune and Mefford 1999). The axes represent gradients in environmental variables, and hence enable get a dimensional view of the distribution patterns of sites and species with regard to variations in environmental variables.

4.2.4 Environmental variables and community type relationships

The relationships between the plant community types and the environmental variables were mainly inferred from their patterns in the species-plots biplot of the PCA. Furthermore, the relationships between PCA axes and environmental variables were obtained from the PCA of environmental variables in order to support the interpretation of the gradients in the PCA axes.

Additionally, the mean difference in environmental variables among the community types was tested using one-way ANOVA and Duncan's multiple range tests. The relationships between the environmental variables themselves and their relationship with the most characteristic species of each group or community type were also tested using Pearson's correlation coefficient. The environmental variables used in these analyses are altitude, slope, silt, clay, soil moisture content, soil pH, CEC, C-N ratio and distance from Geba river. Methods for collecting the environmental data are described in chapter 3.2.1.

4.3 Results

4.3.1 Floristic composition

A total of 220 species of flowering plants, a conifer and ferns representing 73 families were recorded from the study area (For the list of all plant species from the area and the vouchers, see Appendices 1 and 10 respectively). Out of these, there were 71 tree, 28 shrub, 27 climber and 94 herbaceous plant species. The only conifer recorded in the area is *Podocarpus falcatus*; it was, however, not recorded in the sample plots. Likewise, many species are rare in their occurrence and hence, only 160 species, representing 50 families, were recorded in the study plots. Of these, 102 species were woody plants (trees, shrubs and climbers). Quantitative data were collected for trees, shrubs and climbers species and analyzed (Table 4.1,). The results and subsequent discussions in this study are restricted to these 102 woody species, unless otherwise mentioned.

Among the woody plants, trees are the dominant growth form, represented by 59 species (57.8%), followed by shrubs (24 species, 23.5%) and climbers (19 species, 18.6%) (Table 4.1). All species recorded in the study plots are native. Most tree species have a widespread distribution (Table 4.1, Appendices 1 and 2). There are also many tree species with a restricted distribution range as either endemic or near-endemic (with some populations occurring in other floristic regions) to the Afromontane forest region (Table 4.1 and Appendix 1).

The summary of abundances, frequencies and basal areas of all plant species used in quantitative analysis, including distribution types of tree species is presented in Table 4.1. A few species of trees, shrubs and climbers dominate the forest vegetation. About 50%

of the total abundance is contributed by only three species (Rank order 1-3, Table 4.1), and nearly 99% of the total abundance is accounted for by half of the total number of species (Rank 1-51, Table 4.1). The five most abundant and common trees in the canopy layer are *Diospyros abyssinica, Albizia grandibracteata, Blighia unijugata, Trichilia dregeana* and *Celtis africana,* while most dominant trees in the lower stratum are *Dracaena fragrans, Coffea arabica, Argomuellera macrophylla, Canthium giordanii* and *Clausena anisata*. Among the climbers, the most dominant ones are *Landolphia buchananii, Paullinia pinnata, Hippocratea africana, Tiliachora troupinii* and *Combretum paniculatum*, while the dominant shrubs include *Maytenus gracilipes, Justicia schimperiana, Rhus ruspoli, Justicia betonica* and *Phyllanthus ovalifolius.*

A relatively small number of species were widespread in the forest, with only 23 occurring in more than 50% of the plots. At the other extreme, 17 species were recorded only once (frequency 1.7%), while 38 species occurred in fewer than five plots. Local abundance (the average number of individuals of a species in the plots where it occurred) varied widely. *Dracaena fragrans, Coffea arabica, Argomuellera macrophylla, Landolphia buchananii* and *Justicia betonica* had the highest local abundance, in descending order (Table 4.1). On the other hand, many species are rare even in the plots where they occur. Twenty-one of the 102 species found in the sample plots have average local abundance values of less than 5 individuals, while 64 plant species had the mean abundance of less than 5 individuals per plot. Seven species, namely: *Schefflera abyssinica, Apodytes dimidiata, Ficus mucuso, Aningeria altissima, Celtis zenkeri, Stereospermum kanthianum* and an unidentified tree specie (*Genus7 sp.)* had only one individual in just one sample plot.

Table 4.1. List of trees (T), shrubs (S) and climbers (C) in abundance rank order. The column head 'RO'= rank order of the average abundance per plot of the species (N) in a descending; i.e., rank order and 1 is the first and most abundant species. Note also other columns: N = average abundance; %N = relative abundance of the species; LN = local abundance; F = absolute frequency; %F = relative frequency; BA= basal area (m^2 ha^{-1}). The list that includes all species with authors is found in Appendix 1. Full description of the abbreviated distribution type of some trees given below is found in Appendix 3.

RO	**Species**	**Family**	**N**	**%N.**	**LN**	**F**	**%F**	**BA**	**GF**	**Distribution type**
1	Dracaena fragrans	Dracaenaceae	793	23.63	807	57	98.3	1.56	T	GC-ZI-SZfr.
2	Coffea arabica	Rubiaceae	611	18.21	669	53	91.4	1.1	T	AfrM/e
3	Landolphia buchananii	Apocynaceae	330	9.83	336	57	98.3	0.14	C	
4	Paullinia pinnata	Sapindaceae	230	6.87	262	51	87.9	0.03	C	
5	Argomuellera macrophylla	Euphorbiaceae	200	5.96	400	29	50	0.46	T	GC/n-e (-SZfr).
6	Diospyros abyssinica	Ebenaceae	156	4.65	159	57	98.3	0.85	T	GC-SZ-ZI-AfrM
7	Maytenus gracilipes	Celastraceae	135	4.02	156	50	86.2	0.33	S	
8	Albizia grandibracteata	Fabaceae	95	2.83	98	56	96.6	5.44	T	Sub-AfrM/e
9	Justicia schimperiana	Acanthaceae	85	2.52	182	27	46.6	0.14	S	
10	Canthium giordanii	Rubiaceae	77	2.3	88	51	87.9	0.88	T	Sub-AfrM/n-e (-SZfr-Arab)
11	Rhus ruspoli	Anacardiaceae	59	1.75	66	52	89.7	0.08	S	
12	Clausena anisata	Rutaceae	50	1.49	68	43	74.1	0.09	T	GC-SZfr-ZI-AfrM-Asia)
13	Blighia unijugata	Sapindaceae	47	1.39	71	38	65.5	0.55	T	GC-ZI-SZfr.
14	Canthium oligocarpum	Rubiaceae	39	1.15	62	36	62.1	0.32	T	AfrM/e
15	Trichilia dregeana	Meliaceae	33	0.97	39	48	82.8	0.86	T	Sub-AfrM/n-e
16	Hippocratea africana	Celastraceae	31	0.92	43	42	72.4	0.06	C	
17	Justicia betonica	Acanthaceae	30	0.9	292	6	10.3	0.04	S	
18	Olea capensis ssp. hochstetteri	Oleaceae	25	0.75	43	34	58.6	0.16	T	AfrM/e
19	Tiliachora troupinii	Menispermaceae	22	0.65	43	29	50	0.04	C	
20	Vepris dainelli	Rutaceae	21	0.64	28	45	77.6	0.4	T	AfrM/e
21	Teclea noblis	Rutaceae	21	0.63	32	38	65.5	0.11	T	AfrM/n-e (-SZfr)
22	Celtis africana	Ulmaceae	19	0.55	28	39	67.2	0.48	T	GC-AfrM-SZ-CP
23	Pterolobium stellatum	Fabaceae	18	0.54	46	23	39.7	0.07	C	
24	Phyllanthus ovalifolius	Euphorbiaceae	16	0.48	49	19	32.8	0.05	S	
25	Trilepisium madagascariense	Moraceae	14	0.41	33	24	41.4	2.28	T	GC-O-SZfr_Mad
26	Mimusops kummel	Sapotaceae	12	0.36	19	36	62.1	0.95	T	AfrM-SZfr
27	Eugenia bukobensis	Myrtaceae	12	0.35	53	13	22.4	0.03	T	Sub-AfrM/n-e (-SZfr)
28	Pittosporum viridiflorum	Pittosporaceae	12	0.35	23	29	50	0.08	T	Sub-AfrM/n-e (-SZfr)
29	Combretum paniculatum	Combretaceae	12	0.34	21	32	55.2	0.27	C	
30	Hippocratea sp.	Celastraceae	11	0.33	34	19	32.8		C	
31	Anthiaris toxicaria	Moraceae	10	0.29	20	29	50	1.85	T	GC-ZI-SZfr.
32	Cassipourea malosana	Rhizophoraceae	9	0.28	19	28	48.3	0.04	T	AfrM/n-e
33	Ehretia cymosa	Boraginaceae	9	0.27	11	46	79.3	1.43	T	GC-ZI-SZfr-Mad.

RO	Species	Family	N	%N.	LN	F	%F	BA	GF	Distribution type
34	Bersama abyssinica	Melianthaceae	9	0.25	16	30	51.7	0.12	T	AfrM/e
35	Ritchiea albersii	Capparidaceae	7	0.2	10	37	63.8	0.27	T	AfrM/e
36	Canthium sp1.	Rubiaceae	6	0.17	110	3	5.2		S	
37	Elaeodendron buchananii	Celastraceae	6	0.17	16	21	36.2	1.58	T	Sub-AfrM/n-e (-SZfr)
38	Senna petersiana	Fabaceae	6	0.17	36	9	15.5	0.02	T	Sub-AfrM/n-e (-SZfr-Mad)
39	Millettia ferruginea	Fabaceae	5	0.15	12	24	41.4	1.54	T	AfrM/e
40	Celtis toka	Ulmaceae	5	0.15	22	13	22.4	0.03	T	SZfr/n-e (-Arab)
41	Maesa lanceolata	Myrsinaceae	5	0.15	19	15	25.9	0.02	T	GC-ZI-Mad
42	Olea capensis ssp. welwitschii	Oleaceae	5	0.14	11	25	43.1	1.61	T	AfrM/n-e
43	Acalypha acrogyna	Euphorbiaceae	5	0.14	273	1	1.7	0.03	S	
44	Gouania longispicata	Rhamnaceae	5	0.14	89	3	5.2	0.00	C	
45	Scutia myrtina	Rhamnaceae	4	0.11	13	16	27.6	0.03	C	
46	Genus2 sp.	Family 2	4	0.1	17	12	20.7	0.00	T	
47	Capparis micrantha	Capparidaceae	3	0.1	17	11	19	0.00	C	
48	Abutilon cecilli	Malvaceae	3	0.09	34	5	8.6	0.00	S	
49	Dracaena steudneri	Dracaenaceae	3	0.08	6	25	43.1	1.16	T	Sub-AfrM/n-e (-SZfr)
50	Cissus quadrangularis	Vitaceae	3	0.08	13	12	20.7	0.02	C	
51	Hibiscus ludwigii	Malvaceae	3	0.07	47	3	5.2	1.17	S	
52	Ekebergia capensis	Meliaceae	2	0.07	9	16	27.6	0.01	T	GC-SZ-AfrM-CP
53	Oxyanthus speciosus	Rubiaceae	2	0.07	43	3	5.2	0.00	T	GC/n-e
54	Genus3 sp.	Celastraceae	2	0.06	15	8	13.8	0.00	C	
55	Urera trinervis	Urticaceae	2	0.06	14	8	13.8	0.04	C	
56	Capparis tomentosa	Capparidaceae	2	0.05	33	3	5.2	0.00	C	
57	Vernonia sp 1.	Asteraceae	2	0.05	98	1	1.7	0.00	S	
58	Pavonia urens	Malvaceae	1	0.04	16	5	8.6	0.00	S	
59	Vernonia sp 2.	Asteraceae	1	0.04	20	4	6.9	0.00	S	
60	Canthium sp2.	Rubiaceae	1	0.04	27	3	5.2	0.00	S	
61	Sapium ellipticum	Euphorbiaceae	1	0.04	4	20	34.5	1.23	T	GC-ZI-SZfr.
62	Morus mesozygia	Moraceae	1	0.03	3	22	37.9	0.69	T	GC-ZI-SZfr.
63	Dalbergia lactea	Fabaceae	1	0.03	13	5	8.6	0.00	S	
64	Acanthus eminens	Acanthaceae	1	0.03	53	1	1.7	0.00	S	
65	Jasminum abyssinicum	Oleaceae	1	0.03	53	1	1.7	0.00	S	
66	Ficus thonningii	Moraceae	1	0.02	8	6	10.3	0.08	T	GC-AfrM-ZI-SZfr
67	Galiniera saxifraga	Rubiaceae	1	0.02	9	5	8.6	0.03	T	AfrM/e
68	Ficus exasperata	Moraceae	1	0.02	5	9	15.5	0.98	T	GC-ZI-SZfr
69	Phoenix reclinata	Arecaceae	1	0.02	12	3	5.2	0.00	T	GC-ZI-SMfr-SZfr-Mad.
70	Oncinotis tenuiloba	Apocynaceae	1	0.02	18	2	3.4	0.01	C	
71	Pavetta abyssinica	Rubiaceae	1	0.02	18	2	3.4	0.01	S	
72	Ficus vallis-choudae	Moraceae	1	0.02	36	1	1.7	0.15	T	GC-SZfr-ZI-AfrM-ZI
73	Cordia africana	Boraginaceae	1	0.01	2	17	29.3	2.39	T	AfrM-SZfr-Arab
74	Croton macrostachyus	Euphorbiaceae	1	0.01	2	14	24.1	0.53	T	GC-AfrM-SZfr-ZI

RO	Species	Family	N	%N.	LN	F	%F	BA	GF	Distribution type
75	Clematis simensis	Ranunculaceae	1	0.01	14	2	3.4	0.00	C	
76	Psychotria orophila	Rubiaceae	1	0.01	27	1	1.7	0.00	T	AfrM/e
77	Vernonia auriculifera	Asteraceae	< 1	0.01	9	2	3.4	0.02	S	
78	Chionanthus milds	Oleaceae	< 1	0.01	9	2	3.4	0.00	S	
79	Rhoicissus tridentata	Vitaceae	< 1	0.01	9	2	3.4	0.00	C	
80	Rubus apetalus	Rosaceae	< 1	0.01	18	1	1.7	0.00	S	
81	Ficus lutea	Moraceae	< 1	0.01	1	12	20.7	3.17	T	GC-ZI-SZfr-Mad.
82	Ficus sur	Moraceae	< 1	0.01	2	10	17.2	0.60	T	GC-ZI-TP-SZfr
83	Ficus vasta	Moraceae	< 1	0.01	2	7	12.1	4.09	T	
84	Flacourtia indica	Flacourtiaceae	< 1	0.01	4	3	5.2	0.02	T	GC-SZ-AfrM-Asia
85	Crossopteryx febrifuga	Rubiaceae	< 1	0.01	4	3	5.2	0.01	S	
86	Grewia ferruginea	Tiliaceae	< 1	0.01	6	2	3.4	0.00	S	
87	Genus6 sp.	Celastracceae	< 1	0.01	6	2	3.4	0.00	T	
88	Phytolacca dodecandra	Phytolaccaceae	< 1	0.01	5	2	3.4	0.01	C	
89	Albizia gummifera	Fabaceae	< 1	0.01	1	7	12.1	0.55	T	Sub-AfrM/n-e (-SZfr-Mad)
90	Sida ternata	Malvaceae	< 1	0.01	9	1	1.7	0.00	S	
91	Clematis longicauda	Ranunculaceae	< 1	0.01	9	1	1.7	0.06	C	
92	Bridelia micrantha	Euphorbiaceae	< 1	0	1	5	8.6	0.17	T	GC-ZI-AfrM-SZfr
93	Prunus africana	Rosaceae	< 1	0	2	3	5.2	0.39	T	AfrM/n-e
94	Polyscias fulva	Araliaceae	< 1	0	2	2	3.4	0.18	T	AfrM/n-e (-SZfr)
95	Maytenus senegalensis	Celastraceae	< 1	0	3	1	1.7	0.00	T	
96	Schefflera abyssinica	Araliaceae	< 1	0	1	1	1.7	0.17	T	AfrM/n-e (-SZfr)
97	Apodytes dimidiata	Icacinaceae	< 1	0	1	1	1.7	0.05	T	AfrM/n-e (-SZfr-Mad-Asia)
98	Ficus mucuso	Moraceae	< 1	0	1	1	1.7	0.91	T	GC/n-e
99	Aningeria altissima	Sapotaceae	< 1	0	1	1	1.7	0.01	T	GC/n-e (-SZfr).
100	Celtis zenkeri	Ulmaceae	< 1	0	1	1	1.7	0.02	T	GC-ZI-SZfr
101	Stereospermum kanthianum	Bignoniaceae	< 1	0	1	1	1.7	0.02	S	
102	Genus7 sp.	Family 3	< 1	0	1	1	1.7	0.00	T	

At the family level, Moraceae and Rubiaceae are the most diverse with 10 species each, followed by Celastraceae with 8 species, and Euphorbiaceae and Fabaceae with 6 species each. In terms of stand density, Dracaenaceae is the most abundant, mainly due to *D. fragrans*, followed by Rubiaceae, mainly due to *C. arabica* (Table 4.1 and Appendix 3).

4.3.2 Classification and indicator species

Three vegetation groups (Figure 4.1) were identified using cluster analysis in combination with MRPP. The analysis was based on abundance data of the plant species in the study plots. One plot (Plot68) was an outlier due to the very high abundance of *Diospyros abyssinica* (mainly seedlings) and was, therefore, excluded from the analysis. The T-value statistic for the seven groups was –22.18 (P < 0.001), while the A statistic (chance-corrected within-group agreement) was 0.19. The T test statistic is based on Pearson type III distribution. The *P*-value associated with T is determined by numerical integration of the Pearson type III distribution. The A statistic is a descriptor of within-group homogeneity, and falls between 0 and 1. When the items are identical, A=1. In community ecology values of A are commonly below 0.1 (McCune and Mefford 1999). The community types varied in size, ranging from 13-23 plots.

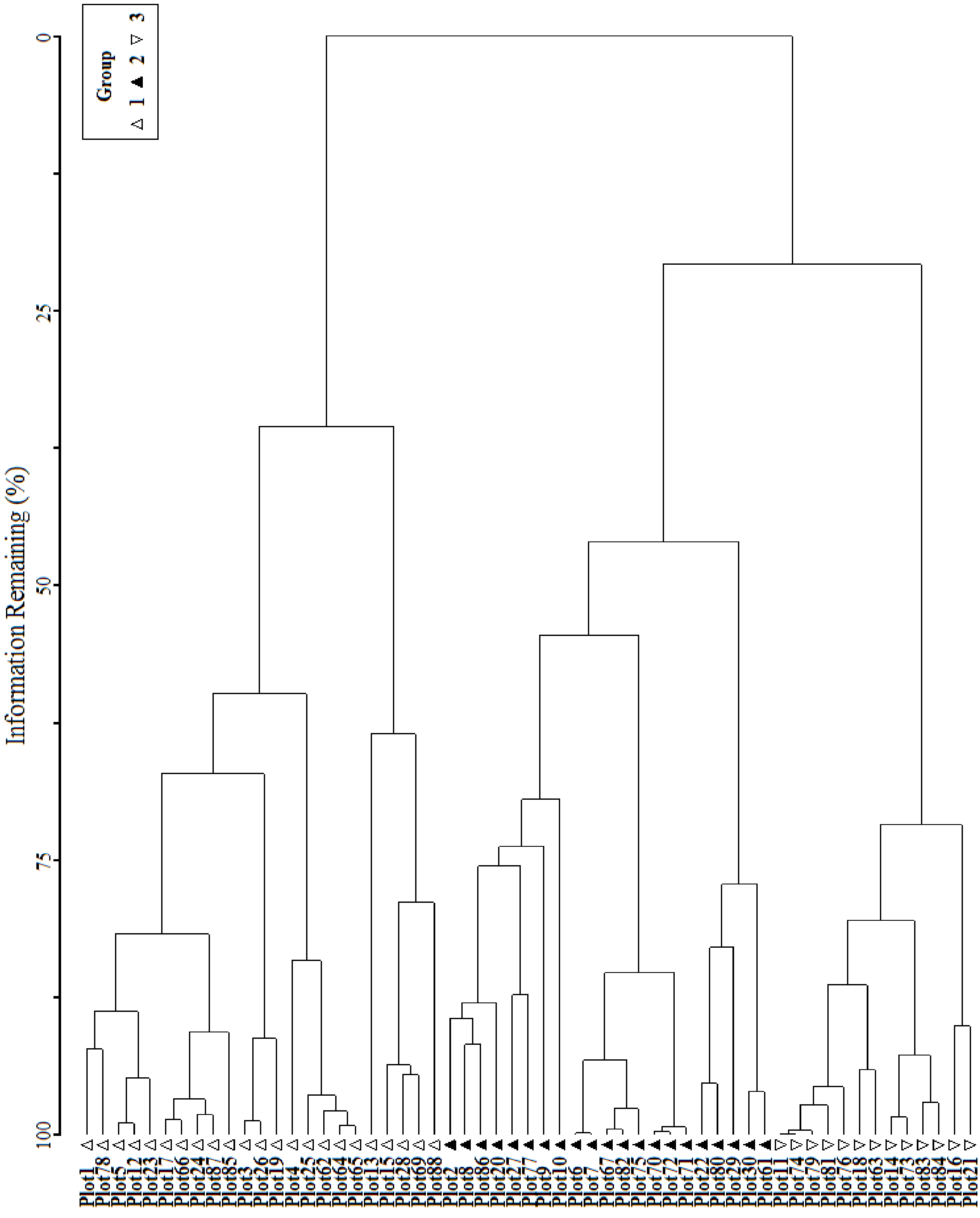


Figure 4.1. Dendrogram of the cluster analysis results of species abundance data of the undisturbed forest. Groups were identified at 25% remaining information within groups. Plots forming the same cluster group have similar symbols.

The results of the indicator species analyses for determining the degree to which species were associated with the different groups are presented in Table 4.2. Each group has 3-4 indicator species with significant indicator values.

Table 4.2. Results of indicator species analyses. Species are listed by group affinity in the ascending order of the probability values. The probability values refer to Monte Carlo tests, while values under each group are indicator values, which indicate the faithfulness of occurrence of a species within a particular group (Dufrêne and Legendre 1997). Bold values indicate significant indicator values (P < 0.5) in each group.

Species	**Probability**	**1**	**2**	**3**
Group 1				
Coffea arabica	0,001	**68**	15	12
Maytenus gracilipes	0,023	**46**	26	15
Paullinia pinnata	0,028	**47**	28	14
Cassipourea malosana	0,031	**39**	5	10
Bersama abyssinica	0,068	34	14	6
Trichilia dregeana	0,114	42	30	10
Ehretia cymosa	0,119	41	26	13
Ficus vasta	0,179	18	0	1
Prunus africana	0,182	13	0	0
Capparis tomentosa	0,192	13	0	0
Clausena anisata	0,207	41	29	7
Pittosporum viridiflorum	0,244	36	9	8
Olea capensis ssp. welwitschii	0,265	28	14	1
Maesa lanceolata	0,297	23	8	0
Senna petersiana	0,299	14	0	7
Canthium sp1.	0,435	8	0	1
Abutilon cecilli	0,447	10	2	0
Crossopteryx febrifuga	0,499	7	1	0
Albizia gummifera	0,513	10	0	5
Sapium ellipticum	0,582	18	5	14
Ficus thonningii	0,629	7	2	0
Anthiaris toxicaria	0,649	22	10	17
Cissus quadrangularis	0,688	11	4	5
Canthium giordanii	0,741	40	15	33
Bridelia micrantha	0,845	5	1	4

Species	**Probability**	**1**	**2**	**3**
Albizia grandibracteata	0,941	35	31	31
Urera trinervis	0,956	6	2	6
Pavonia urens	0,979	4	3	1
Group 2				
Argomuellera macrophylla	0,003	0	**50**	25
Justicia betonica	0,007	0	**29**	0
Ekebergia capensis	0,027	3	**34**	0
Celtis africana	0,083	11	47	11
Pterolobium stellatum	0,084	3	33	14
Flacourtia indica	0,085	0	14	0
Justicia schimperiana	0,091	10	35	6
Hibiscus ludwigii	0,096	0	14	0
Diospyros abyssinica	0,168	26	42	30
Phyllanthus ovalifolius	0,170	6	28	2
Vernonia sp.	0,239	0	12	1
Galiniera saxifraga	0,261	2	11	0
Gouania longispicata	0,267	0	9	0
Dracaena steudneri	0,277	9	27	7
Mimusops kummel	0,291	22	32	9
Cordia africana	0,314	5	18	7
Rhus ruspoli	0,367	34	39	15
Blighia unijugata	0,391	22	32	12
Olea capensis ssp. hochstetteri	0,417	8	33	26
Millettia ferruginea	0,424	4	22	20
Combretum paniculatum	0,454	12	28	17
Eugenia bukobensis	0,518	2	15	9
Ritchiea albersii	0,591	20	28	16
Dalbergia lactea	0,592	1	8	2
Capparis micrantha	0,605	10	11	1
Genus3 sp.	0,617	3	9	3
Hippocratea sp.	0,647	6	18	9
Genus2 sp.	0,656	3	12	9
Hippocratea africana	0,657	20	30	24
Elaeodendron buchananii	0,739	4	20	11
Canthium sp2.	0,871	2	3	0
Canthium oligocarpum	0,902	18	25	20

Species	**Probability**	**1**	**2**	**3**
Ficus exasperata	0,938	4	6	2
Scutia myrtina	0,960	9	11	6
Group 3				
Dracaena fragrans	0,001	31	17	**53**
Teclea noblis	0,028	10	18	**46**
Phoenix reclinata	0,030	0	0	**15**
Vepris dainelli	0,059	20	20	43
Tiliachora troupinii	0,115	7	16	34
Trilepisium madagascariense	0,127	1	9	38
Morus mesosygia	0,332	8	11	23
Celtis toka	0,403	2	8	17
Ficus lutea	0,512	9	2	13
Ficus sur	0,583	4	4	10
Oxyanthus speciosus	0,698	0	1	7
Landolphia buchananii	0,750	35	28	36
Croton macrostachyus	1,000	6	7	7

In this analysis, a plant species with a significant indicator value at $P < 0.05$ is considered as an indicator species of the group (Table 4.2.). Group 1 comprises 23 plots; 28 species are associated with this group. The group has 4 indicator species with significant indicator values, namely: *Coffea arabica*, *Maytenus gracilipes, Paullinia pinnata,* and *Cassipourea malosana*. There are many other species with high indicator values, like *Trichilia dregeana, Ehretia cymosa,* and *Canthium giordanii*. However, they also have high indicator values in the other groups, and hence are not significant indicators of the group (Table 4.2). However, those species with indicator values of $\geq$ 15 are considered as common species of the group. The common tree species forming the canopy layer above 15 m in the group are: *Albizia grandibracteata, Anthiaris toxicaria, Blighia unijugata, Cassipourea malosana*, *Diospyros abyssinica, Mimusops kummel, Olea capensis* ssp. *welwitschii, Prunus africana, Sapium ellipticum,* and *Trichilia dregeana*. Common tree species in the middle storey of 10-15 m include *Bersama abyssinica, Canthium giordanii, Canthium oligocarpum, Ficus vasta, Maesa lanceolata, Pittosporum viridiflorum, Ritchiea albersii* and *Vepris dainelli,* while small trees and shrubs commonly occurring in the lower storey of less than 10 m are *Clausena anisata, Coffea arabica, Dracaena fragrans, Ehretia cymosa, Maytenus gracilipes, Rhus ruspoli,* and *Senna petersiana. Coffea arabica* is the most dominant species in this stratum. The major climber species in this group are *Hippocratea africana, Landolphia buchananii,* and *Paullinia pinnata.* Most of the tree species in this group are Afromontane endemics or near-endemics (e.g., *Bersama abyssinica, Cassipourea malosana, Canthium oligocarpum*, *Coffea arabica, Vepris dainelli, Albizia grandibracteata, Olea capensis* ssp. *welwitschii, Prunus africana, Trichilia. dregeana,* and *Mimusops kummel*), and some Guineo-Congolian forest species (e.g., *Anthiaris toxicaria, Ehretia cymosa,* and *Dracaena fragrans*).

Group 2 comprises 21 plots; 34 species are associated with the group. The group has 3 indicator species with significant indicator values, namely: *Argomuellera macrophylla, Justicia betonica* and *Ekebergia capensis* (Table 4.2). The common tree species in the canopy layer are: *Albizia grandibracteata, Blighia unijugata*, *Celtis africana, Cordia africana, Croton macrostachyus, Diospyros abyssinica, Elaeodendron buchananii, Ekebergia capensis, Mimusops kummel,* and *Trichilia dregeana.* Common tree species in the middle storey include *Canthium giordanii, Canthium oligocarpum, Millettia ferruginea, Ritchiea albersii, Olea capensis* ssp. *hochstetteri, Teclea noblis* and *Vepris dainelli.* Small trees and shrubs with higher representation in the lower storey include: *Argomuellera macrophylla, Celtis toka, Clausena anisata, Dracaena fragrans, Dracaena steudneri, Eugenia bukobensis, Justicia betonica, Justicia schimperiana, Maytenus gracilipes, Phyllanthus ovalifolius,* and *Rhus ruspoli. Argomuellera macrophylla* is the most abundant plant species in this storey. The major climber species in this community type are *Combretum paniculatum*, *Gouania longispicata, Hippocratea africana, Landolphia buchananii, Paullinia pinnata, Pterolobium stellatum,* and *Tiliachora troupinii*. The major tree species in this community are Afromontane endemic and near-endemic (e.g., *Albizia grandibracteata, Ekebergia capensis, Millettia ferruginea, Mimusops kummel, Olea capensis* ssp. *hochstetteri, Ritchiea albersii, Trichilia dregeana,* and *Vepris dainelli*). There are also many Guineo-Congolian forest tree species, some of which are the dominant species in the group (e.g., *Argomuellera macrophylla, Blighia unijugata*, *Celtis africana, Dracaena fragrans, Ehretia cymosa, Sapium ellipticum,* and *Trilepisium madagascariense*).

Group 3 comprises 13 plots; 13 species are associated with this group. It has three indicator species with significant indicator values, namely: *Draceana fragrans, Teclea noblis,* and *Phoenix reclinata* (Table 4.2). The common tree species in the canopy layer are: *Albizia grandibracteata, Anthiaris toxicaria, Diospyros abyssinica, Morus mesozygia,* and *Trilepisium madagascariense*, while the common tree species in the middle storey are *Canthium giordanii, Olea capensis* ssp. *hochstetteri, Phoenix reclinata, Ritchiea albersii, Teclea noblis* and *Vepris dainelli.* The common species in the lower storey are *Argomuellera macrophylla* and *Dracaena fragrans;* the common climber species in this group are *Combretum paniculatum, Landolphia buchananii* and *Tiliachora troupinii*. Like the other two groups, this group also has many Afromontane endemic and near-endemic species (e.g., *Albizia grandibracteata, Olea capensis* ssp. *hochstetteri, Teclea noblis,* and *Vepris dainelli*), and the Guineo-Congolian forest species (e.g., *Argomuellera macrophylla, Anthiaris toxicaria, Diospyros abyssinica, Dracaena fragrans Morus mesozygia,* and *Trilepisium madagascariense*).

4.3.3 Ordination

Ordination was performed using PCA (Ter Braak and Šmilauer 1998). The results of the PCA ordination are presented in Figure 4.2, Tables 4.4 and 4.5. The first four PCA axes explain 81.1% of the variation in species data, with the first two axes accounting for 64.1% of the variation (Table 4.4).

Table 4.3. Percentage variance explained by the first four PCA axes

Axis	**I**	**II**	**III**	**IV**	**Total variance**
Eigenvalues	0.408	0.233	0.111	0.058	1
Cumulative % variance of species data	40.8	64.1	75.3	81.1	
Total eigenvalues	1				

The distribution pattern of most species in the species-plots biplot was densely concentrated around the center of the ordination space where the two axes cross each other. For clarity, only the indicator species for the community types were shown in the biplot (Figure 4.2). A list of the plant species with an absolute value species score greater than or equal to 0.1 in the first axis is presented in Table 4.5. The value of the species scores under different axes show how strongly that species is correlated with the axes.

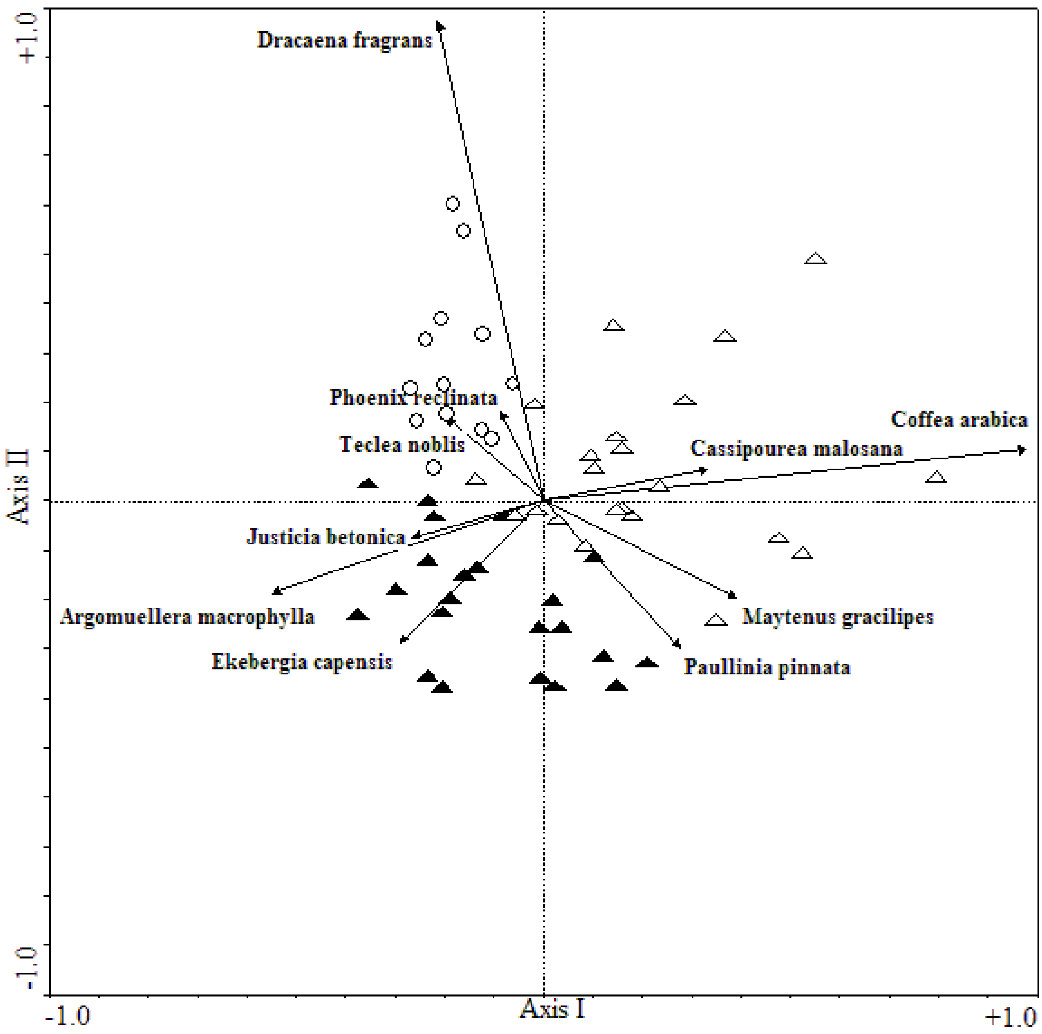


Figure 4.2. PCA biplot of species and plots, and the community types identified by cluster analysis. Only species with significant indicator value are shown. Group membership of plots is identified by symbols: △ - group 1; ▲- group 2; **O**- group 3

Coffea arabica is negatively correlated with many species such as *Argomuellera macrophylla* and *Justicia betonica* (Figure 4.2; Table 4.4). The angle between the arrows of *C. arabica* and *Dracaena fragrans* is almost perpendicular, showing that the two species are not correlated (Figure 4.2). The direction of the arrows show the direction towards which the abundances of the species increases most, while the length shows the rate of change in that direction. The angle between the arrows of species and the PCA axes indicates how strongly correlated they are: a narrow angle shows strong correlation. For example, *C. arabica* is strongly correlated with the first axis (Axis I) of the PCA (Figure 4.2).

The first PCA axis is positively correlated with *Coffea arabica, Cassipourea malosana, Maytenus gracilipes, Paullinia pinnata, Rhus ruspoli,* and *Trichilia dregeana,* while it is negatively correlated with *Albizia grandibracteata, Argomuellera macrophylla, Justicia betonica, Diospyros abyssinica,* and *Dracaena fragrans*. The second axis is positively correlated with *Dracaena fragrans, Canthium giordanii, Trilepisium madagascariense, Croton macrostachyus, Anthiaris toxicaria, Teclea noblis, Vepris dainelli* and *Coffea arabica*, while it is negatively correlated with *Clausena anisata, Trichilia dregeana, Argomuellera macrophylla, Maytenus gracilipes, Gouania longispicata, Galiniera saxifraga, Ekebergia capensis, Rhus ruspoli* and *Paullinia pinnata.* (For a list of further species and their respective relationships with the axes, see Table 4.5).

Table 4.4. Species scores of the PCA result. Shown here are only those species with |species score|≥ 0.1

	Species	**Axis I**	**Axis II**	**Axis III**	**Axis IV**
1	Coffea arabica	0.9769	0.1072	0.1822	0.0068
2	Argomuellera macrophylla	-0.5484	-0.1863	0.7781	0.1258
3	Maytenus gracilipes	0.3903	-0.1922	-0.2136	0.1631
4	Trichilia dregeana	0.3398	-0.1635	-0.0669	0.2867
5	Cassipourea malosana	0.3327	0.0635	0.0519	0.0727
6	Canthium sp2.	0.3042	-0.1571	0.0678	0.1375
7	Ekebergia capensis	-0.2901	-0.2865	0.167	-0.2065
8	Paullinia pinnata	0.2757	-0.2961	-0.4057	-0.0544
9	Canthium sp1.	0.2735	-0.0298	0.0995	-0.0437
10	Justicia betonica	-0.2669	-0.0712	0.3648	0.2534

	Species	Axis I	Axis II	Axis III	Axis IV
11	Abutilon cecilli	0.2657	-0.1043	0.1525	-0.0349
12	Bersama abyssinica	0.2474	-0.0499	-0.1143	-0.022
13	Anthiaris toxicaria	0.2423	0.2002	0.1636	0.1064
14	Canthium giordanii	0.2353	0.2649	0.1741	-0.1571
15	Rhus ruspoli	0.217	-0.2904	-0.0348	0.1012
16	Dracaena fragrans	-0.2108	0.9724	0.0014	0.0043
17	Ehretia cymosa	0.2029	-0.0543	0.0908	0.2049
18	Galiniera saxifraga	-0.2001	-0.2214	0.3505	-0.0313
19	Hippocratea africana	-0.1998	0.0902	0.3153	0.0011
20	Tiliachora troupinii	-0.1968	0.0564	-0.1687	0.2082
21	Teclea noblis	-0.194	0.1689	0.2315	0.0613
22	Trilepisium madagascariense	-0.1719	0.2066	0.0421	0.0964
23	Scutia myrtina	0.1659	0.0604	-0.1017	0.1883
24	Landolphia buchananii	0.157	0.0047	-0.3134	0.9188
25	Eugenia bukobensis	-0.1508	-0.0233	0.3168	0.0367
26	Maesa lanceolata	0.1448	0.0128	-0.0935	0.0967
27	Diospyros abyssinica	-0.1439	0.0145	0.4667	-0.22
28	Urera trinervis	0.1427	-0.0437	0.0324	0.0149
29	Morus mesosygia	0.1384	0.0117	-0.0544	-0.028
30	Albizia grandibracteata	-0.1342	0.0662	0.0573	0.1006
31	Gouania longispicata	-0.1302	-0.2112	0.116	0.1621
32	Croton macrostachyus	-0.1134	0.2036	-0.1106	0.0508
33	Vepris dainelli	-0.1113	0.1093	-0.0571	-0.0397
34	Celtis toka	-0.1044	-0.0133	0.2191	-0.1118
35	Cissus quadrangularis	0.1032	0.0431	-0.0903	0.0629
36	Clausena anisata	0.1023	-0.1634	-0.1652	-0.1276

4.3.4 Relationships between environmental variables and community type

The three groups identified by cluster analysis are distinct and show a clear distribution pattern with respect to the axes in the PCA species-plots biplot (Figure 4.2). Group 1 is mainly positively correlated with the first axis, while some plots in the group are positively and others negatively correlated with the second axis. Group 2 is negatively correlated with both the first and the second axis. On the other hand, Group 3 is mainly positively correlated with second axis, and slightly negatively correlated with first axis (Figure 4.2). The first axis is the strongest gradient, accounting for 40.8% of the variation, while the second axis accounts for 23.3% of the variation species distribution (Table 4.3). The gradients in the PCA axes can be attributed to some environmental variables (Table 4.5). The gradient in first axis increases with decreasing slope, silt and pH, and with increasing distance from Geba river. On the other hand, the gradient in the second axis increases with altitude, silt, soil moisture, CEC, distance from Geba river and C-N ratio.

Table 4.5. Correlations between environmental variables and PCA axes

Environmental variable	Axis I	Axis II
Altitude	0.269	0.696
Slope-percent	-0.506	-0.084
Sand	0.323	-0.314
Silt	-0.535	0.327
Soil moisture	-0.351	0.093
pH	-0.519	-0.208
CEC	-0.340	0.243
Distance from Geba river	0.625	0.458
C : N ratio	0.170	0.718

The mean difference in these environmental variables was tested using the one-way analysis of variance and Duncan's multiple range tests. The three groups differ significantly from each other with regard to three environmental variables, namely: altitude ($F_{2,54} = 5.671$, $P < 0.01$), slope ($F_{2,54} = 3.510$, $P < 0.05$) and distance from the Geba river ($F_{2,54} = 10.841$, $P < 0.001$). The summary of the mean difference between groups with regard to the significantly varying environmental variables is presented in Table 4.6.

Table 4.6. Summary of the Duncan's multiple range test of difference in environmental variables among the three groups. The numbers in the columns of each variable show Mean; ±Standard deviation. Means that are not significantly different from each other at $P < 0.05$ are marked with the same letter in superscript.

Group	Altitude	Slope	Distance from river
1	1450.0^{a}; ±61.6	26.8^{a} ; ±11.2	1100.9^{a}; ±444.0
2	1388.3^{b}; ±68.0	43.0^{b}; ±27.5	513.3^{b}; ±418.7
3	1439.9^{a}; ±58.4	40.1^{ab}; ±20.4	837.7^{a}; ±367.3

Group 1 has higher mean altitude and distance from the Geba river, and lower mean slope (Table 4.6). In contrast, Group 2 has lower altitude, steeper slope and shorter distance from the Geba river. Group 3, however, has steeper slope and higher altitude and an intermediate distance from the Geba river. Groups 1 and 2 differ significantly ($P < 0.05$) from each other in mean altitude, slope, and distance from the Geba river; and groups 2 and 3 differ from each other significantly ($P < 0.05$) in terms of mean altitude and mean distance from the Geba river. There is no significant difference between groups 1 and 3 in terms of the environmental variables; the differences between these groups are only in terms of plant species associated with groups (Table 4.2).

There is a strong correlation between the indicator species of the community types and some environmental variables. Abundance of *Coffea arabica* (of Group 1) decreases with increasing slope ($r = -0.305$, $P < 0.05$), and increases with increasing distance from the Geba river ($r = 0.327$, $P < 0.05$). Similarly, the abundance *Argomuellera macrophylla* (Group 2) decreases with increases in altitude ($r = -0.43$, $P < 0.01$) and distance from the Geba river ($r = -0.453$, $P < 0.01$). On the other hand, the abundance of *Dracaena fragrans* does not show any significant relationship ($P > 0.05$) with the three major terrain-related environmental variables.

4.4 Discussion

4.4.1 Floristic composition

Tropical forests have the highest species diversity among forest ecosystems of the world (Wilson 1988; Gentry 1992). The East African Mountains are considered as one of the richest and most diversified regions of Africa with respect to flora (Coetzee 1978; Tamrat

1994). However, diversity decreases towards the north, and only few species common to the rest of the East African Mountains are to be found in the Ethiopian highlands (Friis et al. 1982; Tewolde 1991; Tamrat 1994).

The results of this study show that Yayu forest is one of the most diverse forests in Ethiopia with respect to plant species diversity. Several authors have studied the Afromontane forest vegetation of Ethiopia, i.e., the dry Afromontane forest (Tamrat 1994; Demel 1995; Demel and Tamrat 1995; Tadesse 1998) and the Afromontane rain forest (Friis et al. 1982; Friis 1992; Mesfin and Lisanework 1996; Abayneh 1998; Kumelachew and Tamrat 2002). Direct comparison of the species diversity with other forest is not feasible due to differences in size of the forests, survey methods and objectives. However, the over all species richness of the forests can give a general impression of their diversity. In this regard, with about 220 plant species, Yayu forest excels other similar rain forests like the Harrena forest, in SE Ethiopia (128 species; Mesfin and Lisanework 1996), and the Bonga forest in SW Ethiopia (154 species; Friis et al. 1982). Other studies also show that the forests at Gore and Yayu are the richest in species (Friis et al. 1982). The number of plant species in Yayu forest is also higher than that of most the dry Afromontane forests of Ethiopia; for example, Chilimo forest (90 species, Tadesse 1998); Jibat forest (54 species, Tamrat 1994); Dakata Valley forest (202 species, Demel 1995). Wofwasha forest is the only forest known to have a higher number of plant species than Yayu, with more than 250 species (Demel and Tamrat 1995).

Yayu forest, however, is poor in the diversity of plant species endemic to Ethiopia. Only three endemic species, namely: *Millettia ferruginea, Phyllanthus limuensis,* and *Vepris dainelli* were recorded in the area. *Phyllanthus limuensis,* however, is rare and was not even recorded in any of the sample plots. The proportion of endemic plant species in other Afromontane forests of Ethiopia is high, ranging between 11-15% of the total number of species (Friis et al. 2001). For instance, Demel and Tamrat (1995) report that 12% (29 species) of the plant species occurring in Wofwasha forest are endemic. Low diversity in endemic plant species, however, is a common feature of all montane rain forests of SW Ethiopia (Friis et al. 2001). On the other hand, Yayu forest is more diverse in rain forest tree species such as the Guineo-Congolian forest vegetation species, which do not occur in other similar forests of Ethiopia and is discussed in more detail in the following section.

4.4.2 The plant community types and differences in environmental variables

Community ecology has a long tradition in which discrete habitats or community types are distinguished in terms of species composition or environmental variables (Van Tongeren 1995; McCune and Grace 2002). Nowadays, different numerical classification methods are commonly used as alternatives to the subjective classification methods like the Zuerich-Montpellier phytosociological system in order to identify internally homogeneous and distinct groups (Leps and Simlauer 2003). The major distinguishing features of the three groups identified in this study are the dominant plant species in the lower stratum (below 10 m) of small trees and shrubs. The use of indicator taxa is commonly practiced in reserve selection (Balmford 1998; Howard et al. 1998). Identifying community that have some indicator species and understanding the relation of the community types with variations in environmental variables are important for making decisions in reserve design.

It has long been established that the patterns in vegetation are correlated with gradients in environmental variables (Whittaker 1967; Smith and Huston 1989). The multivariate analysis including classification and ordination can provide more detailed and comprehensive information on the patterns in vegetation and the response of plant species to the underlying gradients (Gauch 1982; Ter Braak 1995). In Yayu forest, the plant species distribution, and hence the patterns in forest vegetation are mainly influenced by the gradients in terrain variables such as altitude, slope and distance from the river banks. Vegetation in mountainous regions responds to small-scale variation in terrain (Bolstad et al. 1998), because, micro-climatic conditions affecting plant species distribution like temperature and soil moisture vary with changes in the terrain characteristics.

Altitude is an important terrain variable, since it affects atmospheric pressure, moisture and temperature, which in turn influence the growth and development of plants, and the patterns in vegetation distribution (Hedberg 1964). The vegetation types in SW Ethiopia are mainly delimited by altitude (Friis 1992; Bonnefille et al. 1993; Kumelachew and Tamrat 2002). Slope also has a strong influence on soil chemical properties, since the soils on steeper slopes are influenced by bedrock and tend to be less moist and less acidic (Tewolde 1986). Hence, slope strongly affects the composition and structure of forest vegetation. Maximum tree size tends to decrease with increasing slope, while abundance of stems tends to increase (Takyu et al. 2002). However, different species respond differently to gradients. Distance from river bank and soil moisture content are also known to be inversely related (Carr 1998), and hence play an important role in zonation of vegetation along riversides. Carr (1998) observed different vegetation zones along the Omo river in SW Ethiopia.

The patterns of occurrence of the sites or plots representing the three groups or community types are influenced by the three terrain variables mentioned above and the resulting micro-climate and soil characteristics (texture, moisture content and chemical properties) as a result of their direct or indirect impacts. The dominance of coffee in Group 1 (*Coffea arabica* group) is, for instance, not random, but related to the gradients in the environmental variables; this group has the lowest mean slope and the highest mean altitude. It also has the longest mean distance from the Geba river. Similar to the results in this study, Tewolde (1966) observed that the abundance of coffee decreases with increasing. On the other hand, contrary to Tewolde's observations at Yassera and Toba forests (Tewolde 1986), it appears that the coffee occurrence at Yayu increases with increasing altitude. This is quite possible, since Yayu forest lies in the lower half of the altitudinal range in which coffee occurs in the natural forests of SW Ethiopia, while Yassera and Toba are located in the upper half, at altitudes ranging from 1600 m to 1850 m (Tewolde 1978; 1986). The altitudinal distribution range of the wild coffee populations in SW Ethiopia is between 1000 m and 2000 m (Meyer 1965; Friis 1979). Similarly, the abundances of coffee trees decrease with increasing altitude in Bonga forest at areas higher than 1700 m (Abayneh 1998). On the other hand, the upper altitudinal limit for coffee in Harrena forest, SE Ethiopia, is 1700 m and the lower limit is defined by changes in vegetation composition and moisture (Mesfin and Lisanework 1996). The maximum development of the coffee trees and abundance in Harrena, however, occurs between 1390 m and 1450 m, and 1550 m and 1600 m (Mesfin and Lisanework 1996).

Contrary to the *Coffea arabica* group, the *Argomuellera macrophylla* group is characterized by very steep slope, lower altitude and shorter distance from the Geba river.

The strong negative correlation between altitude and *A. macrophylla* indicates that the forest area is perhaps near the upper limit of the altitudinal range of the species. The *Dracaena fragrans* group, on the other hand, holds an intermediate position in the gradients of the major environmental variables influencing the distribution patterns of the community types. The plots representing the group have steeper slopes than those of the *C. arabica* group, and are at higher altitude and greater distance from the Geba river than that of the *A. macrophylla* group.

The observed species composition in the three community types is similar to the general trend of the forest vegetation types or zones occurring in SW Ethiopia. *Argomuellera macrophylla,* the most dominant and best indicator species of Group 2, is one of the characteristic species of the dry peripheral semi-deciduous Guineo-Congolian forests (Friis 1992). Even though Yayu forest is located at a much higher altitude than the areas where such forests have been described (450-600 m), a large proportion of the study plots (37%) fall under Group 2. This can be due to the drying effect of steep slopes (Tewolde 1986), which may give a comparative advantage to the plant species from a relatively lower altitude and drier area enabling them to dominate the vegetation on the very steep areas along the Geba river.

The most dominant and best indicator species of Group 3, *D. fragrans,* is also one of the characteristic species in the small tree and shrub layer of the transitional rain forest (Friis 1992). Many tree and shrub species associated with the group are also characteristic species of this forest type. Beside the similarity of the species composition of the vegetation in this group to that in the transitional rain forest, the altitudinal range and overall climatic conditions also match the description of this forest type (Friis 1992). The most dominant and best indicator species of Group 1, *C. arabica,* is considered as one of the characteristic species of the Afromontane rain forest vegetation (Friis 1992). The majority of the tree and shrub species associated with the group are also characteristic species of this forest type. Even though the mean altitude of the group is slightly lower than the lower limit of the altitudinal range of the Afromontane rain forest, many plots are located at sites higher than the 1500 m lower limit of this forest type. This group represents the major community type, with about 40% of the plots investigated in the study belonging to the group. Many characteristic species of both the Afromontane and the transitional rain forests were recorded in this study. The list of plant species belonging to the transitional rain forest includes *Aningeria altissima, Celtis zenkeri, Dracaena fragrans, Elaeodendron buchananii, Eugenia bukobensis, Ficus exasperata, Phoenix reclinata, Trichilia dregeana, Trilepisium madagascariense,* and *Vepris dainelli.* Characteristic plant species of the Afromontane rain forest that are also either endemic or near-endemic to the Afromontane region recorded in this study are *Apodytes dimidiata, Bersama abyssinica, Canthium oligocarpum, Cassipourea malosana, Coffea arabica, Galiniera saxifraga, Millettia ferruginea, Olea capensis* ssp. *hochstetteri, Olea capensis* ssp. *welwitschii, Polyscias fulva, Prunus africana, Psychotria orophila, Ritchiea albersii, Schefflera abyssinica,* and *Teclea noblis*.

From its species composition, climatic conditions and topographic position, Yayu forest can best be described as a transitional rain forest. Transitional rain forest occurs on the mountain escarpments, mainly in river valleys and at areas of high water table at altitudes of 500-1500 m. The climatic conditions of Yayu forest (Chapter 3.1.4) are also quite similar with that of transitional rain forest (Friis 1992 and Chapter 2.1.1, B). Two groups or community types: the *Argomuellera macrophylla* (Group 2) and the *Dracaena fragrans* (Group 3) are more dominated by characteristic species of the transitional rain forest and the dry peripheral semi-deciduous Guineo-Congolian forest than the *Coffea arabica* group. The two groups are also relatively at lower altitude and close to Geba river. With increase in altitude and distance from Geba river, however, dominance of the characteristic species of the Afromontane forest type increases, like the case of the *C. arabica* group. The lesson learnt from this result regarding the ecological distribution of coffee is that in areas where the slope is gentle, and it is within the geographic and climatic range of the species, maximum density of stems can be expected at altitude of about 1500 m.

4.4.3 Implications for the conservation of the Yayu forest

Demel et al. (1998) suggested Yayu forest as one of the potential forest areas for *in situ* conservation of the wild *C. arabica* populations in Ethiopia. The findings of this study support the proposition that Yayu forest is an important keystone forest ecosystem for the conservation of wild *Coffea arabica* populations. Two major reasons supporting the proposition are: (1) the status of the wild coffee populations; and (2) the floristic diversity of the forest.

Firstly, the study revealed that *C. arabica* is one of the most abundant plant species in the forest. In the preliminary study by Demel et al. (1998), only the presence of wild population was reported, and the pattern and extent of distribution of *C. arabica* in the forest was investigated. This study presents precise data which shows that coffee is indeed very abundant and widely distributed in the forests (Table 4.1). It occurs in most parts of the forest (in about 91% of the plots; Table 4.1), and is the most abundant and best indicator species of a plant community type (Group 1). The forest in general has the highest abundance of wild coffee stems compared to all other similar forests studied to date (e.g., Harrena forest, Mesfin and Lisanework 1996; Bonga forest, Abayneh 1998). Within the forest landscape of Yayu, sections of the forest at higher altitudes and on flat to gentle slopes are more suitable for coffee. However, such areas are also suitable for agricultural production and human settlement, and hence are prone to deforestation. For this reason, only few such forest areas with wild coffee populations remain in the country, covering a total area of less-than 2000 km^2 (Tewolde 1990). The fact that there is still large area of intact forest at Yayu can be attributed to two reasons: the economic value of the wild coffee for the livelihood of the local community and the topography of the landscape. Coffee production is the major source of income for the majority of the local population (ca. 60%, Tafesse 1996). Coffee is harvested either directly from the wild plants in the undisturbed forest or from traditionally managed forests in the area. The topography of the area is also difficult for other types of agricultural practices. The area is characterized by a rolling topography, highly dissected by valleys of small streams with some flat to gentle slopes on the ridges in between valleys. These can positively contribute for the long term conservation of the wild coffee population in the forest while sustainably using it, as long as coffee production is economically viable and appropriate arrangements for such management are put in place by the government. More discussion on such issues is found in chapter 6 of this dissertation.

Secondly, being one of the most floristically diverse forest areas in Ethiopia, Yayu forest can be considered as an important area for biodiversity conservation. The forest is quite diverse in tree species, since it is very humid compared to most areas in the country. Many of the tree species are restricted to the Afromontane forest vegetation. The Afromontane region is considered as being the most threatened habitat in Africa and needs immediate conservation measures (White 1983). A large part of the Afromontane region is found within Ethiopia (Yalden 1983; Tewolde 1991). Hence, conservation of the Afromontane forest vegetation in Ethiopia, such as Yayu forest, is important for the conservation of plant species restricted to this ecological region. Yayu forest is also rich in the Guineo-Congolian forest type tree species, since it is a transitional rain forest between the Afromontane rain forest and the dry peripheral semi-deciduous Guineo-Congolian forest (Friis 1992). Furthermore, threatened tree species also occur in Yayu: *Cordia africana* and *Podocarpus falcatus* are considered to be locally threatened in Ethiopia, and are protected by proclamation (Government of Ethiopia, Proclamation No 94/1994), while *Prunus africana* is globally threatened (IUCN 2002). Especially for *C. africana* and *P. africana,* the forests in this region are the major remaining habitats in the country. These trees are threatened because, beside deforestation which affects the whole forest ecosystem uniformly, these trees are selectively harvested for their timber. *Prunus africana* is also an important medicinal plant and it is mainly the bark that is used for medicine. Debarking is the major threat to *P. africana* globally. *Prunus africana* is very rare and was recorded only in 2 plots of the 58 undisturbed forest sample plots. *Cordia africana* is relatively common, occurring in 17 plots, but has very low abundance. The forest is less important for *P. falcatus* since its habitat is in drier and higher altitude parts of the Afromontane region than Yayu (Friis 1992).

The diversity of plant species and presence of the gene pool of useful plants such as coffee also make the forest more attractive for research on the biodiversity of other taxa like birds, insect and mammals. This is because some argue that diversity in the species of different taxa like flowering plants, birds, insects and mammals are highly correlated at a large regional scale (Biby et al. 1992; Kay et al. 1997; Statterfield et al. 1998; Brooks et al. 2001), even though other studies at fine scales for reserve planning found poor correlation

(Flather et al. 1997; Howard et al. 1998; Van Jaarsvveld et al. 1998). Different groups of researchers have already shown interest. On a recent expedition, ornithologists discovered three birds that are not taxonomically determined at species level and might in fact be new species (Anteneh Shimelis, personal communication, February 2003). Similarly, some researchers are planning to study the diversity of spiders in Yayu forest and their potentials as biological insect control for the coffee plant (Negusu Aklilu, personal communication, February 2003).

The information from this study can be used to compare Yayu forest with other similar forests in the future and develop a national conservation strategy for wild coffee populations and the associated rain forest areas. It provides some baseline information on the vegetation and the status of wild coffee population. The knowledge of the abundance and frequency of the plant species in the forest and their growth forms (tree, shrub, or climber) can provide some indications on the importance of the species in the ecosystem. This information can support further research on the genetic diversity of the coffee populations, the economic and breeding values of the available genetic diversity, and the monitoring of changes in the floristic diversity of the forest vegetation. Monitoring changes is very important in biodiversity conservation and is strongly emphasized in the Convention on Biological Diversity (UNCED 1992).

The information in this study can also serve as a base for further research on species that can be useful for improving the livelihood of the local community, and as justification for future research on the diversity of other taxa. Information on the abundance and frequency will help to understand the biological importance of the species in the ecosystem. Then, such questions will have to be answered like: Which of these species are useful to improve the livelihood of the local community and for what purpose? How can these be used without severely affecting the forest biodiversity? To answer such questions, further research on the reproductive biology, ecophysiological requirements, etc. of the respective species and on the management practices that could be applied for the sustainable use of these plants is necessary. The results of the current study show that Yayu forest is very important for the conservation of wild coffee populations and the diversity of the forest flora. From the status of the wild coffee population and floristic diversity, the forest has a good potential for a coffee gene reserve. Establishing a coffee gene reserve in Yayu forest can foster the conservation of other plant species within the forest ecosystem, and hence coffee can be a flagship species.

5 IMPACTS OF HUMAN USE ON THE STRUCTURE AND SPECIES COMPOSITION OF THE YAYU FOREST

5.1 Introduction

Apart from their function as reservoirs of biodiversity, forests provide different ecosystem services; forests also provide human beings with many goods and services for livelihood. The use of forests and forest products dates back several centuries in human history. For instance, some 30,000 – 40,000 years ago, people in New Guinea were thinning forest trees to increase natural stands of Taro, bananas and Yam (Wiersum 1997). Still today, millions of people living in and around the forest environment in the tropics depend on forests to a large extent (Byron and Arnold 1999). Forests are sources of food, fuel wood, timber, construction wood, and the like. Depending on the cultural background and the management objectives, local communities in different parts of the world have developed different indigenous management practices and perceptions of forests. For some communities, forests are important not only for subsistence, but also for their spiritual life, which may influence the way they manage the forest (Byron and Arnold 1999). In any case, people modify the floristic composition and structure of forest during the process of use in order to get the best of goods and services (Wiersum 1997; Bakes 2001; Straede et al. 2002). The indigenous management practices may include several activities such as conserving some patches of forest, sparing or planting desirable species, introducing new species, eliminating competing species, thinning to protect the forest from fire, mulching, stimulating fruit production, etc. (Wiersum 1997). Such forest management by local communities was sustainable and contributed greatly to the conservation of biodiversity and protection of the environment (Bakes 2001; Long and Zhou 2001).

In Ethiopia, people mainly depend on forests for fuel wood, construction wood, timber, honey production and grazing. However, the level of dependency and mode of management varies from place to place, depending on the type of product taken from the forest. In the montane rain forest areas of SW Ethiopia, where coffee (*Coffea arabica*) occurs naturally, the local communities living in and around the forest traditionally manage the forest for coffee production. Coffee production is an important land use in the tropics (Perfecto et al. 1996). In most parts of the tropics, the practice of coffee production is not older than two to three hundred years (Marano-Vega et al.

2002), when forests were first cleared for plantations. In Ethiopia, however, the tradition of using and producing coffee is older than 2000 years (Luxner 2001). The traditional coffee production system in SW Ethiopia differs from that in the rest of the world since it mainly depends on the naturally regenerating coffee populations, where coffee trees are indigenous to the montane rain forests.

The local communities have traditional coffee production systems of different management intensities in the rain forest. In general, three production systems can be recognized: (a) undisturbed forest, which only involves harvesting of coffee; (b) semi-forest, which involves thinning out trees and shrubs competing with coffee in the lower storey as well as the large trees in the canopy layer, and (c) Semi-forest plantations, which involve modification of the forest vegetation in the same way as semi-forest, but include planting of coffee (Demel 1999). Semi-forest-plantations in the area are small-scale, about 1-2 ha in size, and established by converting old semi-forest system to uniform aged coffee stand. The coffee seedlings used for planting in the semi-forest-plantations come either from the natural forests, or seedlings of traditional or modern cultivars raised in nurseries (Tadesse et al. 2001). Areas managed as semi-forest systems are often converted into semi-forest-plantations after several years of production. Coffee production from these traditional management systems is the main source of livelihood for more than 60% of the local population in the coffee-growing montane rain forest areas of SW Ethiopia (Tafesse 1996). The traditional management practices obviously affect both the structure and species composition of the forest. Therefore, they may have an important long-term implication for the conservation of forest biodiversity and the wild coffee populations. Besides impacts directly influencing the species composition, the alteration of the structure of populations may affect the genetic diversity of forest trees and of *Coffea arabica*.

All the above-mentioned traditional coffee production systems are found in Yayu forest, SW Ethiopia. This offers a great opportunity to study the vegetation of the different management systems, and to evaluate the systems from conservation and use aspects. The main research questions in this study are: How do different management intensities of the forest for coffee production affect the vegetation in terms of species composition and structure? Which species or species groups disappear in the managed forests? Which species affected by the management may require restoration? What is the condition of secondary forest vegetation after having been abandoned by the people for a long period? The latter question was added to the research topic after discovering by chance that some areas in the undisturbed forest part of Yayu forest were inhabited 45 years ago, and abandoned since then.

The study was carried out on the undisturbed forest areas and the forests traditionally managed for coffee production in Yayu. Vegetation structure, species diversity and composition of the managed forests were compared to the undisturbed forests.

5.2 Material and methods

5.2.1 Vegetation categories and datasets

Depending on the current management intensity, three major forest categories can be identified in the area: undisturbed forest, semi-forest coffee production systems and semi-forest-plantation coffee production systems. Moreover, during the floristic inventory of the undisturbed forest, indicators of human disturbance or former settlements were found in some plots. These included old and large *Eucalyptus camaldulensis* trees, pieces of clay pots recovered from the soil, and fence-like regularly arranged stands of *Dracaena fragrans*. *Eucalyptus camaldulensis* is an exotic tree species usually planted around homesteads, while *D. fragrans* is often used as a living fence around houses and gardens in the region. Based on these indicators of a former settlement, the local people living in the nearby area were asked about the history of the forest in those study plots. It was learnt that there had been a settlement in the area about 45 years ago, which had been abandoned following the outbreak of disease among the inhabitants. Hence, the undisturbed forest was divided into two further categories: undisturbed natural forest (NATFOR), and old secondary forest (SECFOR). Similarly, the semi-forest coffee production system varies with respect to age of management. In some areas, the management interventions were very recent, in others, the coffee plants and forest vegetation had been managed for a long time. Therefore, the semi-forest coffee production system was divided into three categories: new semi-forest coffee production system that has been managed for less than 5 years (SEMIFOR-NEW), old semi-forest coffee production systems that has been managed for more than 10 years (SEMIFOR-OLD) and the very old semi-forest production system in which the old coffee trees are already replaced by planting of new stands of uniform age, and hence called semi-forest-plantation (SEMIFOR-PLAN). This was done under the assumption that the species diversity, composition and vegetation structure of the managed forest vegetation may vary wit age and intensity of management. In total, five different forest categories were considered in this analysis.

The SEMIFOR-NEW represents a forest area with a high density of wild coffee, which has recently (< 5 years) been opened up for coffee production. In this system, all shrubs and small trees other than coffee and some canopy trees are cut down in order to improve the light conditions, and to reduce competition of other plants with coffee. This enhances development of side-branches of the coffee trees increasing productivity (Tewolde 1978). The actual management activities of the SEMIFOR-OLD are similar to that of the SEMIFOR-NEW except for the duration of the management. However, with the duration of human intervention, SEMIFOR-OLD is assumed to have lower density of shade trees and species diversity. The coffee stand also grows in average stem and crown diameter. The SEMIFOR-PLAN is the oldest managed forest type, since it is established by replacing the old coffee stands in SEMIFOR-OLD with new plantation of uniform age coffee trees. After a long period of use of the forest as a semi-forest coffee production system, the coffee stock is replaced, mainly by cultivars. The demand for shade of the land races then used is assumed to be low compared to the coffee trees of the wild populations, and hence the number of shade trees needed is also assumed to be much lower compared to the SEMIFOR-NEW and the SEMIFOR-NEW. Vegetation data of 10 study plots from each forest category were used for the comparative analysis (For details of the data and plots of the different forest categories, see Appendix 11). The forest categories were compared for differences in overall number of species, species composition, abundances in different height classes (vegetation structure), and mean basal area.

In this study, vegetation structure is considered as the vertical distribution of the abundance of plants in the community. For comparison of the abundance distribution of plants in different management systems, the abundances of coffee trees were omitted. They are comparably similar in all the analyzed forest categories. In NATFOR and SECFOR, however, there are many species as abundant or even more abundant than coffee, while in the managed forest categories, coffee is much more abundant than the other plant species. The abundance of coffee was omitted in order to compare the contribution of non-coffee plant species to the vegetation structure. Because, inclusion of coffee in the abundance data contributes only slightly to the total abundance of the NATFOR and SECFOR. On the other hand, in the managed forest categories coffee overwhelmingly dominates (as high as 50%) due the low abundance of other species. In the structural analysis, plants were grouped into four major height classes (HC): HC 1 (< 1.5 m tall), HC 2 (1.5-12.5 m), HC 3 (12.5-24.5 m), and HC 4 (>24.5 m). This height class with different ranges was used to capture the existing conditions of the forest vegetation structure with respect to coffee. The first class, HC1, represents seedlings and young saplings that are too small for diameter measurement, and does not contribute to the basal area. The stems or individuals in the HC2 include shrubs, saplings and the majority of small trees. Individuals in the HC2 occupy a similar height class with mature coffee trees and hence are the ones that compete with coffee for space. Height classes HC3 and HC4 constitute shade trees in lower and upper canopy layers.

5.2.2 Analysis of differences in species composition

The difference in the mean number of species per plot among the studied forest categories was tested using one-way analysis of variance (ANOVA). One-way ANOVA is similar to the t-test except that it allows comparison of more than two groups of datasets. In order to test how one forest category differs from another, the Mann-Whitney-U-test was used. The U-test is the nonparametric equivalent of the independent samples t-test and is recommended for counting data such as number of species and abundances of this kind.

The Shannon index was calculated using the software EstimateS 6.01b (Colwell 2000). The Shannon index represents the information statistic indices of the measures of heterogeneity. It takes into account the evenness of the abundances of species. Additionally, Shannon evenness (E) was calculated as the ratio of the Shannon diversity index (H) to the maximum diversity (H_{max}). The value of H_{max} is the natural logarithm of the number of species (Magurran 1988).

The relationship of the number of species and abundance can be used to detect the prevalence of human intervention in a community, using species abundance models.

A species abundance model is the most complete mathematical description of a community (Magurran 1988). The Fisher's logarithmic model (Fisher et al. 1943), which is often known as log-series distribution (Magurran 1988), was used to describe the relationship of the number of species and abundance. The logarithmic model describes the natural pattern of species abundance in a community, because there is naturally no community in which all species are equally common, but usually a few species are very abundant, some with medium abundance, while the majority of species is represented by only few individuals. Hence, a natural community in an undisturbed habitat has a characteristic logarithmic species-abundance distribution pattern (Magurran 1988; Crawley 1997). The log-series distribution can occur only when the dynamics in the community are maintained by a few factors like competition, predation, regeneration, and mortality of the species constituting the community. Presence of other external factors like disturbance modifies the species abundance distribution, and a community in such condition does not have a log-series distribution. Using the log-series model, it is possible to calculate the expected number of species, based on the relationships of species number and abundance. The chi-squared goodness-of-fit test or G test (Sokal and Rohlf 1981) of the distribution of expected and observed number of species was performed to see if the species-abundance distributions of the vegetation in different forest categories follow the log-series distribution. To obtain the expected number of species, the following formula was used (Magurran 1988):

$$S' = \alpha[-\ln(1-x)]$$

where x is a constant value that is estimated from the iterative solution of

$$\frac{S}{N} = \frac{(1-x)}{x[-\ln(1-x)]}$$

and S' is the expected number of species, S the total number of species, and N the total number of individuals. Fisher's index, α, is given by:

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

In some cases, the plant species were grouped into four growth forms: large trees (trees which can attain a maximum height of 15 m or more), small trees (trees whose maximum height is below 15 m), shrubs and climbers.

5.2.3 Ordination

The principal component analysis (PCA) and redundancy analysis (RDA) ordination techniques were used to analyze the vegetation data of the different forest categories, in order to assess the patterns of sites and species distribution with respect to environmental gradients. The ordination result is presented in a two-dimensional diagram in which the sites are represented by points. The aim of ordination is to arrange the points such that points that are close together correspond to sites that are similar in species composition, and points that are far apart correspond to sites that are dissimilar in species composition (Ter Braak 1995).

PCA is an indirect gradient analysis. It explores the underlying environmental variation responsible for species distribution from the species composition and abundances of the vegetation data. RDA, on the other hand, is a canonical form of PCA, i.e., it is a direct gradient analysis. RDA assesses the patterns of distribution of species in terms of measured environmental gradients.

In RDA, only environmental variables that were statistically significant ($P < 0.05$) in explaining the variation were included in the list of explanatory variables. The nonparametric Monte Carlo Permutation test was run, with a permutation number of 199. The list of variables that were tested includes altitude, canopy cover, human impact, northness aspect, and slope. Altitude refers to elevation of the sample plots above sea level, and is measured in meters. Canopy cover is percent overstorey density, as measured by the spherical densiometer Model-A (Lemmon 1956, 1957). Human impact refers to the intensity of management or disturbance of the different forest categories. It is categorical and the values are 1, 2, 3, 4 and 5 for NATFOR, SECFOR, SEMIFOR-NEW, SEMIFOR-OLD and SEMIFOR-PLAN, consecutively. The best environmental variable is the one that gives the smallest total residual sum of squares.

Results can better be interpreted when PCA and RDA are used together (Ter Braak 1995). Both PCA and RDA were analyzed using CANOCO 4.0 (Ter Braak and Šmilauer 1998) following the default procedures.

5.2.4 Vegetation structure and basal area

Vegetation structure is the vertical distribution of the abundances of plants in the community. To analyze the vegetation structure, the abundances of plants in the four height classes, HC1-HC4, were summarized for each plot. The difference in abundance of the respective height classes of the forest categories was compared using one-way ANOVA. To test how an individual forest category is different from another, the paired Mann-Whitney-U-test was used. The population structure of selected tree species was also compared, by summarizing abundances in a table. Besides, the height class distribution of three selected species was illustrated graphically. Finally, the basal area of the forest stands in the different forest categories was compared using one-way ANOVA, and paired t-test, since the basal area is a continuous variable.

5.3 Results

5.3.1 Impacts on species diversity and composition

A total of 92 species of trees, shrubs, and climbers representing 41 families of flowering plants were recorded in 50 plots in the 5 different forest categories (Table 5.1). The NATFOR had the highest number of species and SEMIFOR-PLAN the lowest. There were 44, 52, 60, 71, and 74 species per 10 study plots in the SEMIFOR-PLAN, SEMIFOR-OLD, SEMIFOR-NEW, SECFOR and NATFOR, respectively (Table 5.3).

Table 5.1. Plant species recorded in the sample plots of the five forest categories in alphabetical order of the species names. Note: GR = 'growth form', CL = climber, LT = large tree, SH = shrub, and ST = small tree. Species in the forest categories is indicated by X.

No.	Species	GR	NATFOR	SECFOR	SEMIFOR-NEW	SEMIFOR-OLD	SEMIFOR-PLAN
1	Abutilon cecilli	SH	X	X			X
2	Acanthus eminens	SH		X			
3	Albizia grandibracteata	LT	X	X	X	X	X
4	Albizia gummifera	LT	X	X	X	X	X
5	Aningeria altissima	LT			X		
6	Antiaris toxicaria	LT	X	X	X	X	X
7	Apodytes dimidiate	LT		X	X		
8	Argomuellera macrophylla	ST	X		X	X	X
9	Bersama abyssinica	LT	X	X	X	X	
10	Blighia unijugata	LT	X	X	X	X	X
11	Bridelia micrantha	LT	X	X			
12	Canthium giordanii	ST	X	X	X	X	X
13	Canthium oligocarpum	ST	X	X	X	X	X
14	Canthium sp. 1	SH		X			

No.	Species	GR	NATFOR	SECFOR	SEMIFOR-NEW	SEMIFOR-OLD	SEMIFOR-PLAN
15	Capparis micrantha	CL	X	X	X		X
16	Capparis tomentosa	CL		X			
17	Cassipourea malosana	LT	X	X	X	X	X
18	Catha edulis	SH				X	
19	Celtis africana	LT	X	X	X	X	X
20	Cissus quadrangularis	CL	X	X		X	
21	Citrus medica	SH				X	
22	Clausena anisata	ST	X	X	X	X	X
23	Clematis longicauda	CL		X			
24	Clematis simensis	CL		X			
25	Coffea arabica	ST	X	X	X	X	X
26	Combretum paniculatum	CL	X	X	X	X	X
27	Cordia africana	LT	X	X	X	X	X
28	Crossopteryx febrifuga	ST	X			X	
29	Croton macrostachyus	LT	X	X	X		
30	Dalbergia lactea	SH	X	X		X	X
31	Diospyros abyssinica	LT	X	X	X	X	X
32	Dracaena fragrans	ST	X	X	X	X	X
33	Dracaena steudneri	ST	X	X	X		
34	Ehretia cymosa	ST	X	X	X	X	X
35	Ekebergia capensis	LT	X	X		X	X
36	Elaeodendron buchananii	LT	X	X	X	X	
37	Entada abyssinica	ST				X	X
38	Eugenia bukobensis	ST	X		X		
39	Ficus exasperata	LT	X	X	X	X	X
40	Ficus lutea	LT	X	X	X	X	
41	Ficus sur	LT	X	X	X		
42	Ficus thonningii	LT	X	X	X	X	X
43	Ficus vasta	LT	X	X		X	
44	Flacourtia indica	LT			X	X	X
45	Galiniera saxifraga	ST	X	X			
46	Genus-3 sp.	LT	X	X			X
47	Genus-5 sp.	ST	X				
48	Genus-6 sp.	LT	X				
49	Genus-8 sp.	SH			X		
50	Gouania longispicata	CL	X				
51	Grewia ferruginea	ST	X				
52	Hippocratea africana	CL	X	X	X	X	X
53	Hippocratea sp.	CL	X	X			X

No.	Species	GR	NATFOR	SECFOR	SEMIFOR-NEW	SEMIFOR-OLD	SEMIFOR-PLAN
54	Justicia betonica	SH	X		X		
55	Justicia schimperiana	SH	X	X	X	X	
56	Landolphia buchananii	CL	X	X	X	X	X
57	Maesa lanceolata	ST	X	X	X	X	X
58	Maytenus gracilipes	SH	X	X	X	X	X
59	Millettia ferruginea	LT	X	X	X	X	X
60	Mimusops kummel	LT	X	X	X		
61	Morus mesosygia	LT	X	X	X	X	
62	Olea capensis ssp. hochstetteri	ST	X	X	X		
63	Olea capensis rain forest welwitschi	LT	X	X	X	X	
64	Oncinotis tenuiloba	CL	X	X	X	X	
65	Oxyanthus speciosus	ST	X				
66	Paullinia pinnata	CL	X	X	X	X	X
67	Pavetta abyssinica	SH		X			
68	Pavonia urens	SH	X			X	X
69	Phoenix reclinata	ST	X	X			
70	Phyllanthus ovalifolius	SH	X	X	X		X
71	Physalis peruviana	SH			X		
72	Phytolacca dodecandra	CL		X	X		X
73	Pittosporum viridiflorum	ST	X	X	X		
74	Prunus Africana	LT	X	X			
75	Pterolobium stellatum	CL	X	X		X	
76	Rhoicissus tridentate	CL		X	X		
77	Rhus ruspoli	SH	X	X	X	X	X
78	Ricinus communis	ST			X		
79	Ritchiea albersii	ST	X	X	X	X	X
80	Rubus apetalus	CL	X	X			
81	Sapium ellipticum	LT	X	X	X	X	X
82	Scutia myrtina	CL	X	X			
83	Senna petersiana	ST	X	X	X	X	X
84	Teclea noblis	ST	X	X		X	X
85	Tiliachora troupinii	CL	X	X	X	X	X
86	Trichilia dregeana	LT	X	X	X	X	X
87	Trilepisium madagascariense	LT	X		X	X	
88	Urera trinervis	CL	X	X	X		
89	Vepris dainelli	ST	X	X			
90	Vernonia amygdalina	ST			X	X	X
91	Vernonia auriculifera	SH	X	X	X	X	X
92	Vernonia sp.	SH	X		X		

In all forest categories, only few species dominated the plant community. However, the level of dominance was much more pronounced in the managed forest categories (i.e., SEMIFOR-NEW, SEMIFOR-OLD and SEMIFOR-PLAN) (Table 5.2; 5.3.). In all of the managed forest categories, *C. arabica* was the most abundant species, accounting for 37.4%, 52% and 53.2% of the total abundance in the SEMIFOR-NEW, SEMIFOR-OLD, and SEMIFOR-PLAN, respectively (Table 5.2). The proportions of the most abundant species were much lower in the undisturbed forests. In the NATFOR, *C. arabica* (21.1%) was the most abundant, while *Dracaena fragrans* (29.8%) was the most abundant in the SECFOR. The top five most abundant species contributed 67.8%, 76.9%, 73.8%, 85.5% and 79.1% of the abundances of the species recorded in NATFOR, SECFOR, SEMIFOR-NEW, SEMIFOR-OLD, and SEMIFOR-PLAN, respectively (Table 5.2). This indicates the level of dominance of few species in the forests.

Table 5.2. List of five most abundant species in each forest category. Abundance-number of terms per 10 study plots (0.4 ha). Percent abundance-contribution of the species to total abundance in the forest category, and cumulative-sum of the %-abundance of successive species in rank order.

Rank		Abundance	Percent abundance	Cumulative
	NATFOR			
1	Coffea arabica	7448	21.1	21.1
2	Dracaena fragrans	5993	17.0	38.1
3	Landolphia buchananii	4475	12.7	50.8
4	Paullinia pinnata	4141	11.7	62.6
5	Maytenus gracilipes	1864	5.3	67.8
	SECFOR			
1	Dracaena fragrans	10455	29.8	29.8
2	Coffea arabica	8021	22.9	52.7
3	Landolphia buchananii	3795	10.8	63.5
4	Paullinia pinnata	2855	8.1	71.7
5	Maytenus gracilipes	1842	5.3	76.9
	SEMIFOR-NEW			
1	Coffea arabica	8417	37.4	37.4
2	Maytenus gracilipes	3884	17.2	54.6
3	Paullinia pinnata	2640	11.7	66.3
4	Dracaena fragrans	934	4.1	70.5
5	Landolphia buchananii	738	3.3	73.8
	SEMIFOR-OLD			
1	Coffea arabica	10221	52.0	52.0

2	Maytenus gracilipes	4320	22.0	73.9
3	Blighia unijugata	956	4.9	78.8
4	Clausena anisata	668	3.4	82.2
5	Paullinia pinnata	650	3.3	85.5
	SEMIFOR-PLAN			
1	Coffea arabica	7861	53.2	53.2
2	Maytenus gracilipes	2099	14.2	67.4
3	Clausena anisata	755	5.1	72.5
4	Blighia unijugata	526	3.6	76.1
5	Albizia grandibracteata	449	3.0	79.1

The result of the Shannon evenness (E) index (Table 5.3) is quite consistent with the pattern of dominance of the top five species in the different forest categories (Table 5.2). Lower E values show higher dominance. While the Shannon evenness (Table 5.3) is the descriptor for the forest vegetation as a whole, the percent dominance of the top-five most abundant species (table 5.2) singles out the most dominant species within each forest vegetation category.

From the X^2 goodness-of-fit tests, the NATFOR and SECFOR followed the log-series distribution (Table 5.3; $P > 0.05$; Appendix 4), which is characteristic of the plant community in an undisturbed habitat (Magurran 1988). On the other hand, the observed species-abundance distribution in the three managed forest categories highly significantly differed ($P < 0.01$ for SEMIFOR-NEW and SEMIFOR-PLAN; $P < 0.001$ and SEMIFOR-OLD) from the expected values and hence did not follow the log-series distribution (Table 5.3), which indicates a highly disturbed habitat (Crawley 1997; Magurran 1988). The SEMIFOR-OLD has the highest level of dominance (Table 5.2; 5.3) and deviation from the log-series distribution (Table 5.4).

Table 5.3 Summary of the canopy cover, diversity indices, and X^2 goodness-of-fit test of the log-series distribution of species abundance of the different forest categories. S = species richness or the number of species recorded in 10 study plots of each forest category. H = Shannon diversity index, E- Shannon evenness, and α- Fisher's index of diversity.

	NATFOR	SECFOR	SEMIFOR-NEW	SEMIFOR-OLD	SEMIFOR-PLAN
Canopy cover (%)	86	84	68	57	51
Elevation (m)	1428	1493	1405	1424	1515
S, trees	50	43	41	36	29
S, shrubs	10	10	10	8	7
S, climbers	14	18	9	8	8
S, total	74	71	60	52	44
H	2.72	2.38	2.35	1.70	1.97
E	0.63	0.53	0.57	0.43	0.52
α	9.91	8.53	7.78	6.72	5.44
X^2	X^2_{15}= 23.1	X^2_{13}= 15.9	X^2_{13}= 30.4	X^2_{13}= 38.3	X^2_{12}= 26.5
P	> 0.05	> 0.05	< 0.01	< 0.001	< 0.01

The number of species, S, decreased from 74 in the NATFOR to 44 in the SEMIFOR-PLAN (Table 5.3). The Fisher's diversity index, α, also decreased consistently from 9.91 to 5.44 with the decrease in number of species. However, the Shannon index has a different pattern. It has higher values for the SEMIFOR-PLAN than for the SEMIFOR-OLD despite the higher number of species in the latter, which indicates that the SEMIFOR-PLAN has higher evenness in species-abundance distribution than the SEMIFOR-OLD. The advantage of Fisher's diversity index is that it is not influenced by sample size, and that it is less affected by the abundance of the commonest species than the Shannon index. However, α does not discriminate the situations where species number (S) and abundance (N) are constant, even if there is change in evenness (Taylor 1978 cited in Magurran 1988). That means that two communities may have the same species richness and Fisher's index, but different Shannon diversity indices if they have different degrees of dominance of the commonest species. This is because the Shannon diversity index takes into account the changes in evenness, as is well demonstrated in Table 5.3. This is very important from the conservation point of view, since high dominance of few species indicates some sort of disturbance and hence the need for conservation measures. Hence, it is important to look at all the three commonly used measures of diversity, i.e., the species richness indices (S in this case), species abundance model (Fisher's diversity index, α and the log-series distribution in this case), and the indices based on proportions of species abundances, which accommodate for both richness and evenness (the H and E in this case) (Magurran 1988).

The one-way ANOVA test for differences in the number of species among the forest categories shows a highly significant difference ($F_{4,45} = 31.6$; $P < 0.001$). The results of the test of differences in the number of species between the forest categories using the paired Mann-Whitney-U-test are presented in Table 5.4.

Table 5.4. Difference between number of species in five forest categories using Mann-Whitney-U-test. NS=not significant at 0.05; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$. The mean number of species refers to the average number of species per sample plot.

		1	**2**	**3**	**4**	**5**
	Mean number of species	31	31	22	16	16
1	NATFOR					
2	SECFOR	NS				
3	SEMIFOR-NEW	**	**			
4	SEMIFOR-OLD	***	***	*		
5	SEMIFOR-PLAN	***	***	*	NS	

All the managed forest categories (SEMIFOR-NEW, SEMIFOR-OLD and SECFOR) were significantly different from the undisturbed (NATFOR and SECFOR) (Table 5.4.). The NATFOR and SECFOR were not different from one another (P> 0.05). Among the managed forest categories, the SEMIFOR-NEW was significantly different ($P < 0.05$; Table 5.4) from the SEMIFOR-OLD and SEMIFOR-PLAN forest categories. However, the mean number of species per plot of the SEMIFOR-OLD and SEMIFOR-PLAN categories were similar to each other (P> 0.05; Table 5.4).

5.3.2 Ordination

The ordination of the vegetation using PCA (Figure 5.1) and RDA (Figure 5.2) clearly placed the sites or study plots of the different forest categories along disturbance gradients in the ordination space. All sites representing NATFOR and SECFOR were placed in the direction in which human impact decreases and the managed forest sites in the direction in which human impact increases. The first PCA axis explains about 49% of the variation, while the first four PCA axes together explain 84% of the variation (Table 5.5).

Table 5.5. Summary of PCA analysis results

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.489	0.165	0.113	0.073	1.000
Cumulative % variance of species data	48.9	65.3	76.7	84.0	
Sum of all eigenvalues	1.00				

The first axis of both PCA and RDA represent the gradient in human impact or disturbance. In the PCA species-site biplot (Figure 5.1), the gradient in human impact increases toward the left. All sites representing managed forest categories for coffee production are located in the left half of the ordination space. For sake of clarity, only selected species were shown in the biplot. *Coffea arabica* is strongly correlated with the first PCA axis and its relative abundance increases towards the direction in which human impact increases (Figure 5.1.). Many small trees (*Dracaena fragrans, Vepris dainelli*), climbers (*Landolphia buchananii, Hippocratea africana*), and canopy trees like *Prunus africana, Olea capensis* ssp. *welwitschi* are also strongly correlated with the first PCA Axis, but their relative abundance increases in the direction in which human impact decreases. *Maytenus gracilipes* was strongly correlated with the second axis, and appears to be less affected by human impact. *Maytenus gracilipes* is not correlated with the human impact gradient at all, because it can regenerate vigorously both from seeds and from stumps by coppicing even in the managed forests.

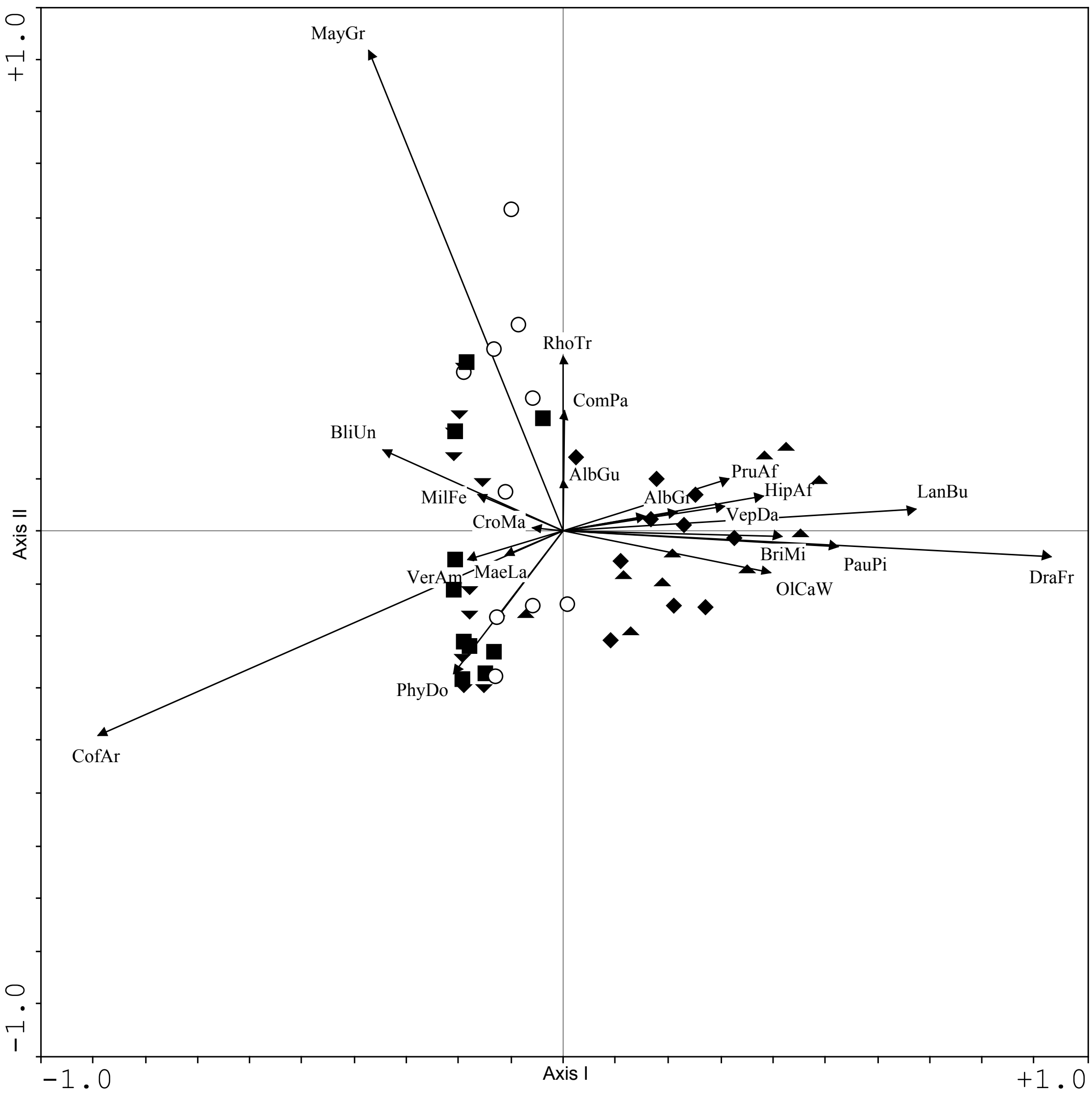


Figure 5.1. PCA species-sites biplot of the plots from different forest categories (◆- NATFOR, ▲- SECFOR, O- SEMIFOR-NEW, ▼- SEMIFOR-OLD, ■- SEMIFOR-PLAN). Abbreviations of plant names: AlbGr=Albizia grandibracteata, AlbGu=Albizia gummifera, BliUn=Blighia unijugata, BriMi=Bridelia micrantha, CofAr=Coffea arabica, ComPa=Combretum paniculatum, CroMa=Croton macrostachyus, DraFr=Dracaena fragrans, HipAf=Hippocratea africana, LanBu=Landolphia buchananii, MaeLa=Maesa lanceolata, MayGr=Maytenus gracilipes, MilFe=Millettia ferruginea, OlCaW=Olea capensis ssp. welwitschi, PauPi=Paullinia pinnata, PhyDo= Phytolacca dodecandra, PruAf=Prunus africana, VepDa=Vepris dainelli and VerAm=Vernonia amygdalina.

The RDA sites and environmental variables biplot strongly support the patterns explained by PCA with regard to the gradient in human impacts. Besides, the RDA made it possible to explain other strong environmental variables responsible for the species distribution in the forests. Three variables were significant in explaining the variations. These were (a) human impact (F-ratio =21.11, $P < 0.01$), (b) altitude (F-ratio = 7.70, $P < 0.01$) and (c) northness (F-ratio = 2.11, $P < 0.05$). The three environmental variables in RDA explain 42.9% of the variability in species distribution in the first three axes (Table 5.6). Partial ordination (variability partitioning) revealed that human impact alone explains 36.7% of the variability in species data, while altitude and northness (aspect) explain 10.4% and 2.6% of the variability in species data, respectively. The sum of the variation explained by each of the three variables is 49.7%, which exceeds the total variation explained by all of the three variables together by 6.8%. This is due to the complementarity of the effects of the environmental variables to each other. By partitioning one variable at a time, it was found that human impact and altitude together explain 41.2%, human impact and northness (aspect) 38.5%, and altitude and northness 12.4% of the total variation. Altitude and human impact complement each other much more than the other cases.

Table 5.6 A summary of RDA analysis of the five forest categories

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.387	0.027	0.016	0.165	1.000
Species-environment correlations	0.894	0.504	0.380	0.000	
Cumulative % variance of species data	38.7	41.4	42.9	59.5	
Cumulative % variance of species-environment relation	90.0	96.4	100.0	0.00	
Sum of all eigenvalues	1.00				
Sum of all canonical eigenvalues	0.429				

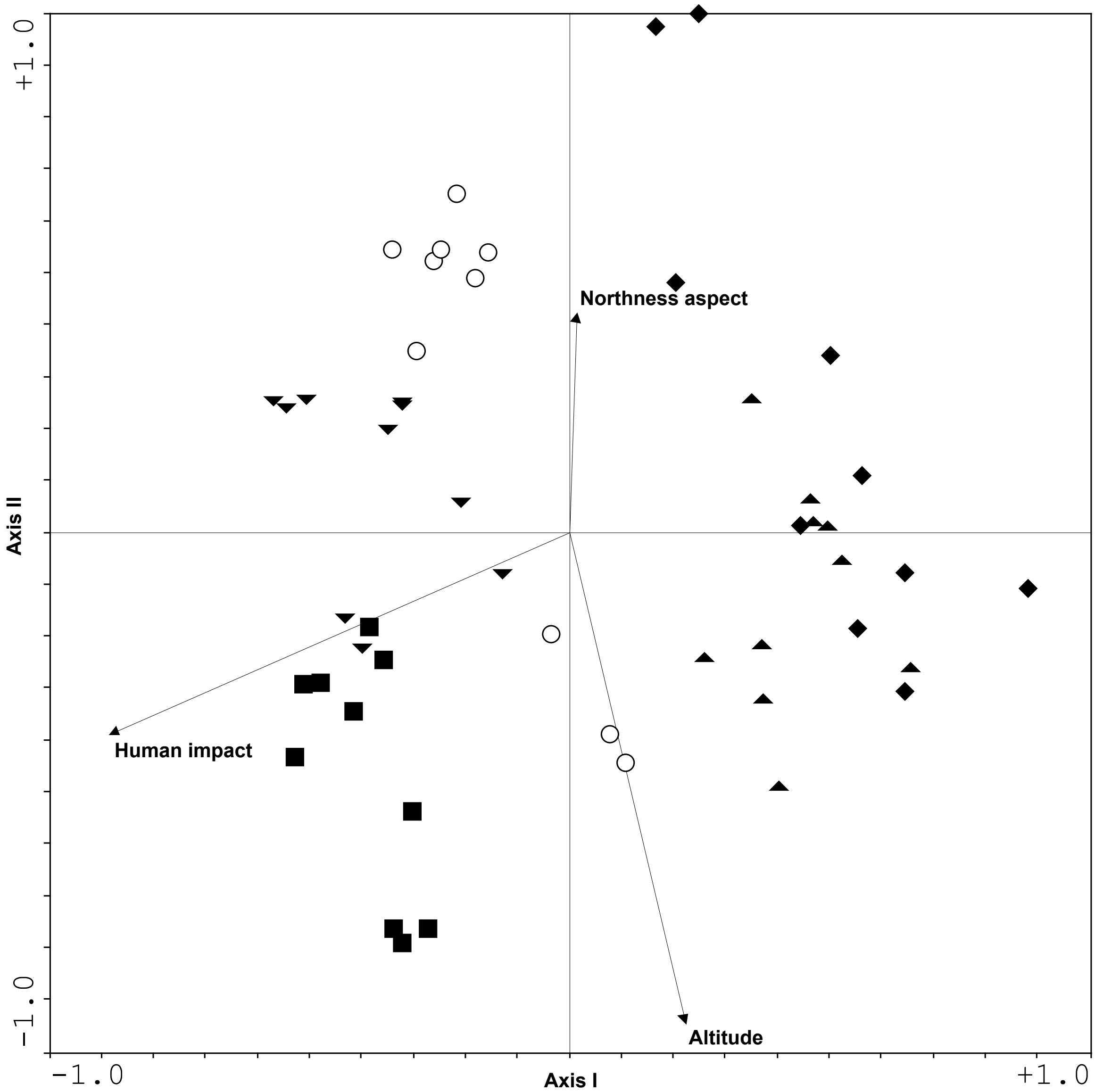


Figure 5.2. RDA plots-environmental variables biplot of the different forest categories (site category symbols as in Figure 5.2.)

From the results of ordination, it can be said that PCA biplots helped to discover two things: a) it placed sites in the ordination space according to the species occurrence, making an indirect inference of the gradient in the first axis easier (human impact gradients), b) it also depicted which species are strongly related both negatively and positively to human impacts, and c) the RDA further depicted the most significant environmental variables for the variation in species composition and the proportion of variations explained by them.

5.3.3 Population structure of trees

The comparative patterns of the population structure of the tree species recorded in the five forest categories are presented in Table 5.7. Besides, the population structure of three selected tree species is shown in Figure 5.3. These three species were chosen since their population structures represent three different regeneration behaviors with respect to the different forest categories.

Some tree species, which regenerate profoundly under natural forest conditions, seem to fail under the managed forest condition. Examples of such species are *Elaeodendron buchananii, Mimusops kummel,* and *Olea capensis* ssp. *hochstetteri (*Table 5.7). For some tree species, regeneration (seedling population) decreased in the managed forest categories. For example, *Diospyros abyssinica* has less seedling populations in the managed forests (SEMIFOR-NEW, SEMIFOR-OLD and SEMIFOR-PLAN) than in the undisturbed forests (NATFOR and SECFOR; see Table 5.7). Three groups of plant species can be recognized based on their population structure in the different forest categories:

(a) **Type I**: Tree species in this group have a high number of seedlings, with decreasing number of stems toward the higher height classes. Hence, the distribution of the population structure resembles an inverted J-shape in all forest categories. Examples of this group are *Albizia grandibracteata* and *Sapium ellipticum* (Figure 5.3; Table 5.7).

(b) **Type II**. Tree species in this group have no or few seedling populations in undisturbed forests, and have a higher number of seedling populations in the managed forests. Examples for these are *Millettia ferruginea* and *Cordia africana* (Figure 5.3; Table 5.7). However, the number of mature stems of *Cordia* decreased in managed forests compared to the undisturbed forests, and finally disappeared from the SEMIFOR-PLAN.

(c) **Type III**: The tree species in this category have no individuals in the managed forest. Examples: *Bridelia micrantha, Galiniera saxifraga,* and *Vepris dainelli*.

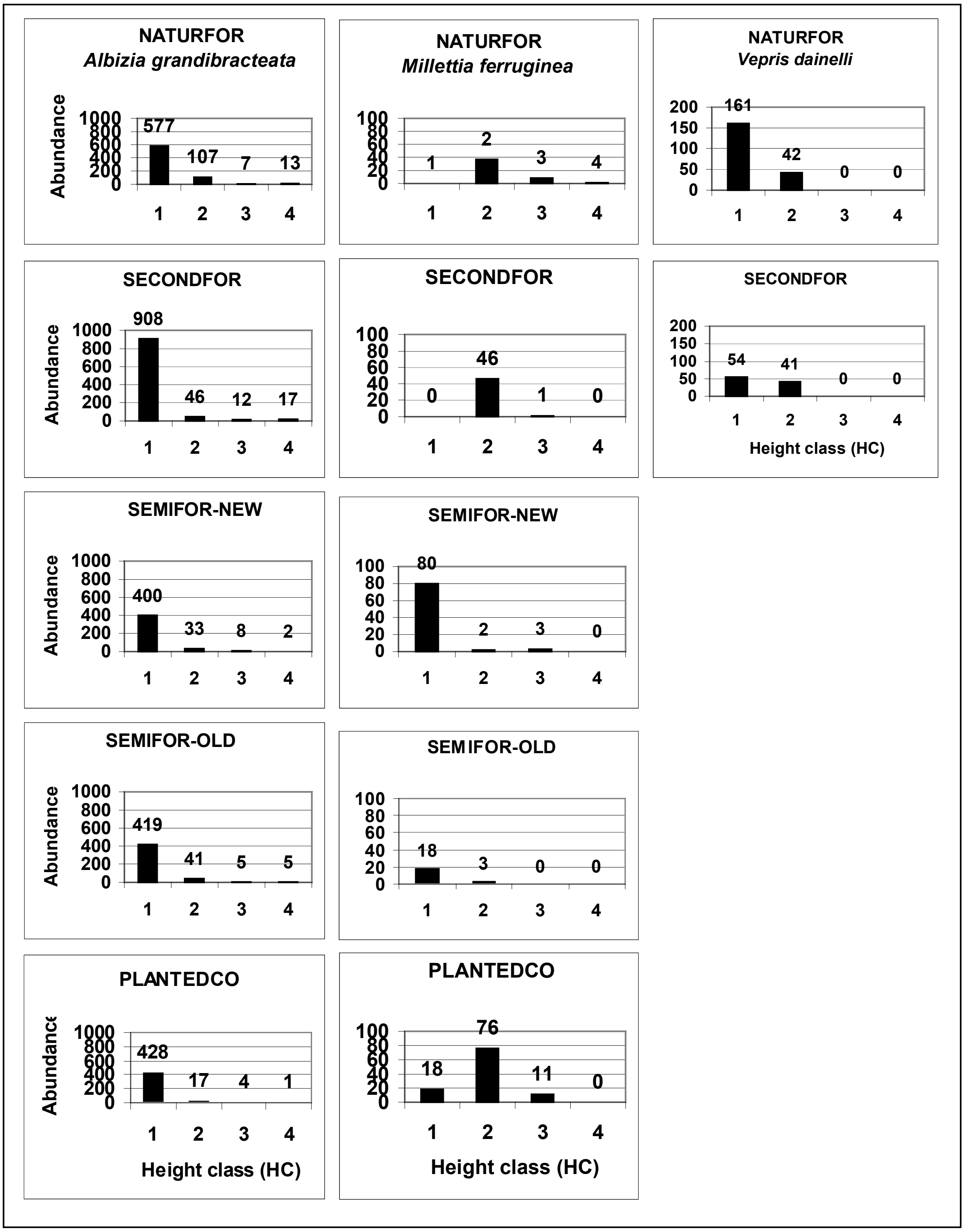


Figure 5.3. Size class distribution of *Albizia grandibracteata* (Type I), *Millettia ferruginea* (Type II), and *Vepris dainelli* (Type III). Graphs in each column are representing the three species in three population structure types.

Table 5.7. Height class distribution some trees in the different forest categories. Height classes: 1 -HC 1, 2- HC 2; 3- HC 3, 4- HC 4. The numbers represent the number of stems recorded in 10 sample plots of 400 m^2.

Species name	**NATFOR**				**SECFOR**				**SEMIFOR-NEW**				**SEMIFOR-OLD**				**SEMIFOR-PLAN**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Albizia grandibracteata	577	107	7	13	908	46	12	17	400	33	8	2	419	41	5	5	428	17	4	1
Bridelia micrantha	-	1	1	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Cordia africana	-	-	3	2	-	4	3	1	97	1	3	2	18	-	-	2	-	-	1	-
Diospyros abyssinica	472	206	8	4	338	169	4	2	205	9	1	-	160	94	-	-	9	36	-	-
Elaeodendron buchananii	9	14	18	-	-	2	4	1	-	-	1	1	-	27	-	-	-	-	-	-
Galiniera saxifraga	9	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Millettia ferruginea	-	37	8	1	-	46	1	-	80	2	3	-	18	3	-	-	18	76	11	-
Mimusops kummel	117	3	-	-	98	20	1	-	9	-	-	-	-	-	-	-	-	-	-	-
Olea capensis ssp. hochstetteri	258	27	-	-	9	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-
Sapium ellipticum	9	4	6	3	-	2	4	1	18	-	4	2	18	1	1	1	9	8	4	-
Vepris dainelli	161	42	-	-	54	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: Height class distribution of all woody plants is found in Appendix 7.

The population structure of coffee also varies in the different forest categories (Table 5.8). The SEMIFOR-OLD has the highest abundance of coffee trees. However, the proportion of seedlings is highest in the NATFOR and lowest in the SEMIFOR-PLAN. The highest proportion (75%) of the abundance of mature coffee trees was recorded in the SEMIFOR-PLAN and the lowest in the NATFOR (Table 5.8).

Table 5.8. Total abundance, proportion of seedlings (< 1.5 m tall) and mature trees (> 1.5 m tall), and basal area of coffee in five forest categories. Note that total abundance is number of stems per 10 sample plots of 400 m^2 (0.4 ha).

	NATFOR	**SECFOR**	**SEMIFOR-NEW**	**SEMIFOR-OLD**	**SEMIFOR-PLAN**
Total abundance	7448	8021	8417	10221	7861
Seedlings (%)	74	69	51	43	25
Trees (%)	26	31	49	57	75
Basal area (m^2/ha)	1.4	1.7	3.8	6.3	7.8

5.3.4 Differences in abundances and vegetation structure

The results of the analysis of the differences in total abundance in different height classes of the five forest categories are presented in Tables 5.9 - 5.10. The ANOVA tables of the height classes can be found in Appendix 5. The five forest categories were highly significantly different ($P < 0.001$; Table 5.9) from each other with respect to total abundance. The differences in abundance of all height classes were also highly significant ($P < 0.001$; Table 5.9).

Table 5.9. Results of one-way ANOVA for differences in abundance among the forest categories in different height classes

Height class	$F_{4, 45}$	***P*-value**
Total abundance	21.269	< 0.001
HC 1	13.963	< 0.001
HC 2	28.860	< 0.001
HC 3	13.319	< 0.001
HC 4	6.853	< 0.001

In all height classes, the three managed forest categories (SEMIFOR-NEW, SEMIFOR-OLD, and SEMIFOR-PLAN) were significantly different from both NATFOR and SECFOR in terms of the abundance of stems per plot of 400 m^2 (Table 5.10.). The difference was very highly significant in height classes 1 and 2 (HC1 and HC2). The mean abundances in HC 2 and HC 3 of undisturbed forests, NATFOR and SECFOR, were almost ten-fold of the abundance of similar height classes in the three managed forest categories (Table 5.10). Likewise, abundances in HC 4 of the undisturbed forests were also at least four-fold of the abundances in the managed forests of the same height class.

Table 5.10. Test of differences in abundance of stems in different height classes, using Mann-Whitney U-test. The levels of significance indicated by asterix, as * = P < 0.05; ** = P < 0.01; *** = P < 0.001, and NS = not significant. Mean abundance is the average number of stems per 400 m^2 sample plot.

		HC 1					HC 2					HC 3					HC 4				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Mean abundance	2927	2766	1908	1419	837	425	563	42	36	97	32	21	3	2	3	8	8	2	2	0.1
1	NATFOR																				
2	SECFOR	NS					NS					NS					NS				
3	SEMIFOR-NEW	*	*				***	***				***	***				*	**			
4	SEMIFOR-OLD	***	***	NS			***	***	NS			***	***	*			*	***	NS		
5	SEMIFOR-PLAN	***	***	**	NS		***	***	NS	NS		***	***	NS	NS		***	***	***	**	

On the other hand, there was no significant difference between NATFOR and SECFOR in all height classes (Table 5.13.). The three managed forest categories were similar to each other in the abundances of HC 2. The SEMIFOR-NEW differs significantly from the SEMIFOR-PLAN in HC 1 and HC 4. The SEMIFOR-NEW and SEMIFOR-OLD differed from each other in HC 3 only. The SEMIFOR-PLAN differed significantly from SEMIFOR-NEW and SEMIFOR-OLD in HC 4.

5.3.5 Changes in basal area

The comparisons of the basal areas (BA) of the five forest categories are presented in Table 5.11 below. The test static used in this case is the paired *t*-test, since the BA is a continuous measured variable as compared to abundance, which is count data. The forest categories differed significantly in their BA ($F_{4,45}$ = 3.78; P < 0.01; Appendix 6).

Table 5.11. Differences in basal area among the forest categories, using paired t-test. Levels of significance denoted by * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$ and NS = no significant difference.

		1	2	3	4	5
	Mean BA (m^2/ha)	46.2	37.6	43.4	27	23
1	NATFOR					
2	SECFOR	NS				
3	SEMIFOR-NEW	NS	NS			
4	SEMIFOR-OLD	*	NS	*		
5	SEMIFOR-PLAN	**	**	**	NS	

From the managed forest categories, the BA of the SEMIFOR-NEW is not significantly different from that of the undisturbed forests, i.e., the NATFOR and the SECFOR (Table 5.11; $P > 0.05$). In absolute figures, the mean BA of SEMIFOR-NEW is even higher than that of SECFOR. The BA of the SEMIFOR-PLAN is highly significantly different from that of the other forest categories except for the SEMIFOR-OLD, while the BA for SEMIFOR-OLD is significantly different from that of the NATFOR and SEMIFOR-NEW, but not significantly different from the SECFOR. Two of the managed forests, the SEMIFOR-OLD and the SEMIFOR-PLAN, had quite lower BA compared to the undisturbed forests and the SEMIFOR-NEW.

5.4 Discussion

Simplification of ecosystems is a typical characteristic of ecological modification by human beings (Western 2001). Through simplification of a complex ecosystem, people maximize production of a specific utility in the ecosystem. The current study on Yayu forest reveals that managing forests for coffee production has changed several vegetation characteristics. The changes are grouped into three and discussed in this section. The three major differences observed among the different forests categories are in: (a) species diversity and composition; (b) population structure of the retained plant species and (c) structure of the forest as a whole.

5.4.1 Differences in species diversity and composition

This study shows that, based on species composition, a clear distinction can be made between the undisturbed forests and the forests managed for coffee production (Figure 5.1; 5.3.). Species richness decreased on average by nearly 40% in the semi-forest-plantations (SEMIFOR-PLAN) as compared to undisturbed natural forest (NATFOR and SECFOR; Tables 5.1; 5.3). The decrease in the mean number of species per sample plot is even higher (Table 5.4). In the older managed forests (SEMIFOR-OLD and SEMIFOR-PLAN), the number of woody plant species per plot declined by about 50%, compared to that of the undisturbed forests (16 vs. 31; Table 5.4). The impact of frequent disturbance for coffee production on the diversity of plant species in the managed forests is very high compared to other types of managed forests in the tropics. For instance, Parthasarathy (1999) observed no difference in species diversity except changes in species composition in a wet evergreen forest frequently disturbed for cardamom production in India. Similarly, Webb and Peralta (1998) also reported only minor changes in species diversity in a forest in which controlled selective logging is practiced in the neotropics. The traditional system of coffee production is quite intensive and far beyond the extractive use system practiced elsewhere in the tropics.

Species diversity tends to decrease with the increase in the length of management period. There are three possible reasons for the higher species diversity in the youngest managed forest category, the SEMIFOR-NEW, as compared to other managed forest categories: (a) presence of seedlings of many species in the seedling bank; (b) regeneration of some pioneer species from the soil seed bank; and (c) re-growth of coppice stands from the stumps of recently cut stems. Most woody plants in mature forests (e.g. undisturbed forests like NATFOR in this case) have multiples of suppressed seedlings awaiting the creation of gaps (Kitajima and Fenner 2000). At the early stage of gap formation, the existing seedlings of mature forest species serve as sources of regeneration, while gap formation also creates favorable conditions for the germination of the seeds of pioneer species from the soil seed bank and the seed rain from the surrounding vegetation (Demel and Tamrat 1995). Coppice regeneration is also a widespread phenomenon in tropical forests (Swaine et al. 1990; Whitemore 1991; Demel and Tamrat 1995). Regeneration of several species from the stumps after coppicing was observed in the managed forests. The most notable species in this regard is *Maytenus gracilipes,* which remained unaffected by management activities (Figure 5.1). For most other species, however, the chance for the regenerated plants to mature is nil, since the regenerated vegetation is removed once or twice a year. Such continued removal of the understorey vegetation leads to a decline in species diversity. This is because such recurrent clearing limits the capacity for species regeneration from the seedling and soil seed banks, and the coppicing ability of stump gradually diminishes, decreasing the species diversity of the older managed forests (see SEMIFOR-OLD and SEMIFOR-PLAN, Tables 5.1 and 5.3). Though the older managed forests have a lower species diversity index, they tend to have a high species evenness (Table 5.3). From this, it appears that the dominance of few plant species in the forest vegetation is more pronounced at the early stage of disturbance (Crawley 1997).

Some of the species that totally disappeared in all managed forests are of conservation interest. For instance, *Vepris dainelli* is endemic to Ethiopia (Mesfin 1991b), while *Prunus africana* is listed on the IUCN Red Book as a vulnerable species (IUCN 2002). Some species are represented only by seedlings, like *Teclea noblis.* On the other hand, there are some species newly introduced in the managed forests, which do not naturally belong to the forest ecosystem. These include cultivated species like *Catha edulis, Citrus medica* and *Ricinus communis* (Table 5.1), and pioneers like *Physalis peruviana* and *Vernonia amygdalina*.

The old secondary forest (SECFOR) is restored in terms of species diversity, composition and structure, and becomes quite similar to undisturbed natural forest (NATFOR) within about 50 years (Figure 5.1; 5.2; Table 5.3; 5.4 and 5.10). The recovery of the forest in terms of species diversity and composition could be attributed to its proximity to the natural forest, which certainly has been the main source of propagules. The land-use system around the old settlement area may also have been managed forest for coffee production. Other studies also showed similar convergence in species diversity and composition between old growth forest and abandoned shade coffee plantations after 30 years (Marcano-Vega et al. 2002), abandoned cropland after 50 years (Grau et al. 1997), and abandoned pasture after 18 years of succession (Guariguata et al. 1997).

5.4.2 Population structure of trees

Some tree species (Type I population structure group) are less affected by disturbance due to management of the forests for coffee production. Species with such population structure are considered as being in good regeneration condition (Demel 1997). It appears that the change in vegetation structure and the light conditions under the managed forests do not affect the ability of their seeds to germinate. These are large canopy trees, which are also important as shade trees in the forests managed for coffee production. Hence, they are less targeted during the thinning of trees and clearing of understorey vegetation, unless there is a higher density of their stems than required for shade. The tree species in Type II appear to be pioneer species, whose seeds require disturbance for germination. The number of mature stems of *Cordia africana,* which belongs to this group, decreased in the managed forest categories compared to the undisturbed forests, and finally disappeared from the oldest managed forest type (SEMIFOR-PLAN) (Table 5.7). This can be due to two possible reasons: (1) broad-leaved deciduous tree species like *Cordia* are considered as unsuitable for shade and are gradually replaced by legumes or other broad-leaved evergreen tree species, and (2) *Cordia* is highly hunted for its quality timber.

The tree species in the Type III appear to be shade-tolerant, and cannot regenerate in gaps created under disturbed forest conditions. The trees in this group are also not represented even in the higher height classes of the vegetation of the managed forest categories, probably because they are not useful trees for shade in coffee production.

5.4.3 The forest structure

There is a clear difference in the structure of the forest vegetation between the undisturbed forests and the forests managed for coffee production. It appears that forests are converted from complex and continuous-structured vegetation in undisturbed forests to two-layered vegetation in the managed forests. The two distinguishable layers in managed forests are: the canopy layer of shade trees and the coffee stand layer. The high degree of decline in the abundances of plants in the lower height classes in the managed forest (Table 5.10), the relatively lower decline in abundances of trees in the higher height class and canopy cover (Table 5.7 and 5.10), and the very high increase in the proportion of matured coffee trees

(Table 5.8) in the managed forests demonstrate this fact. Beside the high degree of change in abundances of lower height classes of the forest trees in the managed forests, many species of climbers that make the structure more continuous and complex have either totally disappeared or are represented only by seedlings (Appendix 7). On the contrary, Parthasarathy (1999) observed higher liana diversity in a frequently disturbed forest than in an undisturbed natural forest. The situation observed in Yayu forest is due to the high intensity of management mainly targeting at understorey vegetation and climbers to avoid competition with coffee and for ease of access during harvesting.

The lowest average canopy cover in the managed forest is 51% (SEMIFOR-PLAN) compared to the highest of 86% in undisturbed forest (NATUREFOR) (Table 5.3). The change in canopy cover is small, even though the decline in the abundance of stems in different height classes is as high as four- to ten-fold in the managed forests as compared to that of undisturbed forests. In spite of enormous changes in vegetation structure, high canopy cover is maintained in the managed forest by keeping those trees with large and spreading canopies. Mature coffee plants fully occupy the lower stratum, since clearing the competing vegetation increases secondary branch development in the coffee trees (Tewolde 1978).

The decline in the basal areas of the two older managed forests (SEMIFOR-OLD and SEMIFOR-PLAN) is very high (Table 5.11). However, the basal area of the SEMIFOR-NEW remained quite similar to the undisturbed forests, even though there is a significant decline in the number of trees in higher height classes (Table 5.10; Table 5.11). This is mainly because the shade trees retained in the forest are big canopy trees with large diameters in the recently opened-up forest.

Even though the abundance of coffee trees in all forests is relatively similar (Table 5.8), the basal area increases greatly in the managed forests (from 1.4 m^2 ha^{-1} in NATFOR to 7.8 m^2 ha^{-1} in SEMIFOR-PLAN), indicating that the population has converted from being dominated by seedlings in the undisturbed forests to being dominated by mature trees in the managed forest. Abayneh (1998) reported a higher number of coffee seedlings in forest gaps than in closed canopy forest. The lower proportion of seedlings in the managed forests at Yayu can be either for biological or human-induced reasons, or both, i.e., due to:

(1) the frequent disturbance of the forests during management clearing of understorey vegetation, or (2) lack of enough seed due to harvesting. The micro-climatic conditions created by disturbance in the managed forest may not be as suitable for regeneration of coffee from seeds. The clearing of the vegetation in the understorey (1-2 times a year) may expose the new seedlings to excessive heat from sunlight, which eventually kills them. Or the farmers harvest all the coffee berries during the fruiting period, which leaves no or only few seeds in such forests. The farmers were even seen collecting the coffee berries that had dropped onto the forest floor after the harvest. When farmers clear the understorey vegetation around the onset of the harvesting season, they also clear all ground vegetation and litter. This is done to facilitate the collection of coffee berries falling to the ground. Total exposure of the mineral soil through removal of the litter layer may also create dry and unfavorable micro-climatic germinating conditions for escaped seeds, since the seeds require mulch for germination (Purseglove 1968).

5.4.4 Implications for conservation

Conserving biodiversity is one of the greatest challenges to humanity today. Habitat conversion or modification by human beings to produce goods and services is the most substantial human alteration of ecosystems threatening biodiversity (Chapin et al. 2000). The current study on Yayu forest shows that managing the forest for coffee production has modified the forest vegetation in terms of species diversity, floristic composition and structure. The changes in vegetation due to management may have implications for the conservation of coffee genetic resources, overall plant species diversity and composition, and diversity and composition of different animal groups that depend on the forest ecosystems.

Implications for the conservation of wild coffee populations: As discussed above, the regeneration capacity of coffee under managed forests has declined, either for biological or human-induced reasons, or combinations of both. The existing regeneration capacity in the managed forests may not be sufficient to replace the old trees and to thus ensure sustainable production in the long term. Information from a local development agent indicates that the mean age of a coffee tree is about 50 years (Tolosa, personal communication), and the tree has to be replaced. Most often, the seedlings available for planting are cultivars, which are selected for certain agronomic qualities. For example, the planted coffee population in the SEMIFOR-PLAN investigated in this study mainly constitutes selected cultivars resistant to coffee berry disease. Cultivars have lower genetic variability than the wild population (Lashermes et al. 1996; Montagnon and Bouharmont 1996; Anthony et al. 2002). Hence, though managing the vegetation composition and structure improves the yield of coffee for farmers, in the long run, the gene pool of the coffee plant itself is threatened.

Implications for the conservation of other plant species' diversity and composition: The major groups of plant species of conservation concern in the region are the Ethiopian endemics, the threatened species, the Afromontane endemics, and the lowland rain forest tree species. From the Ethiopian endemics, the population of *Vepris dainelli* has totally disappeared in the managed forests, while *Phyllanthus limuensis* is quite rare in its occurrence and was not recorded in any of the study plots. Among the plant species in the threatened category, *Prunus africana* is globally threatened, and categorized as vulnerable (IUCN 2002), while *Cordia africana* is locally threatened and is given protection by proclamation (Government of Ethiopia, Proclamation No. 94/1994). As discussed in the previous chapter, Yayu forest is also important for several species endemic or near-endemic to the Afromontane forest vegetation (Chapter 4.3; Table 4.1; Appendix 1). More than 50% of the area covered by such vegetation is found within the Ethiopian boundary (Yalden 1983), which includes this forest. The forest in this area is also unique in having a great number of rain forest species similar to those found in the west and central part of Africa, as discussed in the previous chapter (Chapter 4.3). Barthlott et al. (2001) found that the diversity and abundance of epiphytes decreased by 50% in disturbed and secondary forests as compared to primary montane rain forests in the Andes. Given the frequent disturbance in the managed forests, which has resulted in the decline in woody plants species, a similar change is expected to also have occurred in epiphytes and other groups of plant species at Yayu. Beside for the wild coffee population, Yayu forest has a great value for the conservation of several other plant species. The fact that the population structure of most tree species is negatively affected, and the species diversity is decreasing in the managed forests clearly shows the need to improve the management practice in order to meet the conservation goals, side by side with sustainable utilization.

Implications for conservation of other forest biodiversity: A previous study found that Yayu forest is one of the important forests in Ethiopia for the conservation of highland forest bird species, and it has been recognized as part of the Matte-Gore-Tepi forest Important Bird Area (EWNHS 1996). It also harbors several small mammals, especially primates. Studies on the effect of disturbance on different animal groups show that changes in forest structure and composition are detrimental for their survival. For instance, Thiollay (1997, 1999) found that changes in forest structure negatively affect the forest birds. The most affected groups of birds were mature forest understorey species. Similarly, the composition and diversity of other animal groups like primates (Onderdonk and Chapman 1999), bats (Schulze et al. 2000), ants (Vasconcelos 1999), and butterflies (Hill et al. 1995; Hamer et al. 1996; Hill 1999) are also negatively affected by forest disturbance. Though there is no similar study about the impacts of forest disturbance on any of the animals groups, it is assumed that many rare and habitat-specific species are affected by changes in Yayu forest as result of management.

6 THE *IN SITU* CONSERVATION OF WILD *COFFEA ARABICA* POPULATIONS IN THE YAYU FOREST: SUITABILITY ANALYSIS AND RESERVE ZONING

6.1 Introduction

Modification of ecosystems by human beings, mainly for agriculture, grazing and settlements, is considered to be the major threat to the conservation of biodiversity (Chapin *et al*. 2000), especially in developing countries (Swanson 1999). In Ethiopia, agriculture forms the greatest threat to biodiversity conservation, since over 85% of the total population is engaged in agriculture (MEDaC 1995). This is mainly due to the low production efficiency of the existing agricultural practices in the region (Tsegaye 2001). In such cases, the demands for higher yields to feed the growing population are currently fulfilled by increasing the areas of cultivated land, which is not sustainable resource use practice. Hence, it is important to establish a system of protected areas or reserves to conserve biodiversity (WRI/IUCN/UNEP 1992). Even though Ethiopia is considered as one of the top 20 richest countries in the world in terms of biodiversity (WCMC 1994), most of the ecosystems or habitats important for biodiversity conservation are not included in the country's system of protected areas. According to the protected areas categories of the IUCN (IUCN 1992), Ethiopia has 9 national parks, 3 sanctuaries, and 11 wildlife reserves, which mainly have been established to protect large mammals and birds. Up to now, no area has been formally protected in the country to conserve an ecosystem or habitat important for plant species although Ethiopia's biodiversity is mainly due to the high diversity of plant species (Mesfin 1991b). It is also known for diversity in the genetic resources of plants important for food and agriculture (Melaku 1988; Abebe 1992).

Arabica coffee (*Coffea arabica*) is one of the important crop plants originating from Ethiopia. Wild populations of *C. arabica* still occur in Ethiopia, and are considered as the most valuable source of genetic materials for the world-wide improvement of cultivated coffee (Sylvain 1958, Bertrand et al. 1997; Anzueto et al. 2001). However, large areas of forests with such wild coffee populations have been lost due to deforestation, and the remaining forests are increasingly fragmented, resulting in severe threat to the wild coffee populations (Tewolde 1990; Reusing 1998; Tadesse et al. 2002). Hence, there is an urgent need to conserve the coffee genetic resources and the forest ecosystems by establishing coffee gene reserves (Tadesse et al. 2002). A gene reserve is an *in situ* conservation area established to protect the wild populations of the target species and its habitats.

In the conventional conservation approach of protected areas, management usually excludes human intervention or resource use within the boundaries of the protected areas (McNeely 1994). Today, there is a paradigm change toward collaborative management of the resources together with the local community in the proximity of the protected areas in order to promote both conservation and sustainable use (McNeely 1994). Given the high dependency of the local people on the forests for different non-timber products including coffee (Tafesse 1996), and the importance of the forest for the conservation of coffee genetic resources and other biodiversity (Tewolde 1990), the new conservation approach is very relevant for the forests which are analyzed in this study. Hence, a management approach that optimizes both conservation and sustainable utilization of the forest coffee ecosystems is perceived as the most appropriate option to manage forest ecosystems important for conservation of coffee in Ethiopia (Tadesse et al. 2002).

Conservationists advocate the concepts of the Man and Biosphere (MAB) program of UNESCO (UNESCO-UNEP 1984) as very stimulating ideas to conserve plant genetic resources *in situ* (Maxted et al. 1997). Based on this concept, biosphere reserves are areas of ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use (UNESCO-UNEP 1984). This approach incorporates ecosystem management and human development into a regional context. It advocates the establishment of a multiple-use network of areas, including one or more strictly protected core areas, surrounded by less strictly protected buffer zones, both enveloped within a series of transitions zones (UNESCO-UNEP 1984; Batisse 1986; Wells and Brandon 1993; McNeely 1994; Maxted et al. 1997).

Zoning allows the allocation of non-damaging uses by human beings in some parts while protecting core parts of the reserve (IUCN 1994; Hepcan 2000). The core zones are strictly protected areas for conserving biological diversity. Allowed activities in this zone are low-impact uses such as education and ecotourism as well as non-destructive research. The buffer zones are clearly identified areas, and usually surround the core zones. Buffer zones can be used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism and research. The transition or cooperation zones may contain settlement areas, farms, and other human activities and are the areas where local communities, management agencies, scientists, non-governmental organizations, cultural groups, economic interests, and other stakeholders work together to manage and sustainably develop the area's resources.

GIS-based multi-criteria evaluation methods have been successfully applied for supporting management decisions that address different alternative solutions to spatial decision making problems. The most common application of multi-criteria evaluation methods is the identification of different land suitability classes for different uses (Eastman 1999, Basnet et al. 2001). Recently, multi-criteria evaluation has also been used for mineral favorability mapping (de Araujo and Macedo 2002), conservation of biodiversity and reserve site selection (Reyers et al. 2002), and protected areas zoning (Hepcan 2000).

Zoning requires spatial decision-making by evaluating appropriate multiple criteria that have spatial attributes. Spatial multi-criteria decision-making is an articulation of proper objectives and identification of attributes, which are useful indicators to achieve these objectives (Malczewski 1999). The biological evaluation criteria in forest reserve zoning for a coffee gene reserve can be layers of the extent of wild coffee populations and the diversity of plants species. Spatial representation of the evaluation criteria can be produced using vegetation data from sample plots and respective data of environmental variables.

Forest scientists and managers often use environmental conditions such as terrain, climate, and moisture to map the distribution of plant species and forest communities (Bolstad et al. 1998). The major environmental conditions that determine the distribution patterns of plant species may change at macro- and meso-scales due to changes in latitudinal and continental/ oceanic influences on temperature and precipitation (Bailey 1996). However, the important environmental conditions at micro-level that determine plant species distribution are mainly the soil moisture and temperature. These micro-level environmental conditions are modified by variations in landform, elevation, slope and other terrain characteristics (Bolstad et al. 1998). Hence, specific information about terrain may aid in predicting the occurrence of species or plant communities at a given site, if there are strong relationships between environmental conditions and species occurrences. Besides, environmental gradients identified by the ordination analysis such as the CCA and PCA axes can be used to predict distribution patterns of species and diversity (Reyers et al. 2002). A number of techniques are used for prediction and mapping of plant species distribution within a landscape. Three most often used methods: (1) mosaic or block diagrams, (2) regression models, and (3) geostatistical techniques like kriging and co-kiriging.

The digital elevation model (DEM) provides topographic information such as elevation, slope, landform, aspect, etc. Such terrain-derived data can be used to map actual or potential vegetation across the landscape. Bolstad et al. (1998) used a terrain-based linear regression to predict and map overstorey tree species in a mountainous region. Several other researchers also similarly used terrain based data for vegetating mapping (e.g., Meentemeyer et al. 2001; Guisan et al. 1999; Ostendorf and Reynolds 1998). This study aims to find out the spatial distribution patterns of the abundance of coffee and diversity index, and to classify the forest into different reserve zones based suitability of the forest areas for conservation of the wild coffee population and plant species of the forest.

6.2 Materials and methods

6.2.1 Data sources

Forest vegetation data and terrain data were used in this analysis. For prediction of the distribution patterns of the abundances of coffee and species diversity index, vegetation data from undisturbed forest were used. The forest vegetation data were those described in Chapter 4.2.1 of this thesis and have been collected from 58 sample plots. However, the data of one sample plot (Plot68), which was an outlier in the cluster analysis described in Chapter 4.2.2, was excluded. Hence, only the vegetation survey data of 57 sample plots were used. The types of vegetation data used in the analysis were species abundances, species diversity index and the site scores of the Principal Component analysis (PCA) axes I and II. Abundance refers to the number of stems per sample plot, while the species diversity index used in this analysis is the Shannon diversity index, since it crystallizes both species richness and evenness into one figure (Magurran 1988). The site scores of axes I and II of the PCA were obtained from the results of the analysis presented in Chapter 4.3.3 of this thesis. The terrain data were derived from a digital elevation model (DEM), which in turn was developed from topographic maps. The area of topographic map used in DEM development includes the undisturbed forest and the surrounding managed forests and farm lands (793870-830490 m E and 923320-934340 m N UTM). The procedures used to develop DEM and evaluation criterion maps are presented in the next sections.

6.2.2 Digital elevation model development

The DEM was developed from a topographic map of 1:50,000 scale obtained from the Ethiopian Mapping Agency. The topographic map of the study area was scanned, and then geo-referenced to the UTM coordinate system using the software ERDAS IMAGINE 8.5 (ERDAS, Inc., Atlanta, GA, USA). The vertical interval between the contour lines of the map is 20 m. All contour lines, peak points, depressions, and streams were digitized in ArcView GIS (ESRI Inc., Redlands, CA, USA). The ArcView shape files of the contour lines, peak points, depressions and streams were converted to Arc coverage files of the same map projection. The DEM was prepared from the coverage files using TOPOGRID, a DEM building module built-in ARC/INFO GIS program (ESRI Inc., Redlands, CA, USA), which is based on the procedure developed by Hutchinson (1989). To develop the DEM, a resolution of 20 m pixel size was used. Occasionally, DEMs contain minor errors, such as sinks or peaks. Sinks and peaks are errors in data due to resolution of the data or rounding of elevations to the nearest integer value. Research has indicated that, for 30 meter resolution DEM, 0.9 to 4.7 percent of the cells in a DEM are sinks (Eastman 2001). To improve the accuracy of the DEM, it was made depressionless by filling the sinks using the hydrological modeling extension in ArcView. By filling the sinks, the cells contained in depressions are raised to the lowest elevation value on the rim of the depression (Eastman 2001).

Different data layers were generated from the DEM using the surface analysis module in the ArcView GIS software. These include elevation, slope angle, aspect angle, and hillshade. The ArcView extension called SINMAP (Pack et al. 1998) was used to derive slope stability and wetness indices. The aspect angle was converted to continuous variables of northness and eastness by using cosine and sine transformations, respectively. Aspect is the direction that a slope faces, and is normally measured in degrees. Transformation converts the aspect angle in continuous data ranging between values –1 and 1. The slope angle was also converted to percent slope using tangent transformations and multiplying by 100.

6.2.3 Regression analysis and criteria map layers development

Digital elevation data were overlain with sample plot locations to estimate elevation and other terrain derived data for each plot. The terrain data used as environmental or explanatory variables were elevation, percent slope, and aspect. In addition, the first and second PCA axes site scores were used as explanatory variables. The response variables were abundance data of *C. arabica*, and the Shannon diversity index. The abundance data of coffee was log-transformed to ensure a better fit of the values in the regression model (Jager and Looman 1995).

The map layers of the PCA axes were produced by regressing the PCA axes scores against the terrain-derived environmental variables. The relationships of the abundance of coffee and Shannon diversity index with the PCA axes' site scores and terrain data (aspect, elevation, and slope) were investigated using linear regression. Step-wise linear regression was used to sort out the significant explanatory variables. Those variables significant at 5% level were used in the analysis. Linear regression models were fit to the plot data, regressing coffee abundances and Shannon diversity index against the significant explanatory variables.

Table 6.1 Variable used in regression model to predict and map potential distribution patterns of coffee and diversity index

	Variable	**Source**	**Use**
1	Species abundance data	Vegetation survey	Response variable
2	Shannon diversity index	Calculated from vegetation survey data at each plot	Response variable
3	PCA I site scores	Vegetation survey data analysis in Chapter 4.3.3	Explanatory variable
4	PCA II site scores	Vegetation survey data analysis in Chapter 4.3.3	Explanatory variable
5	Aspect	Derived from DEM using Surface Analysis	Explanatory variable
6	Elevation	Derived from DEM using Surface Analysis	Explanatory variable
7	Slope	Derived from DEM using Surface Analysis	Explanatory variable

The resulting equations were then used to map the predicted potential distribution pattern of the response variables using the map equation function in ArcView GIS. The resulting distribution maps were evaluated in two ways: first, the maps were visually inspected and viewed for consistency, agreement of general trends with known environmental gradients, and distribution patterns; second, the predicted results were compared with the known data from the 57 sample plots. To compare the predicted values with the measured values from the sample plots, the predicted values at the plot locations were extracted from the map. The difference between the predicted and the measured values were tested using the paired *t*-test.

6.2.4 Input criteria and pre-processing

The criteria maps

Three criteria, i.e., one physical and two biological criteria, and a constraint, were used to evaluate reserve area suitability in this study. These criteria were the spatial patterns of the abundance of coffee, species diversity index, and elevation. The first two are biological criteria, and were used to address the conservation of coffee and other plant species diversity in the decision. Elevation was used to incorporate the topographic position in the decision-making. All criteria are continuous variables. In addition to the input criteria for evaluation, a constraint criterion of land-use right was also used to incorporate qualitative data concerning social suitability.

The coffee criterion map is the most important map, since the major objective is to conserve the wild coffee populations occurring in the forest. The diversity of other plant species as the evaluation criterion was accounted for by using the map layer of the Shannon diversity index. Beside conservation of biodiversity, conservation of the landscape, especially of the riverine vegetation on steep slopes at low elevation, can also be considered important part of forest conservation. Areas at lower and mid elevation in the study sites are also more valuable for conservation, since they represent areas that are less disturbed by people and have a diverse plant species. This was accounted for using the elevation map layer as a physical input criterion.

Standardization of criteria maps

Multi-criteria evaluation involves different techniques of combining various criterion map layers. The different map layers may have different units and ranges of scales. In such case, the input map layers should be transformed to a common scale or comparable unit

(Malckzewski 1999). Linear scale transformation is the most frequently used method of transforming input data into criterion maps of a common numeric range.

In this study, all the criteria map layers were transformed by a linear scale transformation method to index values ranging between 0 and 1 (Jiang and Eastman 2000). The two most often used linear transformation methods are maximum score and range score procedures (Malckzewski 1999). The range score procedure of transformation is given by the formula:

$$x'_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \qquad \textbf{Equation 6.1}$$

This formula was used to transform the coffee and diversity index criteria attribute values to criterion scores, where X'_{ij} is the standardized score for the i[th] object (alternative) and the j[th] attribute, X_{ij} is the raw score, X_j^{max} is the maximum score for the j[th] attribute, and X_j^{min} is the minimum score for the j[th] attribute. The elevation criterion attribute values were transformed by the formula:

$$x'_{ij} = 1 - \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \qquad \textbf{Equation 6.2}$$

in order to give more weight to sites at lower altitude. Hence, a point at lowest elevation receives the highest criterion score, 1, and a point at highest elevation receives 0.

Constraints

The constraint map is a qualitative criterion and defines the social suitability of the reserve. It determines the areas that are used by the local people, which can then be excluded from the protected reserve zones. If, for example, a forest area is used by the local people as a semi-forest or plantation coffee production system, it is no longer available for a reserve core zone and has to be excluded. The index of the constraint criterion map layer is Boolean (Jiang and Eastman 2000); i.e., the values are either 1 for suitable or 0 for unsuitable areas. The constraint map is based on a map demarcating the undisturbed forest from the forests managed for coffee production and agriculture, provided by Yayu District Department of Agriculture (unpublished map) and the topographic map of the area obtained from the

Ethiopian Mapping Agency. The district department of agriculture performed the demarcation of undisturbed and managed forests in agreement with the members of the local community. The forest areas currently managed for coffee production, and the farmlands and settlement areas in the surroundings were assigned a value 0 and the undisturbed forest areas were assigned a value 1. The forest area is surrounded by large areas of farmlands and settlement. However, only part of farmlands and settlements closer to the forest falling with UTM coordinates of 793870-830490 m E and 923320-934340 m N, zone 36.

6.2.5 Reserve zoning: the multi-criteria evaluation method

Multi-criteria evaluation (MCE) deals with the allocation of land to suit a specific objective based on a variety of attributes that the selected area should possess. The MCE method makes it possible to combine the information from different evaluation criteria and to form a single index evaluation or map. The IDRISI GIS software has a special MCE module (Eastman 2001). In GIS, two procedures are commonly used for MCE: the Boolean overlay and the index overlay techniques (Jiang and Eastman 2000). In the Boolean overlay, all criteria are assessed by thresholds of suitability to produce Boolean maps, which are then combined by logical operators such as intersection (AND) and union (OR). The index overlay method uses continuous criteria, which are standardized to a common numeric range, and then combined by weights. There are two commonly used index overlay techniques: weighted linear combination (WLC) and order-weighted average (OWA). Since criteria vary in importance for decision-making, the importance of the criteria used in the evaluation is achieved by assigning a weight to each criterion.

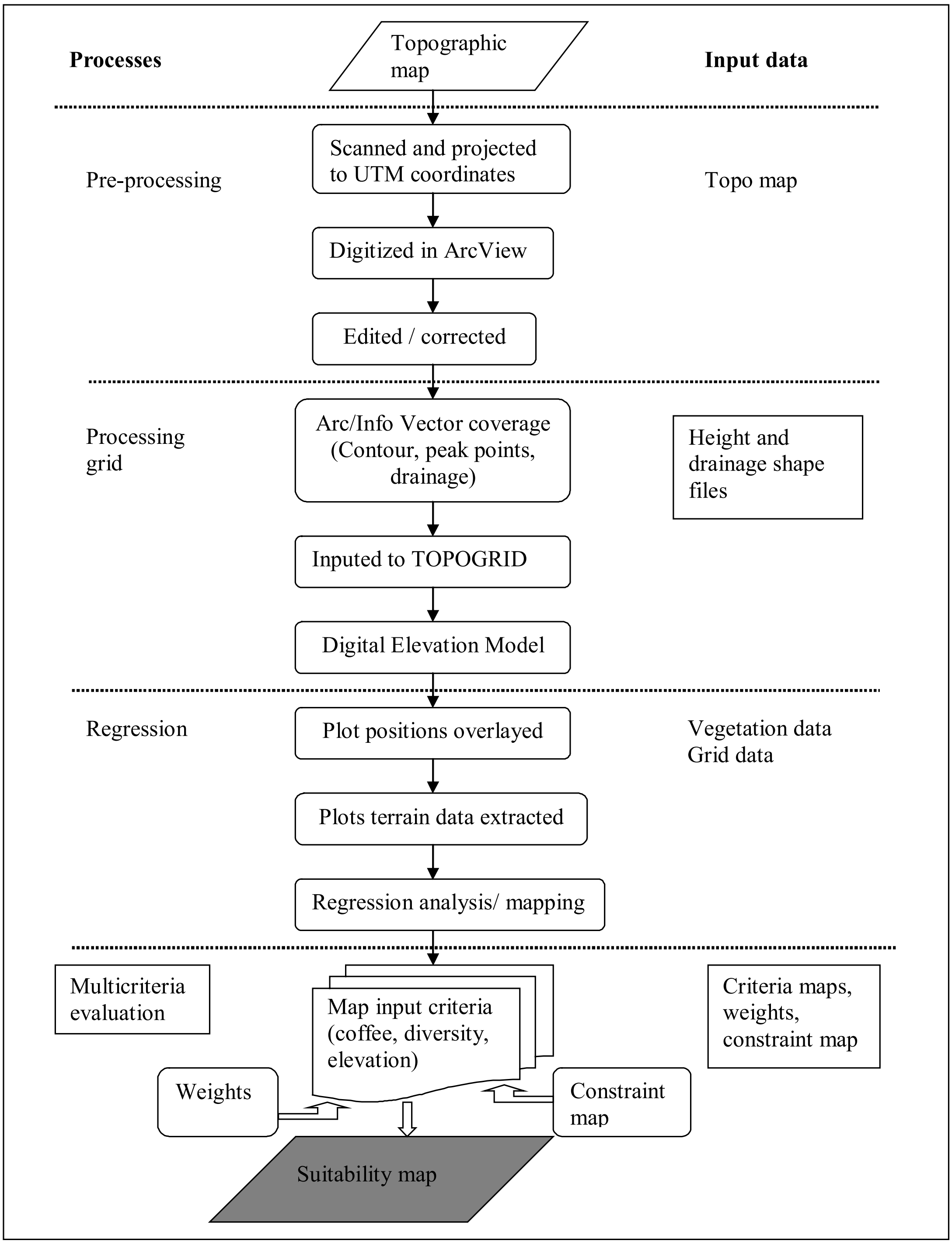


Figure 6.1. Flowchart showing procedures of criteria map development and reserve suitability analysis

Weighted linear combination (WLC)

The weighted linear combination (WLC) is the MCE method in which continuous criteria are combined by means of a weighted average. The WLC enables the decision maker to assign weights of 'relative importance' to each criterion map or attribute. Such weights are called criterion weights. In so doing, the decision maker discriminates between criteria; giving higher weights for the most important criterion and lower for the less important criterion. Criterion weights also represent trade-off weights, i.e., the values express the manner in which they trade with other criteria when aggregated in MCE (Eastman 1999). The criterion weight used in aggregation should sum up to 1 in order to obtain a suitability map of the same range of values as the standardized criterion maps. The result is a continuous map of suitability that may then be masked by one or more Boolean *constraints* to accommodate qualitative criteria, and finally threshold to yield a final decision. The WLC is performed using the following equation (Eastman 2001):

$$S = \sum w_{ij} . x_i \qquad \textbf{Equation 6.3}$$

where S is suitability, w_{ij} is the weight of class j from map i and x_i is the criterion score of map i. Weights were distributed using pairwise comparison method of Saaty (Saaty 1980; Eastman 2001). In the decision-making process, this method is known as the analytical hierarchy process (AHP). In this approach, each criterion is rated for its importance relative to every other criterion using a 9-point reciprocal (Saaty 1980; Eastman 1999; Malckzewski 1999; Basnet et al. 2001; de Araujo and Macedo 2002). For example, if criterion A is twice as preffered as criterion B, then criterion B is only one-half as much as criterion A. Hence, if A receives a score of 2 relative to B, B receives a score of ½ when compared to criterion A. The scale used for pairwise comparison is given in Table 6.2. The reciprocals of the intensity of importance ranges from moderately less important to extremely less important (1/2 to 1/9).

Table 6.2. Scale for pairwise comparison (Malckzewski 1999)

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong importance to extreme importance
9	Extreme importance

Weights are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix. The principal eigenvector of this matrix represents the best-fit set of weights (Eastman 1999). The procedure for weights computation involves three steps (Malczewski 1999; Table 6.3): (I) sum the values in each column of the pairwise comparison matrix; (II) divided each element in the matrix by its column total to get the normalized pairwise comparison matrix; and (III) compute the average of the elements in each row of the normalized matrix, i.e., divide the sum of the normalized scores of each row by 3 (the number of criteria). These averages provide an estimate of the relative weights of the criteria being compared. In IDRISI, a special module named WEIGHT is available to directly calculate the principal eigenvector. This module also tests whether the assigned weights are consistent or not. The weights used for WLC to evaluate the suitability for coffee gene reserves are presented in Table 6.3.

Table 6.3. Procedures to compute criterion weights used in the WLC. Descriptions of computation procedures are given above (I- pairwise matrix; II-normalized pairwise matrix; and III-weights)

		Step I			**Step II**			**Step II**
	Criterion	**1**	**2**	**3**	**1**	**2**	**3**	**Weight**
1	Coffee population	1	3	7	0.68	0.71	0.58	**(0.68+0.71+0.58)/3 = 0.66**
2	Shannon index	1/3	1	4	0.23	0.24	0.33	**(0.23+0.24+0.33)/3 = 0.26**
3	Altitude	1/7	1/4	1	0.10	0.06	0.08	**(0.10+0.06+0.08)/3 = 0.08**
	Sum	1.48	4.25	12.00	1.00	1.00	1.00	1.00

Order-weighted average

The order-weighted average (OWA) is similar to the WLC except that a second set of weights is used. The second set of weights, order weights, control the manner in which the weighted criteria are aggregated (Jiang and Eastman 2000). The OWA is given by the equation (Eastman 2001):

$$S = \sum w_{ij} . x_i . wo_i$$ **Equation 6.4**

where S is the suitability as in WLC (Equation 6.3), w_{ij} is the weight of class j from map i, x_i is the criterion scale of map i and wo_i is the order weight of the map i. The OWA also uses criterion weights similar to the WLC beside the order weights. Criterion weights are applied uniformly to specific criterion maps. However, order weights are applied to the criterion scores on a pixel-by-pixel basis as determined by their rank ordering across criteria at each location (pixel). Order weight 1 is assigned to the lowest-ranked criterion for that pixel (i.e., the criterion with the lowest score), order weight 2 to the next higher-ranked criterion for that pixel, and so forth. Thus, it is possible that a single order weight be applied to pixels from any of the various criteria depending upon their relative rank order in that particular pixel. Both WLC and OWA are available in the MCE module of IDRISI.

The advantage of using OWA is that the decision maker can get several alternative solutions, and can choose one that best fits the objectives of the decision making process. Because, order weights can produce several aggregate solutions that fall anywhere between the ‘minimum’ and ‘maximum’ along the risk continuum. The concept of risk in decision-making originates from the Boolean approaches. The Boolean approaches are extreme functions that result either in very risk-averse solutions when the AND operator is used or in risk-taking solutions when the OR operator is used (Eastman 2001). In the risk-averse solution, a high aggregate suitability score for a given location (pixel) is only possible if all criteria have high scores. In the risk-taking solution, a high score in any criterion will yield a high aggregate score, even if all the other criteria have very low scores. The AND operation can be described as the ‘minimum’, since the minimum score for any pixel determines the final aggregate score. Similarly, the OR operation can be called the ‘maximum’, since the maximum score for any pixel determines the final aggregate score. The AND solution is risk-averse because we can be sure that the score for every criterion is at least as good as the final aggregate score. The OR solution is risk-taking because the final aggregate score only tells us about the suitability score for the single most suitable criterion. In OWA, solutions can fall anywhere in between the AND (weight of 1, 0, 0 in this case) and OR (0, 0, 1). To characterize the nature of the OWA operation, the ANDness parameter was calculated using the formula (Jiang and Eastman 2000):

$$ANDness = (\frac{1}{n-1})\sum(n-i)W_{order}i) \qquad \textbf{Equation 6.5}$$

in which n is the total number of criteria, i is the order of criterion, and $W_{order}i$ is the weight for the criterion of the ith order. ORness is obtained by subtracting ANDness from 1. The value of ANDness and ORness is governed by the amount of skew in order weight. ANDness and ORness reflect attitude toward risk in decision-making. At extreme ends, the logical AND operator is the most risk-averse combination (ANDness is 1) and the logical OR (ORness is 1) is the most risk-taking combination for decision-making (Table 6.4).

Table 6.4 Different order weights used in the OWA analysis

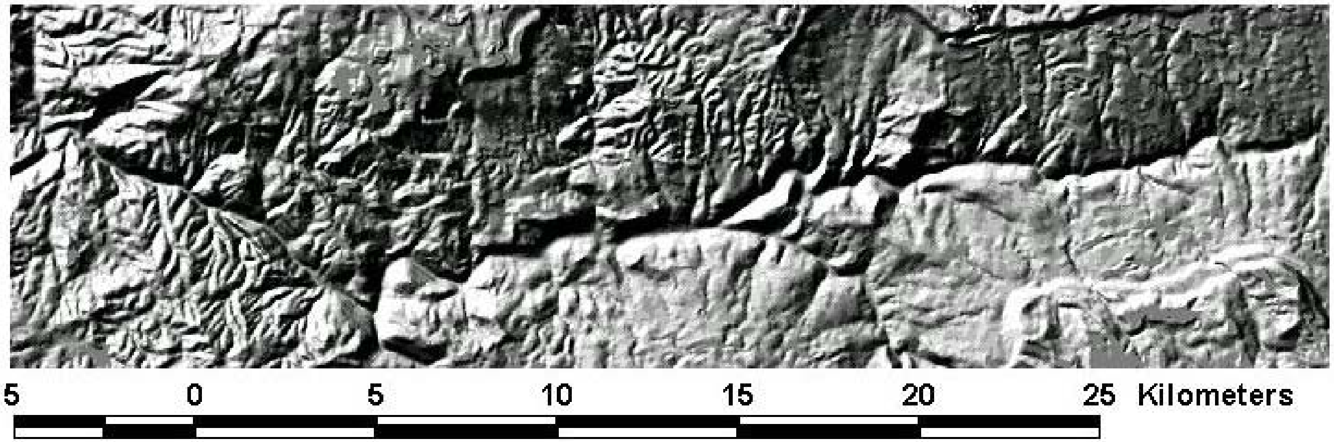
Linguistic terms for OWA operator	**Order weights**	**ANDness**	**ORness**
Very low	1, 0, 0	1	0
Very low to low	0.6, 0.25, 0.15	0.725	0.275
Low	0.45, 0.3, 0.25	0.4	0.6
Average	0.33, 0.33, 0.33	0.333	0.667
High	0.25, 0.3, 0.45	0.267	0.733
High to very high	0.15, 0.25, 0.6	0.183	0.817
Very high	0, 0, 1	0	1

The natural breaks method in ArcView GIS software was used to classify the suitability map into areas of highly, moderately, and slightly suitable classes, based on their suitability values. This method identifies natural breakpoints by looking for groupings and patterns in the data (ESRI 1996). The final map of different reserve zones was prepared using polygon drawing tool in ArcView. The areas of the landscape covered in the analysis were categorized into four reserve zones: core zone, buffer zone-I, buffer zone-II, and transition zone. Highly suitable areas were categorized as ‘core zone’, moderately suitable areas as ‘buffer zone-I’, slightly suitable areas and the forest areas managed by the local people for coffee production as ‘buffer zone-II’, and the surrounding farmlands and settlement areas as ‘transition zone’. The outer boundary of the transition zone is arbitrarily, including only those areas falling a rectangular block of forest and surrounding farmlands digitized from the topographic map (within the range of UTM coordinates of 793870-830490 m E and 923320-934340 m N, zone 36).

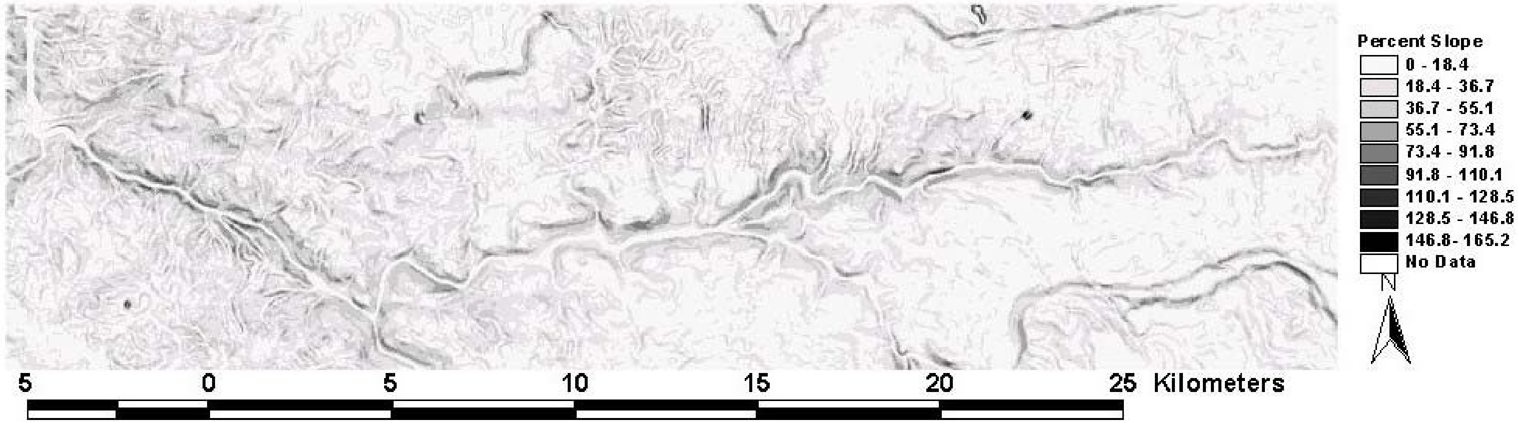
6.3 Results

6.3.1 Digital terrain data

Images characterizing the terrain features of the study area are presented in Figure 6.2. The area is characterized by rugged topography, steep slopes, hills and valleys. Figure 6.2a shows a three-dimensional view (hillshape) of the landscape of the study area, with Geba River passing through the center. Most areas have moderately steep slopes, with some parts having very steep slopes and cliffs. The slopes range from 0 to 165%. The steepest parts are found close to the riverbanks around the valley bottom, and at high elevations.



a) Relief



b) Slope

Figure 6.2. Terrain characteristics of the study area

6.3.2 Relationship of coffee occurrence and species diversity index with the environmental variables

Slope, the site scores of the first and second PCA axes, PCA I and PCA II, show strong relationship to the response variables. The PCA axes are gradients in environmental variables. PCA I is strongly negatively correlated with slope, silt content, CEC and soil pH, and positively with altitude and sand content and distance from river (Chapter 4.3.4). PCA II is strongly positively correlated with altitude, C:N ratio, silt content and distance from river, and negatively correlated with sand content and soil pH (Chapter 4.3.4). The log-linear regression of the abundance of coffee with PCA I and slope were significant ($P < 0.001$ and $P < 0.05$ respectively, with multiple $r^2 = 0.56$). Similarly, the linear regression between the Shannon diversity index and PCA II was highly significant ($P < 0.001$ and $r^2 = 0.34$). Based on the established relationships with environmental variables, the regression equations were used to map the spatial patterns of coffee and the Shannon diversity index. Coffee abundance, CA, was predicted by:

$$\log_e CA = 6.0445 + 1.4273 PCAI - 0.0273 Slope \quad \textbf{Equation 6.6}$$

while the Shannon diversity index was predicted and mapped by the equation:

$$Shannonindex = 2.1516 - 0.1791 PCAII \quad \textbf{Equation 6.7}$$

The potential distribution patterns of coffee and the Shannon diversity index of plants in the landscape are presented in Figure 6.3. The distribution map shows lower abundances of coffee at sites along the Geba River and at sites on very steep slopes at higher elevations. In most parts of the landscape, the predicted abundance of coffee was in the range of medium to high. The predicted distribution patterns of the Shannon diversity index shows higher diversity at lower elevations along the Geba River, and lower diversity at higher elevations on the ridges (Figure 6.3 b). However, most parts of the landscape at higher elevations have already been deforested and changed to other land-use types (Figure 6.4). Hence, the predicted distribution map can only be used to estimate the patterns of distribution within the undisturbed forest area (Figure 6.4). There is no significant difference between the predicted and the observed values of the coffee abundance ($P > 0.1$) and Shannon diversity index ($P > 0.1$) at the sample plots.

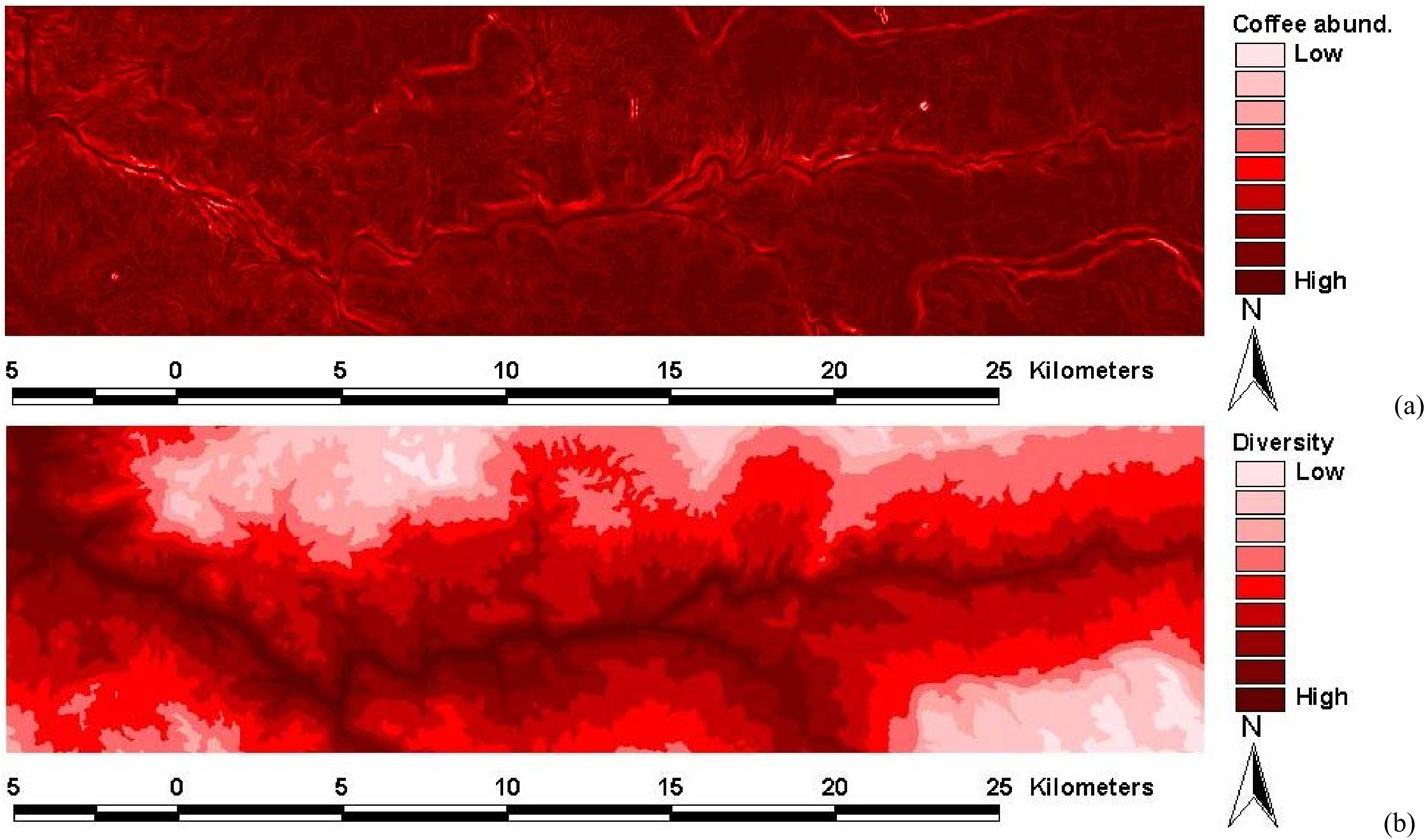


Figure 6.3. Criterion maps of coffee and diversity index

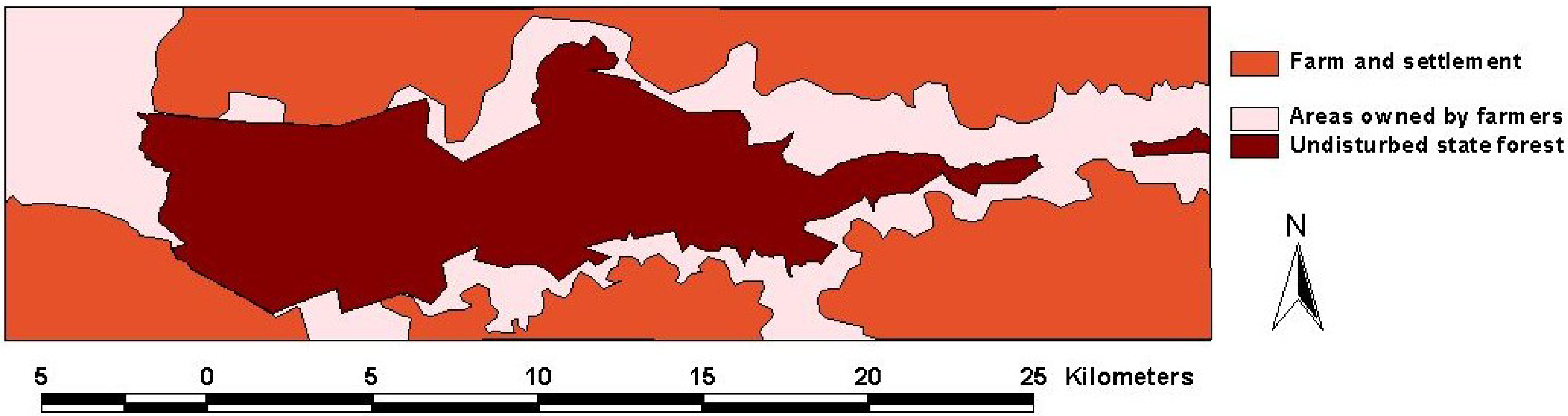


Figure 6.4. The constraint criterion map shows forest areas that can be protected (undisturbed), areas that are owned by farmers for coffee production, and areas that are already converted into agriculture and settlement.

6.3.3 Reserve suitability and zones

The areas suitable for a reserve around Yayu and their degree of suitability are mapped (Figure 6.5). The summary of the results of zoning and reserve suitability classification are presented in Tables 6.5 and 6.6. From all possible solutions of the order-weighted average (OWA), the result obtained by using order weights 0.6, 0.25, 0.15 was used for the final zoning of the reserve, as the resulting suitability map included much of the undisturbed forest and was nearly a risk-averse solution with an ANDness of 0.725 (Figure 6.5; Table 6.4).

The OWA2 (without constraint) option of reserve suitability (Figure 6.5a) shows the potential forest areas that could fall within the three suitability classes. However, most areas in the landscape are currently used by the local people for coffee production, farming and settlement (Figure 6.4). Using such areas as constraint resulted in the suitability map OWA1 in Figure 6.5b. Exclusion of such areas reduced the areas in different suitability classes available for the reserve (Table 6.5).

Table 6.5. Areas (in ha**)** in different reserve suitability classes. Note: *-stands for multiplication. B- available for conservation, while C or Constraints are areas used by local people, and not available for strict conservation.

	Highly Suitable	**Moderately suitable**	**Slightly suitable**	**Total area**
A. Total area without constraint (OWA-2) (= B+C)	**16754**	**15564**	**4268**	**36586**
B. Undisturbed natural forest (OWA1)	**8030**	**2167**	**1**	**10198**
a. Percent undisturbed forest of total (=a/A*100)	21.9	5.9	0.0	27.9
C. Areas of constraint (=b+c)	**8724**	**13396**	**4267**	**26387**
b. Farm and settlement	4229	10263	2292	16784
c. Forests managed for coffee production	4495	3133	1975	9603
d. Percent farm and settlement of total (=b/A*100)	11.6	28.1	6.3	45.9
e. Percent managed forest of total (=c/A*100)	12.3	8.6	5.4	26.2
f. Percent of constraint areas to the total (=C/A*100)	23.8	36.6	11.7	72.1

About 22% and 6% of the total area of the landscape fall into the classes ‘highly’ and ‘moderately’ suitable for reserve, respectively. The highly and moderately suitable areas cover almost the entire undisturbed forest, which is about 28% of the total landscape considered in this study (Table 6.5). The local people currently use about 72% of the area, either as managed forests for coffee production (26%) or as farmland and settlement areas (46%).

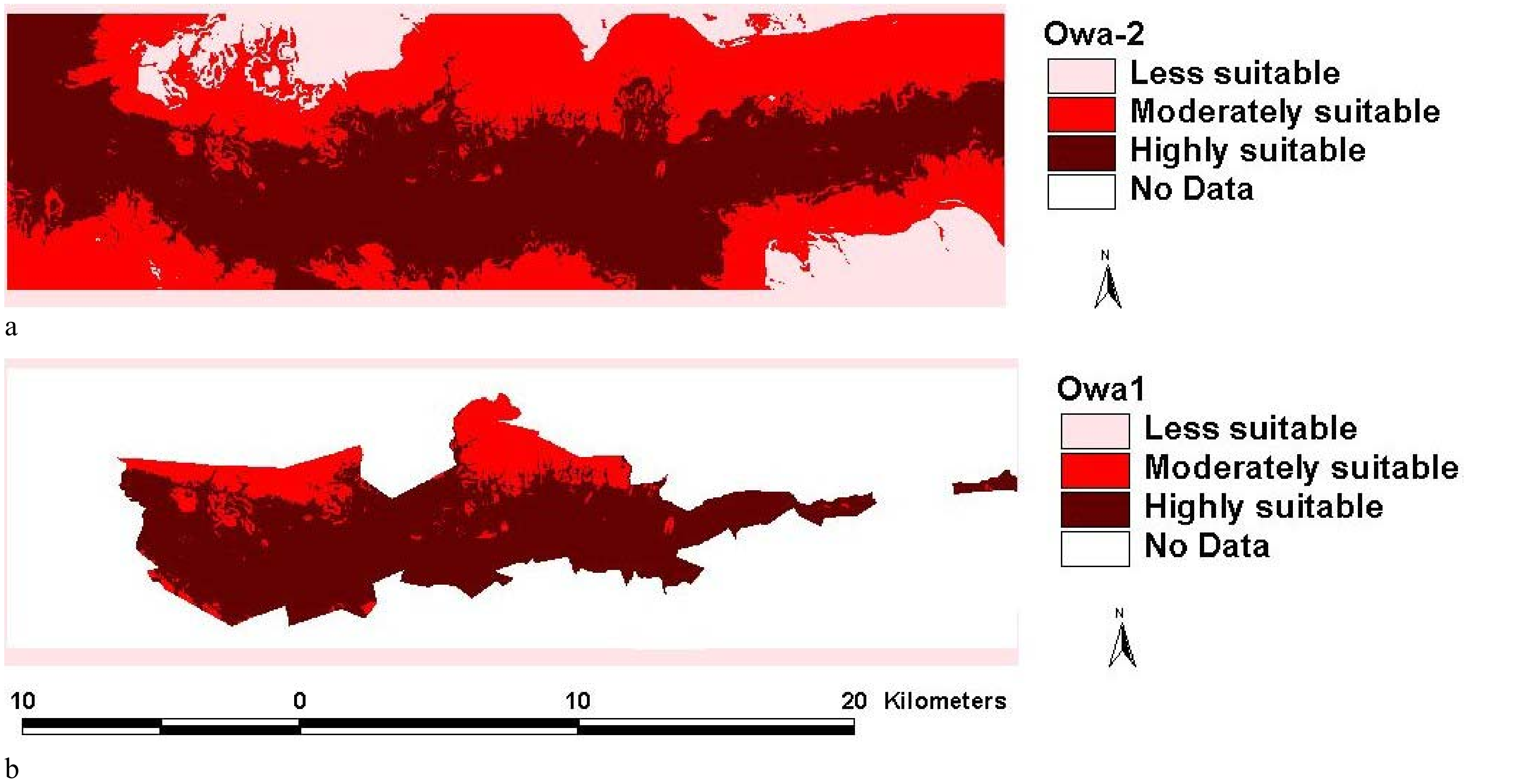


Figure 6.5. Suitability classes for coffee gene reserve. (a) OWA-2, shows potential suitability classes without constraints (b) OWA1, is when land-use right claimed by people is used as a constraint.

The final reserve zones are mapped based on the suitability classes of the sites and the land-use type of the constraint area. Areas that are highly suitable in the OWA1 suitability classes and some very small areas those are moderately suitable, but embedded within a larger area of the highly suitable class, are classified as parts of the core zone. However, very small areas of the high suitability class that are surrounded by moderately suitable areas are excluded. Hence, the moderately suitable areas and very small, isolated areas of highly suitable areas embedded within the moderately suitable class of OWA1 are classified as buffer zone-I. The percentage of the forest area in the less suitable class of OWA1 is almost zero and does not count in the final zoning. The forest areas managed by the local people for coffee production are classified as buffer zone-II. The surrounding farmlands and settlement areas are classified as the transition zone. The management zones for the coffee reserve are presented in Figure 6.6 and Table 6.6 below.

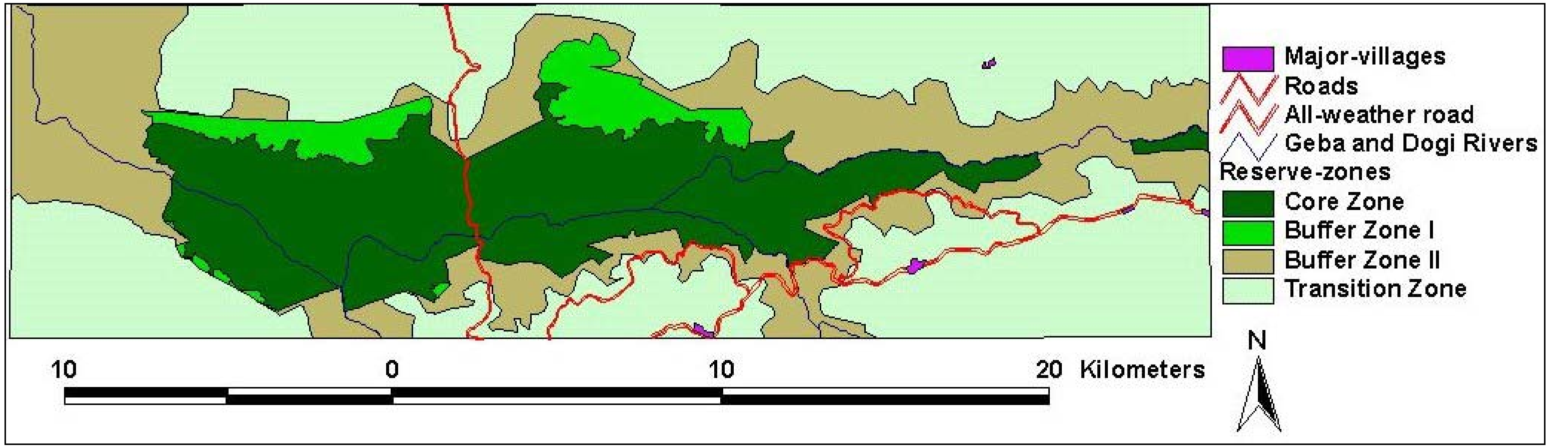


Figure 6.6. Management zones of coffee gene reserve

The core zone and buffer zone-I accounted for 23 and 5% of the total area of land considered in the analysis, respectively. These two zones nearly completely cover the undisturbed forest areas, which is about 28% of the total area. The area allocated as buffer zone-I is smaller than the moderately suitable areas of the undisturbed forest identified in the analysis (Table 6.5), since many small parts of moderately suitable areas are embedded in the highly suitable class (Figure 6.5; OWA1), and were hence classified as part of the core zone (Figure 6.6, Table 6.6).

The relatively small percentage of the total area available for the core zone is attributed to the presence of large proportions of farmland, settlement area, and forests managed for coffee production, which together constitute 72% of the area (Table 6.5). Out of this, buffer zone-II covered 26% of the total area of the landscape (Table 6.6), which is equivalent to that of managed forests (Table 6.5), while the transition zone covered 46% of the area, representing farmlands and settlement areas.

Table 6.6. Reserve zone areas

Management zone	Area (ha)	Proportion of total landscape	Comments
Core zone	8544.4	23.4%	Areas classified as highly suitable in OWA1
Buffer zone-I	1652.2	4.5%	Areas classified as moderately suitable in OWA1
Buffer zone-II	9594.4	26.2%	Forest areas managed as semi-forest for coffee production and slightly suitable in OWA1
Transition zone	16794.0	45.9%	Farmland, rangeland and settlement areas adjacent to forest

6.4 Discussion

6.4.1 Evaluation criteria

The terrain-derived data were very useful to determine vegetation patterns and develop evaluation criteria for a reserve design. The abundance of coffee and the species diversity index are strongly related to some terrain-derived data and the PCA axes scores. Coffee abundance is strongly positively correlated with the first PCA axis scores, which in turn represent the environmental gradient of the combinations of several variables. Among the terrain-derived data, slope has a strong negative correlation with coffee abundance. On the other hand, the diversity index was negatively correlated with the site scores of the second

PCA axis. The second PCA axis represents the second gradient of environmental variables. The PCA axis scores can better explain the variations of environmental gradients, since they account for all possible combinations of variables that were not or could not be measured (Mora and Iverson 2002; Reyers et. al 2002). The distribution patterns of the abundances of coffee and diversity index predicted by these relationships (figure 6.3 a, b) are similar to the patterns observed in the forest vegetation (Chapter 4.3). Similarly, the areas at low altitudes had high diversity indices, and those at the mid and high altitudes on gentle slopes show high coffee abundance.

Ideally, decision-making concerning biodiversity conservation should take into account as many relevant criteria as possible (Kamppinen and Walls 1999). However, in multiple criteria evaluation, increasing the number of input criteria may decrease the degree of suitability and the areas that can be classified as highly suitable (Basnet 2001).

6.4.2 Reserve zones

The multi-criteria decision analysis carried out using the OWA model is found to be suitable for identifying potential reserve areas and, thus, supporting the relevant decision making considerably. In the past, different techniques for designing reserves have been used (e.g., Diamond 1967; MacArthur and Wilson 1967; Higgs and Usher 1980; Higgs 1981; Margules et al. 1982; Buckley 1982; Blouin and Connor, 1985; Usher 1986; Li et al. 1999; Clemens et al. 1999; Heijnis et al. 1999; Akcakaya 2000; Scot and Sullivan 2000). Most of the recent reserve design methods were based the heuristic method, which has rules for including mandatory polygons, forcing adjacency, including desirable and excluding undesirable features (Bedward et al. 1992; Williams and ReVelle 1996; Heijnis et al. 1999; Clemens et al. 1999). These approaches are similar to Boolean evaluation methods in that the input criteria are not continuous map layers, but polygons with values of either 1 or 0. The OWA model is more interesting and relevant since the resulting map has continuous index values and varying degrees of suitability (Jiang and Eastman 2000; Eastman 2001). As opposed to a single solution obtained either using intersection or union in the Boolean operations, OWA provides different sets of solutions, which fall anywhere in between the intersection (AND, or minimum suitability) and union (OR, or maximum suitability). It is more flexible and can be adjusted to fit the interests of the decision-maker. This flexibility is made possible through the order weights (Table 6.4). The resulting different degrees of suitability allow further classification of the suitable areas into zones depending on their level of suitability.

The fact that only smaller parts (ca. 28%; Table 6.5) of the landscape represent undisturbed forest in Yayu, coupled with the threat to similar forests at national level due to deforestation (Reusing 1998) shows the urgent need for conservation (Tewolde 1990; Tadesse et al. 2002). Hence, the core zone and buffer zone-I should be mainly managed for the conservation of the wild coffee population and other plant species diversity, with some restricted extractive use of non-timber forest products in the buffer zone-I.

In situ conservation of biodiversity, especially of genetic resources, deals not only with populations in undisturbed natural ecosystems, but also with populations in the managed systems, farmlands and homegardens where the species is grown (Brush 2000). Defining the managed forest areas currently used by the local people as a socio-buffer (buffer zone-II) is assumed to be the appropriate approach to conserve as well as sustainably use the coffee population in the managed ecosystem. Involving the people in the area can contribute to the sustainable use and conservation of wild coffee and other natural resources in these zones, and also for better protection of the core and buffer zone-I.

6.4.3 Implications for conservation

The area identified as the core zone is not completely surrounded by buffer zones; in some parts, there is no buffer zone between the core and the transition zones, and the core is highly encroached by the farmlands. As can be seen in the final map (Figure 6.6), the southern part of the forest area is highly encroached and the buffer zones are mostly very narrow. This is mainly because the topography of the landscape is easily accessible for farming, and the area is close to Yayu town and other major settlement areas. However, for a better protection of the wild coffee populations and other plant species in the core zone, it is important to have this zone surrounded by a buffer zone. The success of conservation within the core zone also depends on how well the buffer zone is managed (Given 1993; Maxted et al. 1997). Hence, it is a necessity to restore some of the cultivated areas and rangelands bordering the core zones. Restoration through natural succession is a possible reality as supported by results of this study in chapter 5 on the convergence of the composition, species diversity and vegetation structure of NATFOR and SECFOR. If the farm or rangelands bordering the core zone are restored and managed as a buffer zone (socio-buffer), conflicts with owners may probably happen. However, success is also likely since the people will still be able to make a living from coffee production by using the traditional management practices.

A small section of the core zone is separated from the larger core zone by the buffer zone (Figure 6.6). Theoretically, there can be one or more core zones within a biosphere reserve. However, in this case, the isolated core zone is small and might become gradually degraded and converted into managed forest (buffer zone) or farmland. Hence, the possibility of joining these two zones by classifying the buffer zone in between as a core zone should be discussed with the local people. From the biological and suitability point of view, the buffer zone between the core zones appears to be suitable as a core zone (Figure 6.5, OWA2). It also represents the riverine vegetation, which has potentially high species diversity, and is important from the catchment and stream bank conservation aspect.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Yayu forest is a highly valuable forest ecosystem for biodiversity conservation. The availability of abundant wild coffee population makes it a keystone forest ecosystem for the conservation of the genetic resources of coffee in the country. However, flat to gentle slope areas are the most important parts of the forest to find higher abundances of the coffee trees. High diversity of other plant species also makes the forest one of the most important forest areas for the conservation of biodiversity in Ethiopia.

Traditional forest management systems for coffee population in Yayu area hamper the regeneration of most plant species. Highly affected are shade tolerant old-growth forest species and small trees that are not important as shade trees. In general, the following can be concluded: (a) the species diversity decreases sharply with the increase in the age of management; (b) the population structures of many species, including coffee, are modified through management, which negatively affects their ability to regenerate in these forests; and (c) such forests, however, have fairly high plant species diversity and can contribute to biodiversity conservation than other land use types like agriculture. From the status of the old secondary forest, one can also conclude that abandoned settlements areas or managed forests can be restored in species diversity, composition and structure through time. However, minimum time required for such restoration through secondary succession has yet to be investigated.

GIS-based multi-criteria evaluation is a useful tool and objective approach to identify the different management zones of a reserve, based on biological, physical and social suitability criteria. However, the resulting suitability map and identified reserve zones should only be used as guide in the reserve planning, and the final decision be made in agreement with the local community. Some areas identified by the GIS-based model as buffer zones may have to be upgraded to a core zone and some areas of the transition zone to buffer zones for successfully fulfilling the conservation goals.

7.2 Recommendations

Given the high level of dependency of the local community on the forest coffee production, the importance of the forests for conservation of wild coffee population and other plant species, and the threat on such forests due to increasing population pressure and demand for more land, it is less likely that the forest areas that are currently managed for coffee production be abandoned to provide the opportunity for natural restoration through succession. Neither does such management allows regeneration of major tree species. Hence, the following activities are recommended regarding management, conservation and future research:

1. Protection of the undisturbed forest area: This can be achieved by establishing reserve for the conservation of wild coffee population and associated biodiversity in the undisturbed forest parts. Beside the availability of abundant wild coffee population and diverse plant species, the forest constitutes the largest undisturbed forest fragment in the country known to have wild coffee population. The reserve design developed in this study can be used as a starting point for establishing and managing it.
2. Use of other complementary conservation approaches. *In situ* on-farm and homegardens, and the *ex situ* conservation methods such as field gene banks and cryopreservation of seeds can enhance the conservation and use of coffee genetic resources. The traditional coffee production systems and maintenance of the local landraces should be encouraged in areas where there is a threat on cultivated coffee due to replacement by other crops. *Ex situ* methods have the advantage of easy access for characterization and evaluation in order to use the collected genetic materials for breeding or genetic enhancements of the cultivated plants. Currently, there are two field gene banks in SW Ethiopia (in Jimma and Chochie). However, the accessions collected from different areas of different climatic conditions may not easily adapt to the local condition of a single field gene bank for long term. Hence, it is recommended to establish a smaller field gene bank in the locality.

3. Restoration of the major canopy trees in the managed forests areas currently used for coffee production through replanting. This can support the idea of maintaining species diversity in the managed forests or forest coffee systems.
4. Encourage farmers to use seedlings raised from the local coffee population for replanting in the forests managed for coffee production whenever planting is necessary. This can contribute to maintaining the local coffee gene pool.

Research question that has to be further investigated:

5. Further research on other environmental variables (e.g. soil properties, soil depth), vegetation characteristics and other microclimate and other site conditions that are influenced by slope, and hence are affecting the abundances of wild coffee population.
6. Level of congruence of the occurrence of wild coffee population and plant species diversity. From this study, coffee occurrence seems to correlate with forest ecosystem of high plant species diversity. This has to be tested by exploring more forests with wild coffee population and similar forests with out wild coffee within Ethiopia. Such studies also enable to compare and prioritize forest areas based on their importance for the conservation of coffee genetic resources and other forest biodiversity.
7. Further investigation on the regeneration (germination and recruitment) of coffee in the managed forests. The major limiting factors for regeneration of coffee under the managed forest ecosystem are not clearly understood. It is also not clear whether the seedlings can survive and grow into mature trees in these managed systems.

8 REFERENCES

Abayneh Dererro. 1998. Natural regeneration in a broad-leaved Afromontane rain forest, South West Ethiopia. M.Sc. Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Abebe Demissie. 1992. Current status of genetic resources in Ethiopia. In: Adams R.P. and Adams J.E. (Eds.) Conservation of plant genes: DNA banking and in vitro biotechnology. Academic press, San Diego, USA, pp. 273-285.

Admasu Shiferaw, Masresha Fekade, Mehari Eneyewt and Tefsetewolde Biratu. 1989. Coffee area specialization. Ministry of Coffee and Tea Development, Addis Ababa.

Akcakaya H.R. 2000. Conservation and management for multiple species: integrating field research and modelling into management decisions. Environ. Manage. 26: S75-S83.

Aklog Laike. 1990. Forest resources and MOA forestry development and legislation. National Conservation Strategy Conference Document, Vol. 3: Ethiopia's experience in conservation and development. ONCCP, Addis Ababa.

Alemneh Dejene. 1990. Environment, famine and politics in Ethiopia: a view from the village. Lynne Rienner Publishers, Boulder.

Anthony F., Bertrand B., Quiros O., Lashermes, P. Berthaud J. and Charrier A. 2001 Genetic diversity of wild coffee (Coffea arabica L.) using molecular markers. Euphytica 118: 53-65.

Anthony F., Combes M.C., Astorga C., Bertrand B., Graziosi G. and Lashermes P. 2002. The origin of cultivated Coffea arabica L. varieties revealed by AFLP and SSR markers. Theor. Appl. Genet. 104: 894-900.

Asfaw Fanta. 1981. National Atlas of Ethiopia. Ethiopian Mapping Agency, Addis Ababa.

Anzueto F., Bertrand B. Sarah J.L. Eskes A.B. and Decazy B. 2001. Resistance to Meloidogyne incognita in Ethiopian Coffea arabica accessions. Euphytica 118: 1–8.

Backes M.M. 2001. The role of indigenous trees for the conservation of biocultural diversity in traditional agroforestry land use systems: The Bungoma case study. Agroforest. Syst. 52: 119-132.

Bailey R.G. 1996. Ecosystem geography. Springer-Verlag, Berlin.

Balmford A. 1998. On hotspots and the use of indicators for reserve selection. Trends Ecol. Evol. 13: 409.

Barthlott W. 1998. The uneven distribution of global biodiversity: A challenge for industrial and developing countries. In: Ehlers T. and Krafft E. (Eds.) German Global Change Research 1998. German National Committee on Global Change Research, Bonn, Germany, p. 36.

Barthlott W., Schmit-Neuerburg V., Nieder J. and Engwald S. 2001. Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. Plant Ecol. 152: 145-156.

Basnet B.B., Apan A.A. and Raine S.R. 2001. Selecting suitable sites for animal waste application using a raster GIS. Environ. Manage. 28: 519-531.

Batisse M. 1986 Developing and focusing the biosphere reserve concept. Nature Resour. 22: 2-11

Bedward M., Pressey R.L., and Keith D.A. 1992. A new approach for selecting fully representative reserve networks: addressing efficiency, reserve design and land suitability with an iterative analysis. Biol. Conserv. 62: 115–125.

Berthaud J. and Charrier A. 1988 Genetic resources of Coffea. In: Clarke R.J. and Macrae R. (Eds.) Coffee. Vol. 4. Elsevier Applied Science, London, UK, pp. 1-42.

Bertrand B., Aguilar G., Santacreo R., Anthony F., Etienne H., Eskes A.B. and Charrier A. 1997. Comportement d'hybrides F1 de Coffea arabica pour la production et la fertilité en Amérique Centrale. 17th International scientific colloquium on coffee ASIC, Nairobi, Kenya, pp. 415–423.

Bibby C.J., Crosby M.J., Johnson T.H., Long A.J., Statterfield A.J. and Thirgood S.J. 1992. Putting biodiversity on the map: global priorities for conservation. ICBP, Cambridge.

Biondini M.E., Bonham C.E. and Redente E.F. 1985. Secondary successional patterns in a sagebrush (Artemisia tridentata) community as they relate to soil disturbance and soil biological activity. Vegetatio 60: 25-36.

Blouin M.S. and Connor E.F. 1985. Is there a best shape for nature reserves? Biol. Conserv. 32: 277-288.

Bolstad P.V., Swank W. and Vose J. 1998. Predicting southern Appalachian overstory vegetation with digital terrain data. Landscape Ecol. 13: 271-283

Bonnefille R., Buchet G., Friis I, Ensermu Kelbessa and Mohammed M.U. 1993. Modern pollen rain on an altitudinal range of forests and woodlands in southwest Ethiopia. Opera Bot. 121: 71-84.

Braun-Blanquet J. 1932. Plant Sociology: The study of plant communities. McGraw Hill Book Company, New York.

Bridson D.M. 1994. Additional notes on Coffea (Rubiaceae) from tropical East Africa. Kew Bull. 49: 331-342.

Bridson D. 1982. Studies on Coffea and Psilanthus (Rubiaceae sub fam. Cinchonoideae). Kew Bull. 36: 817-59.

Bridson D. and Verdcourt B. 1988. Rubiaceae, Part 2. In: Polhill R.M. (Ed.). Flora of Tropical East Africa. A. A. Balkema, Rotterdam, The Netherlands, pp. 703-723.

Brooks T., Balmford A., Burgess N., Hansen L.A., Moore J., Rahbek C., Williams P., Bennun L.A., Byaruhanga A., Kasoma P., Njoroge P., Pomeroy D. and Mengistu Wondafrash. 1998. Conservation priorities for birds and biodiversity: do East African Important Bird Areas represent species diversity in other terrestrial vertebrate groups? Ostrich S15: 3-12.

Brush S.B. 2000. Genes in the field: On-farm conservation of crop diversity. Lewis Publishers, Boca Raton.

Buckley R. 1982. The habitat-unit model of island biogeography. J. Biogeogr. 9: 334-344.

Byron N. and Arnold M. 1999. What futures for the people of the tropical forests? World Dev. 27: 789-805.

Callaway R.M. 1997. Positive interactions in plant communities and the individualistic-continuum concept. Oecologia 112:143-149

Carr C.J. 1998 Patterns of vegetation along the Omo River in southwest Ethiopia. Plant Ecol. 135: 135-163.
Carvalho A. 1952. Taxonomia de Coffea arabica L. Caracteres morfologicos dos haploides. Bragantia 12: 201-212
Carvalho A. 1988. Principles and practice of coffee plant breeding for productivity and quality factors: Coffea arabica. In: Clarke R.J. and Macrae R. (Eds.) Coffee. Vol. 4. Elsevier Applied Science, London, UK, pp. 129-165.
Carvalho A. and Krug C.A. 1949. Genetica de Coffea XII. Hetereditariedade da cÔr amarela da semente. Bragantia 9: 193-202.
Carvalho A. and Monaco L.C. 1969. The breeding of Arabica coffee. In: Ferwerda F.P. and Wit F. (Eds.) Outlines of perennial crop breeding in the tropics. H. Veenman & Zonen N.V., Wageningen, The Netherlands, pp. 198-216.
Chaffey D.R. 1979. Southwest Ethiopia forest inventory project: a reconnaissance inventory of forest in southwest Ethiopia. Ministry of Overseas Development. Land Resources Development Centre. Project Report 31: 1-316.
Chapin F.S., Zavaleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Reynolds H.L., Hooper D.U., Lavorel S., Sala O.E., Hobbie S.E., Mack M.C. and Díaz S. 2000. Consequences of changing biodiversity. Nature 405: 234 – 242.
Charrier A. and Berthaud J. 1985. Botanical classification of coffee. In: Cliford M.N. and Willson K.C. (Eds.) Coffee: botany, biochemistry, and production of beans and beverage. Crom Helm, London, UK, pp. 13-47.
Clemens M.A., ReVelle C.S. and Williams J.C. 1999. Theory and methodology: reserve design for species preservation. Eur. J. Oper. Res. 112: 273-283.
Clements F.E. 1916. Plant succession. Carnegie Institute, Washington.
Clements F.E. 1936. Nature and structure of the climax. J. Ecol. 24: 252-284.
Coetzee J.A. 1978. Phytogeographical aspects of the montane forests of the chain of mountains on the eastern side of Africa. Erdwiss. Forsch. 11:482-494.
Colwell R.K. 2000. Users guide to EstimateS: statistical estimation of species richness and shared species from samples. University of Connecticut, Storrs.
Crawley M.J. 1997. Plant ecology. 2nd Edition. Blackwell Science, Oxford.
Cros J., Combes M.C., Trouslot P., Anthony F., Hamon S., Charrier A. and Lashermes P. 1998. Phylogenetic analysis of chloroplast DNA variation in Coffea L. Mol. Phylog. Evol. 9:109-117.
Cufodontis G. 1939. Introduzione, Sterculiaceae, etc. In: Zavattari E. (Ed.) Missione Biologica nel Paese dei Borana, 4. Raccolte Botaniche. Roma
Cufodontis G. 1940. La Vegetazione.In: Zavattari E. (Ed.) Missione Biologica nel Paese dei Borana. Vol. Primo. Reale Accademina d'Italia, Roma, Italy, pp. 142-255.
Cufodontis G. 1948. Die Botanische Ergebnisse von F.B. Bieber's Reisen in Aethiopien. Ber. Oesterr. Akad. Wiss., Mat. Nat. Kl., Abt. I, 156: 461-498.
Cufodontis G. 1953-1972. Enumeratio plantarum Aethiopiae Sepermatophyta. Bull. Jard. Bot. Etat. Brux. Bruxelles, Vol. 23-42.
Damaina A.B. 1996. Biodiversity conservation: a review of options complementary to standard ex situ methods. Plant Genet. Resour. Newsl. 107: 1-18.
Davis A.P. 2001. Two new species of Coffea L. (Ribiaceae) from eastern Madagascar. Kew Bull. 56: 479-489.

Davis A.P. and Rokotonasolo F. 2000. Three new species of Coffea L.(Rubiaceae) from Madagascar. Kew Bull. 55:405-416.

Davis A.P. and Rokotonasolo F. 2001a. Three new species of Coffea L. (Rubiaceae) from NE Madagascar. Adansonia 23: 137-146.

Davis A.P. and Rokotonasolo F. 2001b. Two new species of Coffea L. (Rubiaceae) from northern Madagascar. Adansonia 23: 337-345.

de Araújo C.C. and Macedo A.B. 2002. Multicriteria geologic data analysis for mineral favourability mapping application to a metal sulphide mineralized area, Ribeira Valley Mettalogenic Province, Brazil. Nat. Resour. Res. 11:29-43.

Demel Teketay. 1995. Floristic composition of Dakata Valley, southeastern Ethiopia: an implication for the conservation of biodiversity. Mt. Res. Dev. 15: 183-186

Demel Teketay. 1997. Seedling population and regeneration of woody species in dry Afromontane forests of Ethiopia. Forest Ecol. Manag. 98: 149-165.

Demel Teketay. 1999. History, botany, and ecological requirements of coffee. Walia 20: 28-50.

Demel Teketay and Assefa Tegineh. 1994. A study on landraces of Harer coffee in Eastern Ethiopia. Proceedings of the 13th Plenary Meeting of AETFAT 1: 161-169.

Demel Teketay and Tamrat Bekele. 1995. Floristic composition of Wof-Washa natural forest, Central Ethiopia: implications for the conservation of biodiversity. Feddes Repertorium 106: 127-147.

Demel Teketay, Ababu Anage, Getahun Mulat and Mehari Enyew. 1998. Study on forest coffee conservation. CIP/CTA, Addis Ababa.

Diamond J.M. 1967. Island biogeography and design of natural reserves. In: May R.M. (Ed.) Theoretical Ecology: Principles and Applications. Blackwell, Oxford, UK, pp. 163-186.

Dufrêne M. and Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67: 345-366.

Dulloo M.E. 1998. Diversity and conservation of wild Coffea germplasm in the Mascarene islands. Ph.D. Thesis, University of Birmingham, Birmingham, UK.

Dulloo M.E., Guarino L., Engelmann F., Maxted N., Newbury J.H., Attere F. and Ford-Lloyd B.V. 1998. Complementary conservation strategies for the genus Coffea: a case study of Mascarene Coffea species. Genet. Resour. Crop Ev. 45: 565-579.

Dussert S., Chabrillange N., Anthony F., Engelmann F., Recalt C. and Hamon S. 1997b. Variability in storage response within a coffee (Coffea spp.) core collection under slow growth conditions. Plant Cell Rep. 16: 344-348.

Dussert S., Chabrillange N., Engelmann F., Anthony F. and Hamon S. 1997a. Cryopreservation of coffee (Coffea arabica L.) seeds: Importance of the precooling temperature. Cryoletters 18 : 269-276.

Dussert S., Chabrillange N., Engelmann F., Anthony F., Louarn J. and Hamon S. 1998 Cryopreservation of seeds of four coffee species (Coffea arabica, C. costatifructa, C. racemosa and C. sessiliflora): importance of water content and cooling rate. Seed Sci. Res 8: 9-15.

Dussert S., Chabrillange N., Engelmann F., Anthony F. and Hamon S. 2000a. Cryopreservation of coffee (Coffea arabica L.) seeds: toward a simplified protocol for routine use in coffee genebanks. In: Engelmann F., Takagai H. (Eds.)

Crypreservation of tropical plant germplasm: current research progress and application. JIRCAS, Tsukuba, Japan and IPGRI, Rome, Italy, pp. 161-166.
Dussert S., Chabrillange N., Vasquez N., Engelmann F., Anthony F., Guyot A. and Hamon S. 2000b. Beneficial effect of post-thawing osmoconditioning on the recovery of cryopreserved coffee (Coffea arabica L.) seeds. Cryoletters 21: 47-52.
Dussert S., Chabrillange N., Engelmann F., Anthony F., Vasquez N. and Hamon S. 2002. Cryopreservation of Coffea (Coffee). In: Towill L.E. and Bajaj Y.P.S. (Eds.). Crypreservation of plant germplasm II: Biotechnology in Agriculture and Forestry. Springer-Verlag, Berlin, Germany, pp. 220-233.
Eastman J.R. 1999. Multi-criteria evaluation and GIS. In: Longley P.A., Goodchild M.F., Maguire D.J. and Rhind D.W. (Eds.). Geographical information systems. John Wiley and Sons, New York, USA, pp. 493-502.
Eastman J.R. 2001. IDRISI 32.2 Guide to GIS and image processing. Clark Labs for Cartographic Technology and Geographic Analysis, Clark University, Worcester, Massachusetts.
Edwards S., Abebe Demissie, Taye Bekele and Haase G. (Eds.) 1999. Forest genetic resources conservation: principles, strategies and actions. Institute of Biodiversity Conservation and Research and GTZ. Addis Ababa
Edwards S., Mesfin Tadesse, Sebsebe Demissew and Hedberg I. (Eds.) 2000. Flora of Ethiopia and Eritrea, Volume 2, Part 1. National Herbarium, Addis Ababa and Uppsala University, Uppsala.
Edwards S., Sebsebe Demissew and Hedberg I. (Eds.) 1997. Flora of Ethiopia and Eritrea, Volume 6. National Herbarium, Addis Ababa and Uppsala University, Uppsala.
Ehrlich P.R. 1990. Habitats in crisis: why should we care about the loss of species? Forest Ecol. Manag. 35:5-11.
Ehrlich P.R. and Wilson E.O. 1991. Biodiversity studies: science and policy. Science 253:758-762.
Elenga H., Peyron O., Bonnefille R., Jolly D., Cheddadi R., Guiot J., Andrieu V., Bottema S., Buchet G., de Beaulieu J.L., Hamilton A.C., Maley J., Marchant R., Perez-Obiol R., Reille M., Riollet G., Scott L., Straka H., Taylor D., Van Campo E., Vincens A., Laarif F. and Jonson H. 2000. Pollen-based biome reconstruction for southern Europe and Africa 18,000 yr BP. J. Biogeogr. 27: 621-634.
Engelmann F. 1997. In vitro conservation methods. In: Callow J.A., Ford-Lloyd B.V. and Newbury H.J. (Eds.) Biotechnology and plant genetic resources: conservation and use. Biotechnology in Agriculture series 19. CAB International, Oxon, UK, pp. 119-161.
Engels J.M.M. and Hawkes J.G. 1991. The Ethiopian gene center and its genetic diversity. In: Engels J.M.M., Hawkes J.G. and Melaku Worede (Eds.). Plant genetic resources of Ethiopia. Cambridge University Press, Cambridge, UK, pp. 23-41.
Engler A. 1906. Ueber die Vegetationsverhältnisse von Harar und des Gallahochlandes afuf Grund der Expedition von Freih. Von Elanger und Herrn Oscar Neumann. Sitzungsber. Deutch. Akad. Wiss. Berlin, Mat. Naturwiss. Kl. 1906, II: 726-747.
Esayas Aga, Bryngelsson T. Endashaw Bekele and Salomon B. Genetic diversity of forest coffee (Coffea arabica L.) in Ethiopia as revealed by random amplified polymorphic DNA (RAPD). Theor. Appl. Genet., Submitted.

ESRI. 1996. ArcView GIS: Using ArcView GIS. Environmental Systems Research Institute (ESRI) Inc., Redlands.

Ethiopian Wildlife and Natural History Society (EWNHS). 1996. Important Bird Areas of Ethiopia: A first inventory. EWNHS, Addis Ababa.

FAO 1981. Forest resources of tropical Africa. FAO/UNDP, Rome, Italy.

FAO. 1968. FAO coffee mission to Ethiopia, 1964-65. FAO, Rome

Fisher R.A., Corbet A.S. and Williams C.B. 1943. The relationship between the number of species and the number of individuals in a random sample of population. J. Anim. Ecol. 12: 42-58.

Flather C.H., Wilson K.R., Dean D.J. and McComb W.C. 1997. Identifying gaps in conservation networks: Of indicators and uncertainty in geographic-based analyses. Ecol. Appl. 7: 531-542.

Friis I., 1979. The wild populations of Coffea arabica L. and the cultivated coffee. Proceedings of the IXth Plenary Meeting of AETFAT: 63-68.

Friis I. 1983. Phytogeography of the tropical northeast African mountains. Bothalia 14: 525-532.

Friis I. 1986a. The forest vegetation of Ethiopia. Symbolae Bot. Uppsal. 26: 31 - 47.

Friis I. 1986b. Ethiopia in regional phytogeography. Symbolae Bot. Uppsal. 26: 68 - 85.

Friis I. 1992. Forests and forest trees of northeast tropical Africa - their natural habitats and distribution patterns in Ethiopia, Djibouti and Somalia. Kew Bull., Add. Ser. 15: 1-396.

Friis I. and Sebsebe Demissew. 2001. Vegetation maps of Ethiopia and Eritrea: a review of existing maps and the requirements to a new one for the Flora of Ethiopia and Eritrea. Biol. Skr. 54: 399-439.

Friis I., Rasmussen F.N. and Vollesen K. 1982. Studies in the flora and vegetation of SW Ethiopia. Opera Bot. 63: 1-70.

Friis I., Edwards S., Ensermu Kelbessa and Sebesbe Demissew. 2001. Diversity and Endemism in the Flora of Ethiopia and Eritrea - what do the published Flora volumes tell us?. Biol. Skr. 54: 173-193.

Gauch H.G. 1981. Multivariate analysis in community ecology. Canbridge University Press, Cambridge.

Gentry A.H. 1992. Tropical forest biodiversity: distributional patterns and their conservational significance. Oikos 63:19-28.

Given D.R. 1993. Principles and practice of plant conservation. Chapman & Hall, London.

Giordano G. 1940. Cenni Monografici sulle piante forestali e sui legnami dell' A.O. Riv. Forest. Ital. 1: 183-188.

Giordano G. 1940. Cenni Monografici sulle piante forestali e sui legnami dell' A.O. Riv. Forest. Ital. 2: 32-36.

Gleason H.A. 1917. The structure and development of plant association. Bull. Torrey Bot. Club 44:463-481

Gleason H.A. 1926. The individualistic concept of the plant association. Bull. Torrey Bot. Club 53:7-26.

Grace J.B., Allain L. and Allen C. 2000. Vegetation associations in a rate community type-coastal tallgrass prairie. Plant Ecol. 147: 105-115.

Grau H.R., Arturi M.F., Brown A.D. and Acenolaza P.G. 1997. Floristic and structural patterns along a chronosequence of secondary forest succession in Argentinean subtropical montane forests. Forest Ecol. Manag. 95: 161-171.
Greenway P.J. 1973. A classification of the vegetation of East Africa. Kirkia 9: 1-68.
Guariguata M.R., Chazdon R.L., Denslow J.S., Dupuy J.M. and Anderson L. 1997. Structure and floristics of secondary and old-growth forest stands in lowland Costa Rica. Plant Ecol. 132: 107-120.
Guisan A., Weiss S.B. and Weiss A.D. 1999. GLM versus CCA spatial modeling of plant species distribution. Plant Ecol. 143: 107-122.
Hamer K.C., Hill J.K., Lace L.A. and Langan A.M. 1996. Ecological and biogeographical effects of forest disturbance on tropical butterflies of Sumba, Indonesia. J. Biogeogr. 24: 67-75.
Hamilton A.C. 1982. Environmental history of East Africa: A study of the Quaternary. Academic press, London.
Harris D.R. and Hillman G.C. (Eds.) 1989. Foraging and farming: the evolution of plant exploitation. Unwin-Hyman, London.
Harlan J.R. 1969. Ethiopia: a centre of diversity. Econ. Bot. 23: 309-314.
Hedberg I. and Edwards S. (Eds) 1989. Flora of Ethiopia Vol. 3. The National Herbarium, Addis Ababa and Uppsala University, Uppsala.
Hedberg I. and Edwards S. (Eds) 1995. Flora of Ethiopia Vol. 7. The National Herbarium, Addis Ababa and Uppsala University, Uppsala.
Hedberg O. 1951. Vegetation belts of the East African mountains. Svensk Bot. Tidskr. 45: 140-202.
Hedberg O. 1964. Features of Afroalpine plant ecology. Acta Phytogeoger. Suec. 49: 1-144.
Hepcan S. 2000. A methodological approach for designating management zones in Mount Spil National Park, Turkey. Environ. Manage. 26: 329-338.
Heijnis C.E., Lombard A.T., Cowling R.M. and Desmet P.G. 1999. Picking up the pieces: a biosphere reserve framework for a fragmented landscape - The Coastal Lowlands of the Western Cape, South Africa. Biodiver. Conserv. 8: 471-496.
Higgs A.J. 1981. Island biogeography theory and nature reserve design. J. Biogeogr 8: 117-124.
Higgs A.J. and Usher M.B. 1980. Should nature reserves be large or small? Nature 285: 568-569.
Hill J.K., Hamer K.C., Lace L.A. and Banham W.M.T. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. J. Appl. Ecol. 32: 754-760.
Hill J.K. 1999. Butterfly spatial distribution and habitat requirements in a tropical forest: impacts of selective logging. J. Appl. Ecol. 36: 564-572.
Howard P.C., Viskanic P., Davenport T.R.B., Kigenyi F.W., Baltzer M., Dickinson C.J., Lwanga J.S., Matthews R.A. and Balmford A. 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. Nature 394: 472-475.
Hutchinson M.F. 1989. A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. J. Hydro. 106: 211-232.
IAR 1986. Department of Coffee progress report 1983/84. Institute of Agricultural Research (IAR), Addis Ababa.

IUCN 1992. Protected Areas of the World: A review of national systems. Volume 3: Afrotropical. IUCN, Gland.

IUCN. 1994. Guidelines for protected area management categories. CNPPA with the assistance of WCMC, IUCN. World Conservation Union, Gland.

IUCN 2002. IUCN 2002 Red List of threatened species. <www.redlist.org>.

Jager J.C. and Looman C. 1995. Data collection. In: Jongman R.H.G., Ter Braak C.J.F. and Van Tongeren O.F.R. (Eds.). Data analysis in community ecology and landscape ecology. Cambridge University Press, Cambridge, UK, pp. 10-28.

Jiang H and Eastman J.R. 2000. Application of fuzzy measures in multi-criteria evaluation in GIS. Int. J. Geo. Info. Science. 14: 173-184.

Kamppinen M. and Walls M. 1999. Integrating biodiversity into decision making. Biodivers. Conserv. 8: 7-16.

Kay R.F., Madden R.H. Van Schaik C. and Higdon D. 1997. Primate species richness is determined by plant productivity: Implications for conservation. Proc. Natl. Acad. Sci. USA 94: 13023–13027.

Keay R.W.J. 1959. Vegetation map of Africa south of the tropic of Cancer. With one coloured map (1:10 000 000) and Explanatory notes. Oxford University Press, Oxford

Kitajima K and Fenner M. 2000. Ecology of seedling regeneration. In: Fenner M. (Ed.) Seeds: the ecology of regeneration in plant communities. CAB International, Oxon, UK, pp. 331-359.

Kumelachew Yeshitela and Tamrat Bekele 2002. Plant community analysis and ecology of Afromontane and transitional rain forest vegetation of southwestern Ethiopia. SINET: Ethiop. J. Sci. 25: 155-175.

Lashermes P., Trouslot P., Anthony F., Combes M.C. and Charrier A. 1996. Genetic diversity for RAPD markers between cultivated and wild accessions of Coffea arabica. Euphytica 87: 59-64

Lashermes P., Combes M.C., Trouslot P. and Charrier A. 1997. Phylogenetic relationship of coffee-tree species (Coffea L.) as inferred from ITS sequences of nuclear ribosomal DNA. Theor. Appl. Genet. 94: 947-955.

Lashermes P., Combes M.C., Robert J., Trouslot P., D'Hont A., Anthony F. and Charrier A. 1999. Molecular characterization and origin of the Coffea arabica L. genome. Theor. Appl. Genet. 99:259-266.

Legendre P. and Gallagher E.D. 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129: 271-280.

Legendre P. and Legendre L. 1998. Numerical ecology. 2nd English ed. Elsevier, Amesterdam.

Lemmon P.E. 1956. A spherical densiometer for estimating forest overstory density. Forest Sci. 2: 314-320.

Lemmon P.E. 1957. A new instrument for measuring forest overstory density. J. Forest. 55: 667-668.

Leps J. and Smilauer P. 2003. Multivariate Analysis of Ecological Data using CANOCO. Cambridge University Press, Cambridge.

Leroy J.F. 1980. Evolution et taxogenese chez les caféirs. Hypothese sur leur origine. Comtes Rendus de l’Academie des Sciences, Paris 291: 593-6.

Li W., Wang Z., Ma Z. and Tang H. 1999. Designing the core zone in a biosphere reserve based on suitable habitats: Yancheng biosphere reserve and the red crowned crane (Grus japonensis). Biol. Conserv. 90: 167-173.
Logan W.E.M. 1946. An introduction to forests of central and southern Ethiopia. Imp. Forest. Inst. Paper 24: 1-58.
Long C. and Zhou Y. 2001. Indigenous community forest management of Jinuo people's swidden agroecosystems in southwest China. Biodiver. Conser. 10: 753-767.
Looijen R.C. and Van Andel J. 1999. Ecological communities: conceptual problems and definitions. Perspect. Plant Ecol. Ev. System. 2: 210-222.
Luxner L. 2001. Ethiopian coffee industry: overcoming difficulties. Tea and Coffee Trade Journal 174: online at: http://www.teaandcoffee.net/0201/special.htm
MacArthur R.H. and Wilson E.O. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton.
Magurran A.E. 1988. Ecological diversity and its measurement. Chapman and Hall, London.
Malczewski J. 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, New York.
Marcano-Vega H., Aide T.M. and Báez D. 2002. Forest regeneration in abandoned coffee plantations and pastures in Cordillera Central of Puerto Rico. Plant Ecol. 161: 75-87.
Margules C., Higgs A.J. and Rafe R.W. 1982. Modern biogeographic theory: are there any lessons for nature reserve design? Biol. Conserv. 24: 115-128.
Maxted N., Ford-Lloyd B.V. and Hawkes J.G. 1997. Plant genetic conservation: the in situ approach. Chapman & Hall, London.
McCune B. and Grace J.B. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach.
McCune B. and Mefford M.J. 1999. PC-ORD. Multivariate analysis of ecological data, version 4.0. MjM Software Design, Gleneden Beach.
McNeely J.A. 1994. Protected areas for the 21st century: working to provide benefits to society. Biodivers. Conserv. 3: 390-405.
MCTD. 1989. Report on coffee yield assessment. Ministry of Coffee and Tea Development (MCTD), Addis Ababa.
MEDaC 1999. Survey of the Ethiopian economy: review of post reform development (1992/93-1997/98). Ministry of Economic Development and Cooperation (MEDaC), Addis Ababa.
Meentemeyer R.K., Moody A. and Franklin J. 2001. Landscape-scale patterns of shrub-species abundance in California chaparral - The role of topographically mediated resource gradients. Plant Ecol. 156: 19-41.
Melaku Worede. 1998. Diversity and the genetic resource base. Ethiop. J. Agric. Sci. 10: 39-52.
Mesfin Ameha 1991a. Siginificance of Ethiopian coffee genetic resources to coffee improvement. In: Engels J.M.M., Hawkes J.G. and Melaku Worede (Eds.). Plant genetic resources of Ethiopia. Cambridge University Press, Cambridge, UK, pp. 354-359.

Mesfin Ameha and Bayetta Belachew 1984. Resistance of the F1 to coffee berry disease in six parent diallel crosses in coffee. Proceedings of the first regional workshop on coffee berry disease. Association for the Advancement of Agricultural Sciences in Africa, Addis Ababa, pp. 167-177.

Mesfin Tadesse. 1991b. Some endemic plants of Ethiopia. Ethiopian Tourism Commission, Addis Ababa.

Mesfin Tadesse and Lisanework Nigatu 1996. An ecological and ethnobotanical study of wild or spontaneous coffee, Coffea arabica in Ethiopia. In: van der Maesen L.J.G., van der Burgt X.M. and van Medenbach de Rooy J.M. (Eds.) The biodiversity of African plants. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 227-294.

Meyer F. 1965. Notes on wild Coffea arabica from southwestern Ethiopia, with some historical considerations. Economic Botany 19:136-151.

Meyer F. G. 1968. Further observations on the history and botany of the Arabica coffee plant, Coffea arabica L., in Ethiopia. In: FAO (Ed.) FAO Coffee mission to Ethiopia, 1964-65. FAO, Rome, Italy, pp. 1-5.

Mielke P.W. and Berry K.J. 2001. Permutation methods: a distance function approach. Springer series in statistics. Springer-Verlag, New York.

Monaco L.C. 1968 Considerations on the genetic variability of Coffea arabica populations in Ethiopia. In: FAO (Ed.) FAO Coffee mission to Ethiopia, 1964-65. FAO, Rome, Italy, pp 49-69.

Montagnon C. and Bouharmont P. 1996 Multivariate analysis of phenotypic diversity of Coffea arabica. Genet. Resour.Crop Ev. 43: 221-227.

Mora F. and Iverson L. 2002. A spatially constrained ecological classification: rationale, methodology and implementation Plant Ecol. 158: 153-169.

Narasimhaswamy R.L. 1962. Some thoughts on the origin of Coffea arabica. Coffee 4 (12): 1-5.

Nevo E. 1998 Genetic diversity in wild cereals: regional and local studies and their bearing on conservation ex situ and in situ. Genet. Resour. Crop Ev. 45: 355–370.

Noss R.F. and Cooperrider A.Y. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press, Washington.

O'Neill G.A., Dawson I., Sotelo-Montes C., Guarino L., Guariguata M., Current D. and Weber J.C. 2001. Strategies for genetic conservation of trees in the Peruvian Amazon. Biodivers. Conserv. 10: 837–850

Onderdonk D.A. and Chapman C.A. 1999. Coping with forest fragmentation: The Primates of Kibale National Park, Uganda. Int. J. Primatol. 21: 587-611.

Orlóci L. 1967. An agglomerative method for classification of plant communities. J. Ecol. 55: 193-205.

Ostendorf B. and Reynolds J.F. 1998. A model of arctic tundra vegetation derived from topographic gradients. Landscape Ecol. 13: 187–201.

Pack R.T., Tarboton D.G. and Goodwin C.N. 1998. Terrain Stability Mapping with SINMAP: technical description and users guide for version 1.0. Report Number 4114-0, Terratech Consulting Ltd., Salmon Arm, Canada.

Palmer M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74:2215-30.

Parthasarathy N. 1999. Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India. Biodiver. Conserv. 8: 1365–1381.

Paulos Dubale and Demel Teketay 2000. The need for forest coffee germplasm conservation in Ethiopia and its significance in the control of coffee diseases. In: EARO (Ed.) Proceedings of Coffee Berry Disease Workshop. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia, pp. 125-135.

Perfecto I., Rice R.A., Greenberg R. and Van der Voort M. 1996. Shade coffee: a disappearing refuge for biodiversity. Bioscience 46: 598-608.

Peyron O., Jolly D., Bonnefille R., Vincens A. and Guiot J. 2000. Climate of east Africa 6000 C-14 yr BP as inferred from pollen data. Quaternary Res. 54: 90-101.

Pichi-Sermolli R.E.G. 1957. Una carta geobotanica dell'Africa Orientale (Eritrea, Ethiopia, Somalia). Wabbia 12: 15-132.

Pimm S.L. and Raven P. 2000. Extinction by numbers. Nature 403: 843-845.

Purseglove J.W. 1968. Tropical crops: Dicotyledons 2. Longmans, Green and Co. Ltd., London.

Raina S.N., Mukai Y. and Yamanoto M. 1998. In situ hybridization identifies the diploid progenitor species of Coffea arabica (Rubiaceae). Theor. Appl. Genet. 97: 1204-1209.

Rao C.R. 1995 A review of canonical coordinates and an alternative to correspondence analysis using Hellinger distance. Qüestiió 19:23–63

Reusing M. 1998. Monitoring of natural high forests in Ethiopia. Ministry of Agriculture and GTZ, Addis Ababa.

Reyers B., Fairbanks D.H.K, Wessels K.J. and Van Jaarsveld A.S. 2002. A multicriteria approach to reserve selection: addressing long-term biodiversity maintenance. Biodivers. Conserv 11: 769–793.

Roberts D.W. 1986. Ordination on the basis of fuzzy set theory. Vegetatio 66: 123-31.

Saaty T.L. 1980. The analytical hierarchy process. McGraw-Hill, New York.

Sala O.E., Chapin F.S., Armesto J.J., Berlow E., Bloomfield J., Dirzo R., Huber-Sanwald E., Huenneke L.F., Jackson R.B., Kinzig A., Leemans, R., Lodge D.M., Mooney H.A., Oesterheld M., Poff N.L. Sykes M.T., Walker B.H., Walker M. and Wall D.H. 2000. Biodiversity: global biodiversity scenarios for the year 2100. Science 287: 1770-1774.

Samuels C.L. and Drake J.A. 1997. Divergent perspectives on community convergence. Trends Ecol. Evol. 12: 427-432.

Schoen D.J. and Brown A.H.D. 1993. Conservation of allelic richness in wild crop relatives is aided by assessment of genetic markers. Proc. Natl. Acad. Sci. USA. 90: 10623-10627.

Schulze M.D., Seavy N.E. and Whitacre D.F. 2000. A comparison of the phyllostomid bat assemblages in undisturbed Neotropical forest and in forest fragments of a slash-and-burn farming mosaic in Peten, Guatemala. Biotropica 32: 174-184.

Scott T.A. and Sullivan J.E. 2000. The selection and design of multiple-species habitat preserves. Environ. Manage. 26: S37-S53

Smith R.F. 1985. A history of coffee. In: Cliford M.N. and Willson K.C. (Eds.) Coffee: botany, biochemistry, and production of beans and beverage. Crom Helm, London, UK, pp. 1-12.

Smith T. and Huston M. 1989. A theory of spatial and temporal dynamics of plant communities. Vegetation 83: 49-69.

Sokal R.R. and Rohlf F. 1981. Biometry. Freeman, San Francisco.

Statterfield A.J., Crosby A.J., Long A.J. and Wege D.C. 1998. Endemic bird areas of the world: priorities for biodiversity conservation. BirdLife International, Cambridge.

Steiger D.L., Nagai C., Moore P.H., Morden C.W., Osgood R.V. and Ming R. 2002. AFLP analysis of genetic diversity within and among Coffea arabica cultivars. Theor. Appl. Genet. 105: 209-215.

Stohlgren T.J., Chong D. and Kalhan A. and Schell L.D. 1997a. Rapid assessment of plant diversity patterns: a methology for landscapes. Environ. Monit. Assess. 48: 25-43.

Stohlgren T.J., Coughenour M.B., Chong G.W., Binkley D. and Kalhan A. 1997b. Landscape analysis of plant diversity. Landscape Ecol. 12: 155-170.

Straede S., Nebel G. and Rijal A. 2002. Structure and floristic composition of community forests and their compatibility with villagers' traditional needs for forest products. Biodivers. Conserv. 11: 487-508.

Swaine M.D., Liberman D. and Hall J.B. 1990. Structure and dynamics of a tropical dry forest in Ghana. J. Ecol. 71: 601-627.

Swanson T. 1999. Conserving global biological diversity by encouraging alternative development paths: can development coexist with diversity? Biodivers. Conserv. 8: 29-44.

Sylvain P.G. 1955. Some observations on Coffea arabica L. in Ethiopia. Turrialba 5: 37-53.

Sylvain P.G. 1958 Ethiopian coffee- its importance to world coffee problems. Econ. Bot. 12: 111-130.

Tadesse Woldemariam Gole. 1998. Diversity of woody plants and Avifauna in a dry Afromontane forest on the central plateau of Ethiopia. M.Sc. Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden

Tadesse Woldemariam Gole and Denich M. 2001. Subsistence in a mountain forest ecosystem: the case of southwest Ethiopia. In Proceedings of the World Mountain Sympossium 2001, 30 September - 4 October 2001, Interlaken, Switzerland.

Tadesse Woldemariam Gole, Demel Teketay, Denich M. and Borsch T. 2001. Diversity of traditional coffee production systems in Ethiopia and their contribution for the conservation of coffee genetic diversity. Deutscher Tropentag, Conference on International Agricultural Research for Development, Bonn, 9-11 October. Deutscher Tropentag 2001. University of Bonn, Bonn, Germany.

Tadesse Woldemariam Gole, Denich M., Demel Teketay and Vlek P.L.G. 2002. Human impacts on Coffea arabica gene pool in Ethiopia and the need for its in situ conservation. In: Engels J., Ramanatha Rao V., Brown A.H.D. and Jackson M. (Eds.) Managing plant genetic diversity. CAB International, Oxon, UK, pp. 237-247.

Tafesse Asres 1996. Agroecological zones of southwest Ethiopia. Matreialien Zur Ostafrica-Forschung 13: 1-241.

Takyu M., Aiba H.-I. and Kitayama K. 2002. Effects of topography on tropical lower montane forests under different geological conditions on Mount Kinabalu, Borneo. Plant Ecol. 159: 35-49.

Tamrat Bekele. 1994. Studies on remnant Afromontane forests on central plateau of Shewa, Ethiopia. Ph.D. Thesis, Uppsala University, Uppsala, Sweden.

Taylor L.R. 1978. Bates, Williams and Hutchinson- a variety of diversities. In: Mound L.A. and Warloff N. (Eds.) Diversity of insect faunas. Blackwell, Oxford, UK, pp. 1-18.

Ter Braak C.J.F. 1995. Ordination. In: Jongman R.H.G., Ter Braak C.J.F. and Van Tongeren O.F.R. (Eds.). Data analysis in community ecology and landscape ecology. Cambridge University Press, Cambridge, UK, pp. 91-173.

Ter Braak C.J.F. and Prentice I.C. 1988. A theory of gradient analysis. Adv. Ecol. Res. 18:271-317.

Ter Braak C.J.F. and Šmilauer P. 1998. CANOCO reference manual and user's guide to Canoco for Windows. Microcomputer Power, Ithaca.

Tewolde B. G. Egziabher 1978. Some vegetative parameters of coffee, Coffea arabica L., proportional to yield. SINET: Ethiop. J. Sci. 1: 51-57.

Tewolde B. G. Egziabher 1986. Preliminary studies on the ecology of a natural coffee (Coffea arabica) forest with emphasis on coffee. Symb. Bot. Ups. 26: 146-156.

Tewolde B. G. Egziabher. 1990 The importance of Ethiopian forests in the conservation of Arabica coffee gene-pools. Mitt Inst. Allg. Bot. Hamburg Band 23a: 65-72.

Tewolde B. G. Egziabher. 1991. Diversity of the Ethiopian flora. In: Engels J.M.M., Hawkes J.G. and Melaku Worede (Eds.). Plant genetic resources of Ethiopia. Cambridge University Press, Cambridge, UK, pp. 75-81.

Thiollay J.M. 1997. Disturbance, selective logging and bird diversity: a Neotropical forest study. Biodivers. Conserv. 6: 1155-1173

Thiollay J.M. 1999. Responses of an avian community to rain forest degradation. Biodivers. Conserv. 8: 513-534.

Trehane P., Brickell C.D., Baum B.R., Hetterscheid W.L.A., Leslie A.C., McNeill J., Spongberg S.A. and Vrugtman F. (Eds) 1995. International code of nomenclature for cultivated plants. Regnum Vegetabile 133. Quarterjack Publishing, Wimborne.

Tsegaye Yilma Dessalegn. 2001. Attaining food security through improving resource use efficiency of small-holder in southwestern Ethiopia: the case of Jimma Zone. MSc Thesis, University of Bonn, Bonn, Germany.

UNESCO-UNEP. 1984. Conservation, science and society: contributions of the first biosphere reserve congress, Minsk, byelorussia/USSR, 26 September - 2 October 1983. UNESCO, Paris.

United Nations Conference on the Environment and Development (UNCED) 1992. Convention on biodiversity. UNCED, Rio de Janeiro.

Usher M.B. 1986. Species conservation evaluation attributes, criteria and values. In: Usher M.B. (Ed.) Biological Conservation and Evaluation. Chapman and Hall, London, UK, pp. 3-44.

Van der Vossen H.A.M. 1985. Coffee selection and breeding. In: Cliford M.N. and Willson K.C. (Eds.) Coffee: botany, biochemistry, and production of beans and beverage. Crom Helm, London, UK, pp. 48-96.

Van Jaarsveld A.S., Freitag S., Chown S.L., Muller C., Koch S., Hull H., Bellamy C., Krüger M., Endrödy-Younga S., Mansell M.W. and Scholtz C.H. 1998. Biodiversity assessment and conservation strategies. Science 279: 2106-2108.

Van Tongeren O.F.R. 1995. Cluster analysis. In: Jongman R.H.G., Ter Braak C.J.F. and Van Tongeren O.F.R. (Eds.) Data analysis in community ecology and landscape ecology. Cambridge University Press, Cambridge, UK, pp. 174-212.

Vasconcelos H.L. 1999. Effects of forest disturbance on the structure of ground-foraging ant communities in central Amazonia. Biodivers. Conserv. 8: 407-418.

Vavilov N.I. 1951. The origin, variation, immunity and breeding of cultivated plants. Ronald Press, New York.

Von Breitenbach F. 1963. The indigenous trees of Ethiopia. 2nd ed. Ethiopian Forestry Association, Addis Ababa.

WCMC (World Conservation Monitoring Centre). 1994. Priorities for Conserving Global Species Richness and Endemism Caldecott J.O., Jenkins M.D., Johnson T. and Groombridge B. (Eds.). World Conservation Press, Cambridge.

Webb E.L. and Peralta R. 1998. Tree community diversity of lowland swamp forest in Northeast Costa Rica, and changes associated with controlled selective logging. Biodivers and Conserv. 7: 565-583.

Wells M.P. and Brandon K.E. 1993. The principles and practices of buffer zones and local participation in biodiversity conservation. Ambio 22: 157-162.

Western D. 2001. Human-modified ecosystems and future evolution. Proc. Nat. Acad. Sci. USA 98:5458-5468.

Westhoff V. and Van der Maarel E. 1978. The Braun-Blanquet approach. In Whittaker R.H. (Ed.) Classification of Plant Communities. W. Junk, the Hague, The Netherlands, pp. 287-399.

Westphal E. 1975. Agricultural systems in Ethiopia. Poduc, Wageningen.

Whitemore T.C. 1991. Tropical rain forest dynamics and its implications for management. In: Gomez-Pompa A., Whitemore T.C. and Hadley M. (Eds.) Rain forest regeneration and management. UNESCO, Paris, France, pp. 67-89.

Whittaker R.H. 1951. A criticism of the plant association and climatic climax concepts. Northwest Sci. 25:17-31.

Whittaker R.H. 1967. Gradient analysis of vegetation. Biol. Rev. 42:207-264.

White F. 1983. The vegetation of Africa. A descriptive memoir to accompany the Unesco/AETFAT/UNSO vegetation map of Africa. Natur. Resour. Res. 20: 1-356.

Wiersum K.F. 1997. Indigenous exploitation and management of tropical forest resources: an evolutionary continuum in forest-people interactions. Agr. Ecosyst. Environ. 63: 1-16.

Williams J.C. and ReVelle C.S. 1996. A 0-1 programming approach to delineating protected reserves. Environ. Plann. B 23: 607-624.

Wilson E.O. 1988. The diversity of life. Harvard University Press, Cambridge.

Wilson E.O. and Perlman D.L. 2000. Conserving earth's biodiversity: an interactive learning experience for studying conservation biology and environmental science. Island Press, Washington.

Wilson W.G., Nisbet R.M., Ross A.H., Robles C. and Desharnais R.A. 1996. Abrupt population changes along environmental gradients. Bull. Math. Biol. 58: 907-922

Wrigley G. 1988. Coffee. Tropical Agriculture Series. Longman Scientific and John Wiley and Sons, Inc., New York.

WRI/IUCN/UNEP. 1992. Global biodiversity strategy: guidelines to save, study and use the earth's biotic wealth sustainably and equitably. WRI, IUCN, UNEP, Washington, D.C., Gland, Switzerland, and Nairobi, Kenya.

Yalden D.W. 1983. The extent of highground in Ethiopia compared to the rest of Africa. SINET: Ethiop. J. Sci. 6: 35-39.

Zemede Asfaw and Ayele N. 1995 Homegardens in Ethiopia: characteristics and plant diversity. SINET: Ethiop. J. Sci. 18: 235-266.

9 APPENDICES

Appendix 1 List of plant species recorded at Yayu forest and its surroundings. Note: the short abbreviations stand for growth forms, where **[H]** is herb. **[S]** is shrub and **[T]** is tree. The other abbreviations following growth form are for distribution types based on Friis (1992) and White (1983). Their meaning is given in Appendix 2

Acanthaceae
Acanthus eminens CB Clarke. [S]
Brillantaisisa madagascariensis Lindau. [H]
Hypoestus forskaoli (Vahl) R. Br., [H]
Hypoestus sp. [H]
Isoglossa sp. [H]
Justicia betonica L., [S]
Justicia heterocarpa [T] Anderson, [H]
Justicia schimperiana (Hochst. Ex A. Rich.) [T] Anders., [S]
Amaranthaceae
Achyranthes aspera Lam. [H]
Celosia trigyna L. [H]
Gompherena celosioides Mart. [H]
Amaryllidaceae
Scadoxus multiforus (Martyn) Raf. [H]
Anacardiaceae
Rhus quartiniana A Rich. [T] [AfrM/n-e]
Rhus ruspoli Engl., [S]
Apocynaceae
Landolphia buchananii (Hall. f.) Stapf, C
Oncinotis tenuiloba Stapf, [C]
Aquifoliaceae
Ilex mitis (L) Radlk. [T] [AfrM/e]
Araceae
Amorphophallus gallaensis (Engl) N E Br. [H]
Arisaema flavum (Forssk) Schott). [H]
Arisaema schimperanum Schott. [H]
Culcasia falcifolia Engl. [C]
Araliaceae
Polyscias fulva (Heirn) Harms. [T] AfrM/n-e (-SZfr)
Schefflera abyssinica (Hochst ex A Rich) Harms. [T] [AfrM/n-e (-SZfr)]
Arecaceae
Phoenix reclinata Jacq. [T] [GC-ZI-SMfr-SZfr-Mad]
Ascelepidaceae
Gomphocarpus semilunatus A. Rich., [H]
Gomphocarpus truitcosus (L) R Br., [H]
Asparagaceae
Asparagus africanus Lam., [C]
Asparagus officinalis L. [C]
Aspleniaceae
Asplenium hypomelas Kuhn, [H]
A. lunulatum Sw., [H]
A. sandersonii Hook., [H]
Asplenium sp. [H]
Asteraceae
Ageranthum conyzoides L. [H]
Crassocephalum montuosum (S. Moore) Milne-Redh., [H]
Crassocephalum sp. [H]
Galinsoga quadriradiata Ruiz & Pav., [H]
Laggera pterodonta (DC.) Sch. Bip. ex Oli., [S]
Vernonia amygdalina Del. [T] [GC-AfrM-SZ]
Vernonia auriculifera Heirn. [S]
Vernonia hochstetteri Sch-Bip. [S]
Vernonia sp. [H]
Balsaminaceae
Impatiens hochstetteri Warb. [H]
Bignoniaceae
Stereospermum kanthianum Cham. [T]
Boraginaceae
Cordia africana Lam. [T] [AfrM-SZfr-Arab]
Ehretia cymosa Thonn. [T] [GC-ZI-SZfr-Mad]
Brassicaceae
Cardamine africana L., [H]
C. trichocarpa A. Rich., [H]

Cactaceae
Rhipsalis baccifera (J Miller) WT Stearn., [H]
Cannaceae
Canna indica L. [H]
Capparidaceae
Capparis erythrocarpos Isert. [C]
Capparis micrantha A Rich. [C]
Ritchiea albersii Gilg. [T] [AfrM/e]
Celasteraceae
Elaeodendron buchananii (Loes) Loes. [T] Sub-AfrM/n-e (-SZfr)
Hippocratea africana (Willd) Loes. [C]
H. pallens Planchon ex Oliver [C]
H sp [C]
Maytenus arbutifolia (a Rich) Wilczek. [T] [AfrM/n-e (-Arab)]
M. gracilipes (Welw ex Oliv) Exell. [S]
M. obscura (A Rich) Cuf. [S]
M sp T
Combretaceae
Combretum paniculatum Vent. [C]
Commelinaceae
Aneilema beniniense (P Beauv) Kunth. [H]
Commelina foliacea Chiov. [H]
C. latifolia Hochst ex A Rich. [H]
Pollia condensata C B Clarke. [H]
P. mannii C B Clarke. [H]
Convolvulaceae
Ipomoea carica (L) Sweet. [C]
I. hochstetteri House, [C]
Ipomoea tenuirostris Steud. ex Choisy; [H]
Costaceae
Costus afer Ker-Gawl, [H]
Crassulaceae
Kalanchoe densiflora Rolfe. [H]
Cucurbitaceae
Lagenaria abyssinica (Hook. f.) Jeffrey, [S]
Sicyos polyacanthus Cong., [C]
Zeneria scabra (Lf) Sond. [H]
Cyathaceae
Cyathea manniana Hook f. T
Cyperaceae
Cyperus esculentus L. [H]
Dioscoreaceae
Dioscorea bulbifera L. [C]
Dracaenaceae
Dracaena fragrans, (L) Ker-Gawl. [T] [GC-ZI-SZfr]
D steudneri Engler, [T] [Sub-AfrM/n-e (-SZfr)]
Ebenaceae
Diospyros abyssinica (Hiern) F White. [T] [GC-SZ-ZI-AfrM]
Euphorbiaceae
Acalypha acrogyna Pax, [S]
A. ornata A. Rich., [S]
A. psilostachya A Rich. [S]
A. racemosa Baill., [S]
Argomuellera macrophylla Pax. [T] GC/n-e (-SZfr)
Bridelia micrantha (Hochs) Baill. [T] GC-ZI-AfrM-SZfr
Croton macrostachyus Hochst ex Del. [T] [GC-AfrM-SZfr-ZI]
Erythrococca trichogyne (Muell Arg) Prain (det A Radcliffe-Smith). [S]
Euphorbia ampliphylla. Pax [T] [Sub-AfrM/n-e]
E. schimperiana Sheele, [H]
Macaranga capensis var kilimandscharica (Pax) Friis & Gilbert, [T] [AfrM/e]
Phyllanthus limmuensis Cuf., [S]. E
P. ovalifolius Forssk., [S]
Ricinus communis L.
Sapium ellipticum (Hochst) Pax. T GC-ZI-SZfr
Fabaceae
*Albizia grandibracteata.*Taub. [T] Sub-AfrM/e
A. gummifera (J. F. Gmel.) C. A. Sm.. [T] [Sub-AfrM/n-e (-SZfr-Mad)]
A. schimperiana Oliv. T
Calpurnia aurea. (Ait.) Benth. [S]
Dalbergia lactea Vatke, [S]
Desmodium hirtum Guill. & Perr., [H]

D. repandum (Vahl) DC, [H]
Entada abyssinica Steud. ex A. Rich.
Lablab purpureus (L.) Sweet, [S]
Millettia ferruginea (Hochst.) Baker, [T] [AfrM/e]
Pterolobium stellatum (Forsskal) Brenan, [C]
Senna petersiana (Bolle) Lock, [T] [Sub-AfrM/n-e (-SZfr-Mad)]
Flacourtiaceae
Flacourtia indica (Burm. f.) Merrill. [T] [GC-SZ-AfrM-Asia]
Icacinaceae
Apodytes dimidiata, Arn., [T] [AfrM/n-e (-SZfr-Mad-Asia)]
Lamiaceae
Achyrospermum schimperi (DC) Oliv., [H]
Ocimum lamiifolium Hochst. ex Benth., [H]
Lamoriopsidaceae
Elaphoglossum lastii (Bak.) [C] Chr., [H]
Lauraceae
Cassytha filiformis L. [H]
Loranthaceae
Englerina woodfordioides (schweinf.) M. Gilbert
Malvaceae
Abutilon cecilli N.E.Br., [S]
Abutilon sp. [S]
Hibiscus ludwigii Eckl. & Zeyh., [S]
H. micranthus L.f., [S]
Pavonia urens Cav., [H]
Sida collina Schlechtend., [C]
S. sp. [C]
S. ternata L.f., [C]
Wissadula rostrata (Schumach. & Thonn.) Hook. f., [H]
Meliaceae
Ekebergia capensis Sparrm., [T] [GC-SZ-AfrM-CP]
Meliaceae
Trichilia dregeana Sond. [T] [Sub-AfrM/n-e]
Melianthaeceae
Bersama abyssinica Fresen. [T] [AfrM/e]
Menispermaceae
Tiliachora troupinii Cufod., [C]
Moraceae
Antiaris toxicaria Lesch., [T] [GC-ZI-SZfr]
Ficus capreaefolia Del., S
F exasperata Vahl, [T] [GC-ZI-SZfr]
F. lutea Vahl, [T] [GC-ZI-SZfr-Mad]
F. mucuso Ficalho, [T] [GC/n-e]
F. sp [T]
F. sur Forssk., [T] [GC-ZI-TP-SZfr]
F. thonningii Blume, [T] [GC-AfrM-ZI-SZfr]
F. vallis-choudae Del. [T] [GC-SZfr-ZI-AfrM-ZI]
F. vasta Forssk, [T]
Morus mesozygia Stapf [T] [GC-ZI-SZfr]
Trilepisium madagascariense DC., [T] [GC-O-SZfr-Mad]
Myrsinaceae
Maesa lanceolata Forssk., [T], [GC-ZI-Mad]
Myrtaceae
Eugenia bukobensis Engl., [T], [Sub-AfrM/n-e (-SZfr)]
Eucalyptus camaldulensis Dehnh., Exotic
Oleaceae
Chionanthus mildbraedii (Gilg & Scellenb.) Stearn. [T] [GC-AfrM-SZfr]
Olea capensis ssp. *hochstetteri* (Bak.) Friis & Green, [T] [AfrM/e]
O. capensis ssp. *welwitschii* (Knobl.) Friis & Green, [T] [AfrM/n-e]
Orchidaceae
Aerangis brachycarpa (A. Rich.) Th. Dur. & Schinz, [H]
A. thomsonii (Rolfe) Schltr, [H]
Bulbophyllum lupulinum Lindl., [H]
B. sandersonii (Hook. f.) Rchb. f., [H]
Corymborkis corymbis Thourars., [H]
Eulophia guineensis Lindl. [H]
E sp [H]
Habenaria cornuta Lindl., [H]

H. humilior Rchb.f., [H]
H. peristyloides A. Rich., [H]
H schimperiana A. Rich., [H]
Liparis abyssinica A. Rich., [H]
Microcoelia globulosa (Hochst.) L. Johsson, [H]
Nervilia bicarinata (Bl.) Schltr., [H]
Polystachya lindblumii, Schltr., [H]
P rivae Schweinf., [H]
Phytolaccaceae
Hilleria latifolia (Lam.) H. Walter,. [H]
Phytolacca dodecandra L'Her., C
Piperaceae
Piper capense L.f., [H]
Piperomia abyssinica Mig., [H]
P. rotundifolia (L.) Kunth, [H]
P. tetraphylla (Forster) Hook. & Arn., [H]
Pittosporaceae
Pittosporum viridiflorum Sims, [T] Sub-AfrM/n-e (-SZfr)
Poaceae
Arundo donax L., [H]
Leptaspis zeylanica Nees ex Steud., [H]
Olyra latifolia L. [H]
Oplismenus hirtellus (L.) P. Beauv., [H]
Panicum hochstetteri Steud., [H]
Setaria megaphylla (Steud.) Th. Dur. & Schinz, [H]
S sp. [H]
Podocarpaceae
Podocarpus falcatus (Thunb.) Mirb. [T] AfrM/n-e
Polypodaceae
Drynaria sp. [H]
Ranunculaceae
Clematis longicauda Steud. Ex A. Rich., [C]
C. simensis Fresen., [C]
Ranunculus multifilus Forssk., [H]
R sp. [H]
Thalictrum rhychocarpum Dill. & Rich., [H]
T sp. [H]
Rhamnaceae
Gouania longispicata Engl., [C]
Rhamnus prinoides L'Hérit., [T]
Scutia myrtina (Burm. f.) Kurz., [C].
Rhizophoraceae
Cassipourea malosana (Bak.) Alston, T, [AfrM/n-e]
Rosaceae
Prunus africana (Hook. f.) Kalkm., T, [AfrM/n-e]
Rubus apetalus Poir., [C]
Rubiaceae
Breonadia salicina (Vahl) Hepper & Wood, [T] [AfrM/e]
Canthium oligocarpum Hiern, [T] [AfrM/e]
C sp. [S]
Coffea arabica L., [T] [AfrM/e]
Crossopteryx febrifuga (Afz. ex G. Don) Benth.. [S]
Galiniera saxifraga (Hochst.) Bridson, [T] [AfrM/e]
Gardenia lutea Fresen., [S]
Geophila repens (L.) IM Johnst., [H]
Oxyanthus speciosus sbsp. *stenocarpus* (K. Schum.) Bridson, T [AfrM/n-e]
Pavetta abyssinica Fresen., [S]
Pavetta sp [S]
Psychotria orophila Petit, [T] [AfrM/e]
Psydrax parviflora (Afz.) Bridson, [T] [Sub-AfrM/n-e (-SZfr-Arab)]
Sarcocephalus latifolius (Sm.) Bruce, T
Rutaceae
Clausena anisata (Willd.) Benth., [T] [GC-SZfr-ZI-AfrM-Asia)]
Teclea noblis Del., [T] [AfrM/n-e (-SZfr)]
Vepris Dainelli (Pichi-Sermolli) Kokwaro. [T] [AfrM/e]
Sapindaceae
Blighia unijugata Bak. [T] [GC-ZI-SZfr]
Filicium decipiens (Wight & Arn.) Thwaites, [T] [AfroM-ZI-Asia]
Pappea capensis Eckl. & Zeyh. [T] AfrM-SM-SZ-TP-CP
Paullinia pinnata L. [C]

Sapotaceae
Aningeria altissima (A. Chev.) Aubrév. & Pellegr. [T] [GC/n-e (-SZfr)]
Mimusops kummel A. DC., [T] [AfrM-SZfr]
Simaroubaceae
Brucea antidysenterica J. F. Mill., [T] AfrM/e
Solanaceae
Physalis peruviana L., [S]
Solanum incanum L., [H]
S nigrum L., [H]
Taccaceae
Tacca leontopetaloides (L.) O. Ktze., [H]
Tiliaceae
Grewia ferruginea A. Rich., [T]
Ulmaceae
Celtis Africana Burm. f. [T] [GC-AfrM-SZ-CP]
C. philippensis Blanco, [T] [GC-ZI-SZfr-Mad-Asia]
C. toka (Forssk.) Hepper & Wood, [T] [SZfr/n-e (-Arab)]
C. zenkeri Engl., [T], [GC-ZI-SZfr]
Trema orientalis (L.) Blume, [T] [GC-ZI-TP-AfrM-Mad-Asia]
Urticaceae
Urera hypselodendron (Steud.) Wedd., [C]
Urera trinervis (Hochst. ex Krauss) Friis & Immelman, [C]
Vitaceae
Cissus quadrangularis L., [C]
Cyphostemma adenocaule (Steud.) Descoings. [C]
Rhoicissus tridentata (L. f.) Wild & Drummond, [C]
Zingebraceae
Aframomum corrorima (Pereira) Engl., [H]

Appendix 2 Full descriptions of the abbreviated plant 'distribution type' names of the tree species recorded in the study area

Shortened name of distribution types	Full description of the distribution type names
AfrM/e	Afromontane Endemic
AfrM/n-e	Afromontane near Endemic
AfrM/n-e (-SZfr)	Afromontane Endemic with extension into riverine forest in Sudano-Zambezian super region
AfrM/n-e (-SZfr-Mad-Asia)	Afromontane near-endemic
AfrM-SZfr	East African linking species
AfrM-SZfr-Arab	East African linking species. Transgressor
GC/n-e	Guineo-Congolian near-endemic
GC/n-e (-SZfr)	Guineo-Congolian-East African forest belt- Afromontane linking species
GC-AfrM-SZ-CP	Widespread African linking species
GC-AfrM-SZfr-ZI	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'
GC-AfrM-ZI-SZfr	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'
GC-O-SZfr_Mad	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region' and Madagascar
GC-SZ-AfrM-Asia	Widespread Africa-Asia linking species
GC-SZ-AfrM-CP	Widespread African linking species
GC-SZfr-ZI-AfrM-Asia)	Widespread African-Asian linking species
GC-SZfr-ZI-AfrM-ZI	Widespread African linking species
GC-SZ-ZI-AfrM	Widespread African linking species
GC-ZI-AfrM-SZfr	Guineo-Congolian Afromontane linking species
GC-ZI-Mad	Guineo-Congolian-East African forest belt linking species. with extension into Madagascar
GC-ZI-SZfr-SZfr-Mad	Guineo-Congolian-East African forest belt linking species. with extension into Madagascar
GC-ZI-SZfr	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'
GC-ZI-SZfr	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'
GC-ZI-SZfr-Mad	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'
GC-ZI-TP-SZfr	Guineo-Congolian-East African forest belt linking species. with extension into riverine forest in the Sudano-Zambezian 'super-region'. linking species also with Tongaland-Pondoland regional mosaic
Sub-AfrM/e	Afromontane sub-endemic
Sub-AfrM/n-e	Afromontane sub-endemic
Sub-AfrM/n-e (-SZfr)	Near-endemic in the East-African forest belt
Sub-AfrM/n-e (-SZfr-Arab)	Near-endemic in the East-African forest belt
Sub-AfrM/n-e (-SZfr-Mad)	Near-endemic in the East-African forest belt
SZfr/n-e (-Arab)	near-endemic in riverine forest of Sudanian region

Appendix 3 Families of vascular plants and the number of their species.

Family	Number of species	Trees	Shrubs	climbers	Average number of stems per plot
Dracaenaceae	2	2	0	0	7955
Rubiaceae	8	6	2	0	7309
Apocynaceae	2	0	0	2	3535
Sapindaceae	2	1	0	1	2770
Euphorbiaceae	6	4	2	0	2224
Celasteraceae	7	2	2	3	1848
Unidentified	5	3	2	0	1691
Ebenaceae	1	1	0	0	1560
Fabaceae	6	4	1	1	1249
Acanthaceae	3	0	3	0	1157
Rutaceae	3	3	0	0	925
Anacardiaceae	1	0	1	0	655
Meliaceae	2	2	0	0	349
Oleaceae	3	2	1	0	309
Moraceae	10	10	0	0	277
Ulmaceae	3	3	0	0	234
Menispermaceae	1	0	0	1	217
Sapotaceae	2	2	0	0	120
Myrtaceae	1	1	0	0	119
Pittosporaceae	1	1	0	0	117
Capparidaceae	3	1	0	2	116
Combretaceae	1	0	0	1	115
Boraginaceae	2	2	0	0	94
Rhizophoraceae	1	1	0	0	94
Melianthaceae	1	1	0	0	85
Rhamnaceae	2	0	0	2	83
Malvaceae	4	0	4	0	69
Myrsinaceae	1	1	0	0	49
Asteraceae	3	0	3	0	34
Vitaceae	2	0	0	2	30
Urticaceae	1	0	0	1	20
Arecaceae	1	1	0	0	06
Ranunculaceae	2	0	0	2	06
Rosaceae	2	1	1	0	04
Flacourtiaceae	1	1	0	0	02
Phytolaccaceae	1	0	0	1	02
Tiliaceae	1	0	1	0	02
Araliaceae	2	2	0	0	01
Icacinaceae	1	1	0	0	01
Bignoniaceae	1	0	1	0	<01
	102	59	24	19	

Appendix 4. X^2 test of species-abundance distribution

Class	Upper Bound	NATFOR			SECFOR			SEMIFOR-NEW			SEMIFOR-OLD			SEMIFOR-PLAN		
		Exp	Obs	X^2	Exp	Obs	X^2	Exp	Obs	X^2	Exp	Obs	X^2	Exp	Obs	X^2
1	2.5	13.4	7.0	3.1	12.8	5.0	4.7	11.2	6.0	2.4	9.7	9.0	0.0	7.9	2.0	4.4
2	4.5	5.2	4.0	0.3	5.0	5.0	0.0	4.4	3.0	0.4	3.8	0.0	3.8	3.1	1.0	1.4
3	8.5	5.7	2.0	2.4	5.4	8.0	1.2	4.7	0.0	4.7	4.1	0.0	4.1	3.4	4.0	0.1
4	16.5	5.9	10.0	2.8	5.6	7.0	0.3	4.9	10.0	5.2	4.3	10.0	7.8	3.5	0.0	3.5
5	32.5	6.0	6.0	0.0	5.7	7.0	0.3	5.0	7.0	0.8	4.3	9.0	5.0	3.6	7.0	3.3
6	64.5	6.1	10.0	2.6	5.8	11.0	4.7	5.1	7.0	0.7	4.3	7.0	1.6	3.6	7.0	3.3
7	128.5	6.0	10.0	2.6	5.7	6.0	0.0	5.0	9.0	3.2	4.3	7.0	1.7	3.5	7.0	3.4
8	256.5	5.9	6.0	0.0	5.6	6.0	0.0	4.9	5.0	0.0	4.2	2.0	1.2	3.4	7.0	3.7
9	512.5	5.6	7.0	0.3	5.4	6.0	0.1	4.6	5.0	0.0	4.0	3.0	0.2	3.2	4.0	0.2
10	1024.5	5.1	6.0	0.1	4.9	5.0	0.0	4.1	5.0	0.2	3.5	3.0	0.1	2.8	1.0	1.2
11	2048.5	4.3	2.0	1.2	4.1	1.0	2.4	3.2	0.0	3.2	2.8	0.0	2.8	2.2	0.0	2.2
12	4096.5	3.0	0.0	3.0	2.9	2.0	0.3	2.0	2.0	0.0	1.8	0.0	1.8	1.3	1.0	0.1
13	8192.5	1.4	4.0	4.5	1.5	1.0	0.1	0.8	1.0	0.1	0.8	1.0	0.1	0.5	1.0	0.6
14	16384.5				0.4	1.0	1.0				0.1	1.0	5.0			
	Total	**74**	**74**	**22.91**	**71**	**71**	**15.2**	**60**	**60**	**21.0**	**52**	**52**	**35.2**	**42**	**42**	**27.4**
	df			12.00			13.0			12.0			13.0			12.0
	P=			**0.03**			**0.30**			**0.05**			**0.00**			**0.01**

Appendix 5. ANOVA tables: differences in height classes

a) all height classes

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Forest categories	4	49654372	124135931	21269	0000
Residual (error)	45	26264718	583660391		
Total	49	75919090			

b) HC 1

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Forest categories	4	314034618	785086545	13963	1752×10^{-7}
Residual (error)	45	253020402	56226756		
Total	49	56705502			

c) HC 2

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Forest categories	4	240139672	6003492	28860	6503×10^{-12}
Residual (error)	45	9361097	2080244		
Total	49	333750642			

d) HC 3

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Forest categories	4	731788	182947	13319	307×10^{-7}
Residual (error)	45	61811	137358		
Total	49	1349898			

e) HC 4

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Forest categories	4	52288	13072	6853	214×10^{-4}
Residual (error)	45	8584	190756		
Total	49	13813			

Appendix 6. ANOVA table: differences in basal area

Source of Variation	***df***	***SS***	***MS***	***F***	***P-value***
Forest categories	4	41052	10263	378	<001
Residual (error)	45	122050	2712		
Total	49	1631027			

Appendix 7 Height class distribution plant recorded in the different forest categories. Height classes: HC 1 = <1.5 m, HC 2 = 1.5-12.5 m, HC 3 = 12.5-24.5 m and HC 4= ≥ 24.5 m tall stems; GF- Growth form

No.	Species name	GF	UNDFOR				OLSFOR				SF-NEW				SF-OLD				PCOFOR			
			HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4
1.	Abutilon cecilli	SH	18	-	-	-	107	-	-	-	-	-	-	-	-	-	-	-	72	-	-	-
2.	Acanthus eminens	SH	-	-	-	-	36	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.	Albizia grandibracteata	LT	577	107	7	13	908	46	12	17	400	33	8	2	419	41	5	5	428	17	4	1
4.	Albizia gummifera	LT	-	-	-	1	-	3	2	1	-	-	-	1	-	-	1	-	-	3	-	-
5.	Aningeria altissima	LT	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
6.	Antiaris toxicaria	LT	91	19	3	2	63	3	1	1	99	-	1	1	116	2	-	-	45	-	-	-
7.	Apodytes dimidiata	LT	-	-	-	-	-	-	-	1	9	-	-	-	-	-	-	-	-	-	-	-
8.	Argomuellera macrophylla	ST	694	98	-	-	-	-	-	-	658	18	-	-	9	-	-	-	-	9	-	-
9.	Bersama abyssinica	LT	9	57	-	-	63	40	-	-	133	-	-	-	-	2	-	-	-	-	-	-
10.	Pappea capensis	LT	62	27	-	-	9	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-
11.	Blighia unijugata	LT	365	157	6	-	-	20	1	1	339	11	3	4	943	2	4	5	525	-	1	-
12.	Bridelia micrantha	LT	-	1	1	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
13.	Canthium giordanii	ST	409	37	3	-	355	29	2	-	436	-	-	-	44	-	-	-	170	2	-	-
14.	Canthium oligocarpum	ST	126	16	2	-	560	20	-	-	160	19	1	-	89	9	-	-	63	29	-	-
15.	Capparis micrantha	CL	80	-	-	-	63	-	-	-	97	-	-	-	-	-	-	-	63	-	-	-
16.	Capparis tomentosa	CL	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17.	Cassipourea malosana	LT	36	40	-	-	205	46	1	-	9	-	-	-	-	18	-	-	27	4	-	-
18.	Catha edulis	SH	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-
19.	Celasteraceae #7	ST	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20.	Celtis africana	LT	330	65	3	-	9	26	-	-	134	9	-	-	45	1	-	1	9	37	-	-
21.	Cissus quadrangularis	CL	9	-	-	-	18	9	9	-	-	-	-	-	18	-	-	-	-	-	-	-
22.	Citrus medica	SH	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
23.	Clausena anisata	ST	951	50	-	-	349	100	-	-	222	-	-	-	758	19	-	-	746	9	-	-
24.	Clematis longicauda	CL	-	-	-	-	1236	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25.	Clematis simensis	CL	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26.	Coffea arabica	ST	5546	1903	-	-	4696	2092	-	-	4471	4297	-	-	4836	6343	-	-	1938	5954	-	-
27.	Combretum paniculatum	CL	-	28	28	27	27	27	69	23	276	9	-	-	9	-	-	-	63	-	-	-

No.	Species name	GF	UNDFOR				OLSFOR				SF-NEW				SF-OLD				PCOFOR			
			HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4
28.	Cordia africana	LT	-	-	3	2	-	4	3	1	97	1	3	2	18	-	-	2	-	-	1	-
29.	Crossopteryx febrifuga	ST	-	10	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
30.	Croton macrostachyus	LT	-	1	2	-	-	-	3	1	45	-	-	3	-	-	-	-	-	-	-	-
31.	Dalbergia lactea	SH	-	9	-	-	-	9	-	-	-	-	-	-	98	-	-	-	98	18	-	-
32.	Justicia betonica	SH	178	142	-	-	-	-	-	-	98	-	-	-	-	-	-	-	-	-	-	-
33.	Diospyros abyssinica	LT	472	206	8	4	338	169	4	2	205	9	1	-	160	94	-	-	9	36	-	-
34.	Dracaena fragrans	ST	4625	1466	2	-	7866	2887	-	-	1129	-	-	-	89	18	-	-	382	18	-	-
35.	Dracaena steudneri	ST	18	7	1	-	-	7	-	-	9	-	-	-	-	-	-	-	-	-	-	-
36.	Ehretia cymosa	ST	27	51	11	-	71	81	6	-	125	17	-	-	45	4	-	-	27	102	-	-
37.	Ekebergia capensis	LT	-	1	-	-	-	2	-	-	-	-	-	-	-	1	-	-	18	-	-	-
38.	Elaeodendron buchananii	LT	9	14	18	-	-	2	4	1	-	-	1	1	-	27	-	-	-	-	-	-
39.	Entada abyssinica	ST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	1	-
40.	Eugenia bukobensis	ST	267	27	-	-	-	-	-	-	36	-	-	-	-	-	-	-	-	-	-	-
41.	Ficus exasperata	LT	18	12	2	2	-	2	1	2	-	-	3	-	9	-	1	-	44	-	3	-
42.	Ficus lutea	LT	-	-	-	1	-	3	3	-	-	-	1	-	-	-	-	1	-	-	-	-
43.	Ficus sur	LT	-	-	1	2	-	1	1	-	-	1	-	2	-	-	-	-	-	-	-	-
44.	Ficus thonningii	LT	-	4	3	-	-	36	1	-	36	-	1	-	44	9	-	-	-	2	1	-
45.	Ficus vasta	LT	-	-	1	2	-	1	1	1	-	-	-	-	-	-	1	-	-	-	-	-
46.	Flacourtia indica	LT	-	-	-	-	-	-	-	-	9	-	-	-	9	-	-	-	9	-	-	-
47.	Galiniera saxifraga	ST	9	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48.	Gouania longispicata	CL	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49.	Grewia ferruginea	ST	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50.	Hibiscus ludwigii	SH	36	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51.	Hippocratea africana	CL	250	89	2	-	232	71	-	-	89	-	-	-	27	-	-	-	-	9	-	-
52.	Pavonia urens	SH	36	-	-	-	-	-	-	-	-	-	-	-	62	9	-	-	143	-	-	-
53.	Justicia schimperiana	SH	1087	373	-	-	603	355	-	-	588	-	-	-	143	-	-	-	-	-	-	-
54.	Landolphia buchananii	CL	2479	27	10	9	3644	90	48	15	738	-	-	-	249	9	-	-	97	-	-	-

No.	Species name	GF	UNDFOR				OLSFOR				SF-NEW				SF-OLD				PCOFOR			
			HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4
55.	Maesa lanceolata	ST	-	20	-	-	9	18	-	-	116	5	-	-	45	2	-	-	107	1	-	-
56.	Maytenus gracilipes	SH	1378	486	-	-	1334	498	1	-	3768	117	-	-	4294	27	-	-	1964	45	-	-
57.	Millettia ferruginea	LT	-	37	8	1	-	46	1	-	80	2	3	-	18	3	-	-	18	76	11	-
58.	Mimusops kummel	LT	117	3	-	-	98	20	1	-	9	-	-	-	-	-	-	-	-	-	-	-
59.	Morus mesosygia	LT	-	2	1	1	-	1	1	2	-	-	-	1	-	-	-	1	-	-	-	-
60.	Olea capensis ssp. hochstetteri	ST	258	27	-	-	9	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-
61.	Olea capensis ssp. welwitschii	LT	-	39	7	3	-	51	3	2	-	1	-	2	-	9	-	-	-	-	-	-
62.	Oncinotis tenuiloba	CL	1929	9	2	1	9	18	9	-	418	-	-	-	98	-	-	-	-	-	-	-
63.	Oxyanthus speciosus	ST	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64.	Paullinia pinnata	CL	4434	45	62	-	2712	54	-	-	2596	45	-	-	641	9	-	-	303	-	-	-
65.	Pavetta abyssinica	SH	-	-	-	-	9	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
66.	Phoenix reclinata	ST	9	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
67.	Phyllanthus ovalifolius	SH	62	27	-	-	9	135	-	-	45	-	-	-	-	-	-	-	18	-	-	-
68.	Phytolacca dodecandra	CL	-	-	-	-	-	1	-	-	18	-	-	-	-	-	-	-	36	-	-	-
69.	Pittosporum viridiflorum	ST	36	21	-	-	27	14	-	-	-	1	-	-	-	-	-	-	-	-	-	-
70.	Prunus africana	LT	-	-	-	1	-	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-
71.	Pterolobium stellatum	CL	81	27	2	1	133	-	-	-	-	-	-	-	71	-	-	-	-	-	-	-
72.	Rhoicissus tridentata	CL	-	-	-	-	-	9	-	-	45	-	-	-	-	-	-	-	-	-	-	-
73.	Rhus ruspoli	SH	728	42	-	-	739	104	-	-	232	-	-	-	463	18	-	-	293	18	-	-
74.	Ricinus communis	ST	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-
75.	Ritchiea albersii	ST	18	63	-	-	54	22	1	-	54	1	-	-	36	-	-	-	125	11	-	-
76.	Rubus apetalus	CL	71	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
77.	Sapium ellipticum	LT	9	4	6	3	-	2	4	1	18	-	4	2	18	1	1	1	9	8	4	-
78.	Scutia myrtina	CL	63	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
79.	Senna petersiana	ST	36	28	-	-	205	36	-	-	462	63	-	-	9	1	-	-	170	1	-	-
80.	Sida ternata	SH	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
81.	Species P	SH	-	-	-	-	311	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

No.	Species name	GF	UNDFOR				OLSFOR				SF-NEW				SF-OLD				PCOFOR			
			HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4	HC 1	HC 2	HC 3	HC 4
82.	Species Q	SH	-	-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-
83.	Teclea noblis	ST	54	105	-	-	125	18	1	-	-	-	-	-	18	-	-	-	9	-	-	-
84.	Tiliachora troupinii	CL	205	9	36	-	27	27	-	-	9	-	-	-	9	-	-	-	71	-	-	-
85.	tree species B	LT	9	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
86.	Trichilia dregeana	LT	419	22	-	3	277	25	7	1	27	2	-	-	54	1	1	1	205	10	1	-
87.	Trilepisium madagascariense	LT	9	-	2	-	-	-	-	-	9	-	-	-	9	-	-	-	-	-	-	-
88.	Urera trinervis	CL	-	-	-	1	-	53	1	-	-	36	-	-	-	-	-	-	-	-	-	-
89.	Vepris dainelli	ST	161	42	-	-	54	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90.	Vernonia amygdalina	ST	-	-	-	-	-	-	-	-	9	-	-	-	18	1	-	-	-	492	-	-
91.	Vernonia auriculifera	SH	9	-	-	-	18	-	-	-	72	-	-	-	53	9	-	-	18	-	-	-
92.	Vernonia sp. (Kalaala)	SH	53	-	-	-	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-
93.	Hippocratea sp.	SH	204	9	72	-	-	-	-	1	-	-	-	-	-	-	-	-	44	-	-	-
	Coffee seedlings to mature tree ratio		2.9				2.2				1.0				0.8				0.3			

Appendix 10. List of location for specimens collected from Yayu forest, and in order of the voucher numbers.

Number	**Family name**	**Scientific name**	**Location**
51	Asteraceae	Vernonia Sp. 1	035^{0}48´E, 08^{0}23´N
52	Commelinaceae	Pollia mannii	035^{0}48´E, 08^{0}22´N
53	Piperaceae	Piperomia rotundifolia	035^{0}48´E, 08^{0}23´N
54	Ebenaceae	Diospyros abyssinica	035^{0}48´E, 08^{0}23´N
55	Sapotaceae	Mimusops kummel	035^{0}48´E, 08^{0}23´N
56	Rubiaceae	Galiniera coffeoides	035^{0}48´E, 08^{0}23´N
57	Fabaceae	Dalbergia lactea	035^{0}48´E, 08^{0}21´N
58	Family1	Genus1 Sp. 1	035^{0}48´E, 08^{0}22´N
59	Fabaceae	Desmodium hirtum	035^{0}47´E, 08^{0}21´N
60	Fabaceae	Senna petersonia	035^{0}47´E, 08^{0}21´N
61	Acanthaceae	Hypoestus forskaoli	035^{0}47´E, 08^{0}21´N
62	Acanthaceae	Hypoestus sp. 1	035^{0}48´E, 08^{0}23´N
63	Apocynaceae	Oncinotis tenuiloba	035^{0}48´E, 08^{0}23´N
64	Apocynaceae	Landolphia buchananii	035^{0}48´E, 08^{0}23´N
65	Celasteraceae	Hippocratea africana	035^{0}48´E, 08^{0}22´N
66	Amaranthaceae	Achyranthes aspera	035^{0}48´E, 08^{0}22´N
67	Balsaminaceae	Impatiens hochstetteri	035^{0}48´E, 08^{0}22´N
68	Vitaceae	Rhoicissus tridentata	035^{0}48´E, 08^{0}22´N
69a	Rubiaceae	Pavetta abyssinica	035^{0}48´E, 08^{0}22´N
69b	Rubiaceae	Psychotria riparia	035^{0}48´E, 08^{0}22´N
70	Solanaceae	Physalis peruviana	035^{0}48´E, 08^{0}22´N
71	Rubiaceae	Canthium sp.	035^{0}48´E, 08^{0}22´N
72	Flacourtiaceae	Flacourtia indica	035^{0}48´E, 08^{0}22´N
73	Zingiberaceae	Unidentified	035^{0}48´E, 08^{0}22´N
74	Anacardiaceae	Rhus ruspoli	035^{0}48´E, 08^{0}22´N
75	Poaceae	Olyra latifolia	035^{0}48´E, 08^{0}22´N
76	Araceae	Culcasia falcifolia	035^{0}48´E, 08^{0}22´N
77	Orchidaceae	Corymborkis corymbis	035^{0}48´E, 08^{0}22´N
78	Acanthaceae	Justicia betonica	035^{0}48´E, 08^{0}22´N
79	Fabaceae	Senna petersiana	035^{0}48´E, 08^{0}22´N
80	Sapindaceae	Blighia unijugata	035^{0}48´E, 08^{0}22´N
81	Fabaceae	Lablab parpureus	035^{0}48´E, 08^{0}22´N
82	Ascelepidaceae	Gomphocarpus truitcosus	035^{0}46´E, 08^{0}20´N
83	Rubiaceae	Gardenia ternifolia	035^{0}46´E, 08^{0}20´N
84	Moraceae	Trilepisium madagascariense	035^{0}49´E, 08^{0}22´N
85	Cannaceae	Canna indica	035^{0}48´E, 08^{0}23´N
86	Poaceae	Setaria megaphylla	035^{0}48´E, 08^{0}22´N
87	Poaceae	Oplismenus hirtellus	035^{0}48´E, 08^{0}22´N
88	Fabaceae	Desmodium repandum	035^{0}48´E, 08^{0}22´N
89	Lamiaceae	Ocimum lamiifolium	035^{0}48´E, 08^{0}22´N

Number	Family name	Scientific name	Location
90	Acanthaceae	Justicia sp.	035^{0}48´E, 08^{0}22´N
90	Lamiaceae	Achyrospermum schimperi	035^{0}48´E, 08^{0}23´N
91	Rubiaceae	Galiniera coffeoides	035^{0}48´E, 08^{0}23´N
92	Malvaceae	Abutilon cecilli	035^{0}48´E, 08^{0}23´N
93	Phytolaccaceae	Hilleria latifolia	035^{0}49´E, 08^{0}22´N
94	Acanthaceae	Hypoestus forskaoli	035^{0}49´E, 08^{0}22´N
95	Poaceae	Leptaspis zeylanica	035^{0}49´E, 08^{0}22´N
96	Rubiaceae	Geophila repens	035^{0}49´E, 08^{0}22´N
97	Rubiaceae	Canthium giordanii	035^{0}48´E, 08^{0}23´N
98	Malvaceae	Genus8 sp.	035^{0}49´E, 08^{0}22´N
99	Acanthaceae	Brillantaisisa madagascariensis	035^{0}48´E, 08^{0}22´N
100	Lamiaceae	Achyrospermum schimperi	035^{0}48´E, 08^{0}23´N
101	Orchidaceae	Eulophia sp.	035^{0}48´E, 08^{0}23´N
102	Celasteraceae	Genus6 sp. 1	035^{0}48´E, 08^{0}22´N
103	Rubiaceae	Galiniera coffeoides	035^{0}48´E, 08^{0}23´N
104	Rubiaceae	Oxyanthus speciosus	035^{0}48´E, 08^{0}23´N
105	Myrtaceae	Eugenia bukobensis	035^{0}48´E, 08^{0}23´N
106	Acanthaceae	Acanthus eminens	035^{0}48´E, 08^{0}23´N
107	Euphorbiaceae	Euphorbia schimperiana	035^{0}48´E, 08^{0}22´N
108	Piperaceae	Piper capense	035^{0}48´E, 08^{0}22´N
109	Cucurbitaceae	Sicyos polyacanthus	035^{0}48´E, 08^{0}22´N
110	Solanaceae	Solanum incanum	035^{0}48´E, 08^{0}22´N
111	Ascelepidaceae	Gomphocarpus semilunatus	035^{0}48´E, 08^{0}22´N
112	Ranunculaceae	Ranunculus multifilus	035^{0}48´E, 08^{0}22´N
113	Asteraceae	Galinsoga quadriradiata	035^{0}48´E, 08^{0}23´N
114a	Asteraceae	Crassocephalum sp.	035^{0}48´E, 08^{0}23´N
114b	Asteraceae	Vernonia hochstetteri	035^{0}48´E, 08^{0}23´N
114c	Asteraceae	Vernonia bipontinii	035^{0}48´E, 08^{0}23´N
115	Amaranthaceae	Achyranthes aspera	035^{0}48´E, 08^{0}24´N
116	Ranunculaceae	Clematis longicauda	035^{0}48´E, 08^{0}22´N
117	Amaranthaceae	Celosia trigyna	035^{0}49´E, 08^{0}22´N
118	Ascelepidaceae	Gomphocarpus semilunatus	035^{0}49´E, 08^{0}22´N
119	Malvaceae	Sida ternata	035^{0}49´E, 08^{0}22´N
120	Ranunculaceae	Ranunculus sp.	035^{0}49´E, 08^{0}22´N
121a	Brassicaceae	Cardamine africana	035^{0}48´E, 08^{0}22´N
121b	Brassicaceae	Cardamine trichocarpa	035^{0}48´E, 08^{0}22´N
122	Solanaceae	Solanum nigrum	035^{0}48´E, 08^{0}22´N
123	Rutaceae	Clausena anisata	035^{0}48´E, 08^{0}22´N
124	Orchidaceae	Habenaria schimperiana	035^{0}48´E, 08^{0}22´N
125	Orchidaceae	Aerangis brachycarpa	035^{0}46´E, 08^{0}20´N
126	Loranthaceae	Englerina woodfordioides	035^{0}49´E, 08^{0}20´N
127	Rubiaceae	Canthium oligocarpum	035^{0}48´E, 08^{0}22´N

Number	Family name	Scientific name	Location
128a	Sapindaceae	Paullinia pinnata	035^{0}49´E, 08^{0}22´N
128b	Sapindaceae	Filicium decipiens	035^{0}49´E, 08^{0}22´N
129	Asteraceae	Ageranthum conyzoides	035^{0}48´E, 08^{0}22´N
130	Rhizophoraceae	Cassipourea malosana	035^{0}48´E, 08^{0}22´N
131	Anacardiaceae	Rhus quartiniana	035^{0}48´E, 08^{0}22´N
132	Crassulaceae	Kalanchoe densiflora	035^{0}48´E, 08^{0}22´N
133	Solanaceae	Solanum incanum	035^{0}48´E, 08^{0}22´N
134	Family4	Genus10 sp.	035^{0}48´E, 08^{0}22´N
135	Brassicaceae	Unidentified sp.	035^{0}48´E, 08^{0}22´N
136	Euphorbiaceae	Unidentified sp.	035^{0}48´E, 08^{0}22´N
137	Amaranthaceae	Unidentified sp.	035^{0}46´E, 08^{0}20´N
138	Family5	Genus11 sp.	035^{0}46´E, 08^{0}20´N
139	Simaroubaceae	Brucea antidysenterica	035^{0}45´E, 08^{0}20´N
140	Capparidaceae	Ritchiea albersii	035^{0}46´E, 08^{0}20´N
141	Orchidaceae	Eulophia guineensis	035^{0}46´E, 08^{0}20´N
142	Family6	Genus12 sp.	035^{0}46´E, 08^{0}20´N
143	Orchidaceae	Polystachya lindblomii	035^{0}46´E, 08^{0}20´N
144	Asteraceae	Vernonia auriculifera	035^{0}48´E, 08^{0}22´N
145	Asparagaceae	Asparagus officinalis	035^{0}46´E, 08^{0}20´N
146	Orchidaceae	Unidentified sp.	035^{0}48´E, 08^{0}22´N
147	Rhizophoraceae	Cassipourea malosana	035^{0}48´E, 08^{0}22´N
148	Rosaceae	Prunus africana	035^{0}48´E, 08^{0}22´N
149	Euphorbiaceae	Bridelia micrantha	035^{0}48´E, 08^{0}22´N
150	Meliaceae	Trichilia dregeana	035^{0}48´E, 08^{0}22´N
151	Celasteraceae	Elaeodendron buchannani	035^{0}48´E, 08^{0}22´N
152	Rutaceae	Clausena anisata	035^{0}48´E, 08^{0}22´N
153	Euphorbiaceae	Phyllanthus ovalifolius	035^{0}48´E, 08^{0}22´N
154	Euphorbiaceae	Sapium ellipticum	035^{0}53´E, 08^{0}22´N
155	Orchidaceae	Eulophia guineensis	035^{0}53´E, 08^{0}22´N
156	Menispermaceae	Tiliachora troupinii	035^{0}53´E, 08^{0}22´N
157	Commelinaceae	Pollia condensata	035^{0}53´E, 08^{0}22´N
158	Orchidaceae	Unidentified sp.	035^{0}53´E, 08^{0}22´N
159	Rubiaceae	Pavetta abyssinica	035^{0}53´E, 08^{0}22´N
160	Meliaceae	Ekebergia capensis	035^{0}53´E, 08^{0}22´N
161	Orchidaceae	Microcoelia globulosa	035^{0}48´E, 08^{0}22´N
162	Moraceae	Ficus capreaefolia	035^{0}48´E, 08^{0}22´N
163	Capparidaceae	Ritchiea albersii	035^{0}48´E, 08^{0}22´N
164	Combretaceae	Combretum paniculatum	035^{0}48´E, 08^{0}22´N
165	Melianthaceae	Bersama abyssinica	035^{0}48´E, 08^{0}22´N
166	Family7	Genus13 sp.	035^{0}48´E, 08^{0}22´N
167	Rubiaceae	Sarcocephalus latifolius	035^{0}46´E, 08^{0}21´N
168	Capparidaceae	Capparis erythrocarpos	035^{0}47´E, 08^{0}21´N

Number	Family name	Scientific name	Location
169	Orchidaceae	Bulbophyllum lupulinum	035^{0}49´E, 08^{0}23´N
170	Rubiaceae	Gardenia ternifolia	035^{0}49´E, 08^{0}23´N
171	Sapindaceae	Paullinia pinnata	035^{0}49´E, 08^{0}23´N
172	Moraceae	Ficus thonningii	035^{0}49´E, 08^{0}23´N
173	Myrtaceae	Eugenia bukobensis	035^{0}48´E, 08^{0}23´N
174	Celasteraceae	Hippocratea pallens	035^{0}49´E, 08^{0}23´N
175	Family8	Genus14 sp.	035^{0}49´E, 08^{0}23´N
176	Ulmaceae	Trema orientalis	035^{0}48´E, 08^{0}23´N
177	Moraceae	Ficus vallis-choudae	035^{0}48´E, 08^{0}22´N
178	Moraceae	Ficus lutea	035^{0}48´E, 08^{0}23´N
179	Moraceae	Ficus vasta	035^{0}48´E, 08^{0}23´N
180	Moraceae	Ficus lutea	035^{0}48´E, 08^{0}21´N
181	Apocynaceae	Landolphia buchananii	035^{0}49´E, 08^{0}23´N
182	Ulmaceae	Celtis toka	035^{0}49´E, 08^{0}23´N
183	Rubiaceae	Pavetta abyssinica	035^{0}49´E, 08^{0}23´N
184	Dracaenaceae	Dracaena fragrans	035^{0}49´E, 08^{0}23´N
185	Solanaceae	Physalis peruviana	035^{0}46´E, 08^{0}20´N
186	Convolvulaceae	Ipomoea carica	035^{0}46´E, 08^{0}20´N
187	Cucurbitaceae	Lagenaria abyssinica	035^{0}46´E, 08^{0}20´N
188	Aspleniaceae	Asplenium sp.	035^{0}46´E, 08^{0}20´N
189	Ranunculaceae	Thalictrum rhychocarpum	035^{0}48´E, 08^{0}22´N
190	Cucurbitaceae	Zehnaria scabra	035^{0}48´E, 08^{0}22´N
191	Asteraceae	Laggeria ptrodrodonta	035^{0}48´E, 08^{0}22´N
192	Ranunculaceae	Clematis simensis	035^{0}48´E, 08^{0}22´N
193	Malvaceae	Wissadula rostrata	035^{0}48´E, 08^{0}22´N
194	Malvaceae	Hibiscus micranthus	035^{0}48´E, 08^{0}22´N
195	Ranunculaceae	Thalictrum sp.	035^{0}48´E, 08^{0}22´N
196	Solanaceae	Solanum nigrum	035^{0}48´E, 08^{0}22´N
197	Commelinaceae	Commelina foliacea	035^{0}48´E, 08^{0}22´N
198	Solanaceae	Solanum nigrum	035^{0}48´E, 08^{0}22´N
199	Moraceae	Anthiaris toxicaria	035^{0}48´E, 08^{0}22´N
200a	Rubiaceae	Canthium oligocarpum	035^{0}48´E, 08^{0}21´N
200b	Araceae	Ariseama schimeranum	035^{0}48´E, 08^{0}22´N
201	Amaranthaceae	Mimusops kummel	035^{0}48´E, 08^{0}22´N
202	Orchidaceae	Polystachya rivae	035^{0}48´E, 08^{0}22´N
203	Cactaceae	Rhipsalis baccifera	035^{0}48´E, 08^{0}22´N
204	Poaceae	Unidentified sp.	035^{0}48´E, 08^{0}22´N
205	Euphorbiaceae	Acalypha acrogyna	035^{0}48´E, 08^{0}22´N
206	Anacardiaceae	Rhus ruspoli	035^{0}48´E, 08^{0}22´N
207	Tiliaceae	Grewia ferruginea	035^{0}48´E, 08^{0}22´N
208	Celasteraceae	Genus3 sp.	035^{0}48´E, 08^{0}22´N
209	Celasteraceae	Hippocratea sp.	035^{0}48´E, 08^{0}22´N

Number	Family name	Scientific name	Location
210	Euphorbiaceae	Argomuellera macrophylla	035^{0}48´E, 08^{0}22´N
211	Rutaceae	Teclea noblis	035^{0}48´E, 08^{0}22´N
212	Orchidaceae	Habenaria peristyloides	035^{0}48´E, 08^{0}22´N
213	Rhamnaceae	Scutia myrtina	035^{0}48´E, 08^{0}22´N
214	Euphorbiaceae	Acalypha ornata	035^{0}48´E, 08^{0}22´N
215	Family3	Genus7 sp1.	035^{0}48´E, 08^{0}22´N
216	Amsryllidaceae	Scadoxus multiflorus	035^{0}54´E, 08^{0}22´N
217	Urticaceae	Urera hypselodendron	035^{0}54´E, 08^{0}22´N
218	Celasteraceae	Maytenus gracilipes	035^{0}54´E, 08^{0}22´N
219	Rhamnaceae	Gouania longispicata	035^{0}54´E, 08^{0}22´N
220	Amaranthaceae	Celosia trigyna	035^{0}54´E, 08^{0}22´N
221	Orchidaceae	Habenaria humilior	035^{0}48´E, 08^{0}22´N
222	Malvaceae	Sida collina	035^{0}50´E, 08^{0}22´N
223	Convolvulaceae	Ipomoea hochstetteri	035^{0}50´E, 08^{0}21´N
224	Vitaceae	Cissus quadrangularis	035^{0}50´E, 08^{0}22´N
225	Asteraceae	Vernonia amygdalina	035^{0}50´E, 08^{0}22´N
226	Piperaceae	Piper capense	035^{0}50´E, 08^{0}22´N
227	Flacourtiaceae	Flacourtia indica	035^{0}50´E, 08^{0}22´N
228	Family9	Genus15 sp.	035^{0}50´E, 08^{0}22´N
229	Araceae	Amorphophallus gallaensis	035^{0}54´E, 08^{0}22´N
230	Orchidaceae	Aerangis thomsonii	035^{0}54´E, 08^{0}22´N
231	Araceae	Arisaema flavum	035^{0}54´E, 08^{0}22´N
232	Rubiaceae	Pavetta sp.	035^{0}49´E, 08^{0}22´N
233	Celasteraceae	Genus9 sp.	036^{0}02´E, 08^{0}22´N
234	Acanthaceae	Unidentified sp.	036^{0}02´E, 08^{0}22´N
235	Family10	Genus16 sp.	036^{0}02´E, 08^{0}22´N
236	Amaranthaceae	Gompherena celosioides	036^{0}02´E, 08^{0}22´N
237	Amaranthaceae	Celosia trigyna	036^{0}02´E, 08^{0}22´N
238	Amaranthaceae	Unidentified sp.	036^{0}02´E, 08^{0}22´N
239	Orchidaceae	Bulbophyllum sandesonii	035^{0}48´E, 08^{0}22´N
240	Araceae	Culcasia falcifolia	035^{0}54´E, 08^{0}22´N
241	Ulmaceae	Celtis africana	035^{0}48´E, 08^{0}23´N
242	Polypodaceae	Drynaria sp.	035^{0}47´E, 08^{0}23´N
243	Lomariopsidaceae	Elaphoglossum lastii	035^{0}47´E, 08^{0}23´N
244	Aspleniaceae	Asplenium sandesonii	035^{0}47´E, 08^{0}23´N
245	Orchidaceae	Liparis abyssinica	035^{0}47´E, 08^{0}23´N
245	Orchidaceae	Nervilia bicarinata	035^{0}47´E, 08^{0}23´N
246	Orchidaceae	Liparis abyssinica	035^{0}47´E, 08^{0}23´N
247	Oleaceae	Chionanthus milds	036^{0}04´E, 08^{0}22´N
248	Rubiaceae	Galiniera coffeoides	035^{0}48´E, 08^{0}22´N
249	Euphorbiaceae	Bridelia micrantha	035^{0}48´E, 08^{0}22´N
250	Orchidaceae	Habenaria cornuta	035^{0}47´E, 08^{0}23´N

Number	Family name	Scientific name	Location
251	Euphorbiaceae	Unidentified sp.	035^{0}47´E, 08^{0}23´N
252	Ulmaceae	Celtis zenkeri	035^{0}48´E, 08^{0}22´N
253	Family11	Genus17 sp.	035^{0}48´E, 08^{0}22´N
254	Moraceae	Ficus sp.	035^{0}48´E, 08^{0}22´N
255	Euphorbiaceae	Unidentified sp.	035^{0}48´E, 08^{0}22´N
256	Celasteraceae	Maytenus gracilipes	035^{0}48´E, 08^{0}22´N
257a	Acanthaceae	Hypoestus forskaoli	035^{0}48´E, 08^{0}22´N
257a	Rubiaceae	Psychotria orophila	035^{0}48´E, 08^{0}22´N
258	Menispermaceae	Tiliachora troupinii	035^{0}54´E, 08^{0}22´N
259	Tiliaceae	Grewia ferruginea	035^{0}49´E, 08^{0}21´N
260	Costaceae	Costus afer	035^{0}54´E, 08^{0}22´N
261	Rubiaceae	Oxyanthus speciosus	035^{0}54´E, 08^{0}22´N
262	Family12	Genus18 sp.	035^{0}54´E, 08^{0}22´N
263	Piperaceae	Piperomia abyssinica	035^{0}54´E, 08^{0}22´N
264	Family13	Genus19 sp.	035^{0}54´E, 08^{0}22´N
265	Brassicaceae	Cardamine africana	035^{0}54´E, 08^{0}22´N
266	Rubiaceae	Pavetta abyssinica	035^{0}54´E, 08^{0}22´N
267	Phytolaccaceae	Hilleria latifolia	035^{0}48´E, 08^{0}22´N

ACKNOWLEDGEMENTS

I am very grateful to my supervisors Professor Wilhelm Barthlott, director at the Botanical Institute, and Professor Paul L.G. Vlek, director at ZEF, University of Bonn, for accepting me as student, and their continuous guidance during my study. Professor Vlek has also supported to secure the necessary funding for my study.

I would like to extend my heartfelt appreciation to my mentors Dr. Manfred Denich of ZEF, Dr. Thomas Borsch of the Botanical Institute, and Dr. Demel Teketay, Director General of EARO, for their close supervision of my research, and for visiting me during the fieldwork in Ethiopia. Constructive comments from Dr. Denich and Dr. Borsch on the draft dissertation were very helpful to improve it. I am especially thankful to Dr. Demel Teketay, who has continuously supported my work, beginning with inception of the research idea, research site selection, and a number of field visits during the progress of the research.

I would like to thank Ms. Margaret Jend for checking the English of this thesis, and Dr Günther Maske and Ms. Hanna Peters, for their support and excellent coordination at ZEF. I very much appreciate the assistance and friendship of Tewodros Tsegaye, Adefres Worku, Teshome Eshete, Shiferaw Alem, Yonas Yohannes and Dinka Amante during the fieldwork. I also would like to thank Dr. Eyilachew Zewdie for his help in soil sampling, Dr. Soojin Park of ZEF and Dr. Matthias Braun of Center for Remote Sensing on Land Applications (ZFL) for helpful discussions regarding GIS-related analysis, and Mr. Girma Taye of EARO for discussion on sampling design. Prof. Sebsebe Demissew, and Dr Ensermu Kelbessa of Addis Ababa University allowed me to use the facilities of the National Herbarium; Dr. Sileshi Nemomsa, Getachew Tesfaye, Feyera Senbeta, Dagne Duguma and Melaku Wondafrash helped in identification of the plant specimens.

I am very grateful for the support and friendship of the Ethiopian students and Families, especially Dr. Abay Asfaw and his family, Dawit Tesfaye and his family, Edilegnaw Wale, Kassahun Tesfaye, Mekuria Argaw and his family, Samson Kassahun, Tameru Alemu, Tsegaye Yilma and his family, for their hospitality and good friendship which made me feel home during my stay in Bonn. Many friends, both back home and overseas were encouraging and supporting me in different ways, especially Bekele Debele, Dejene Abdissa Merga, Dr. Tilahun Muleta, Fekadu Abrham, Jemal Ibrahim, and Worku Bedhane.

I am grateful to many of the colleagues at ZEF, who come from different parts of the world with different cultural backgrounds, for sharing their ideas and creating a good working atmosphere, just to name few of them: Bart Wickel (the Netherlands), Dr. Crammer Kayuki Kaizzi (Uganda), Daniel Tsegai (Eritrea), Lubica Paparcíková (Slovakia), Luna Bharati (Nepal), Dr. Maria Andrea De Macale (Philippines), Dr. Mercy Gichora (Kenya), Dr. Muhammad Mohsin Hafeez (Pakistan), Dr. Pooja Sawhney (India), Dr. Rahayu Widyastuti (Indonesia), Dr. Rolf Sommer (Germany), Roukayatou Zimmermann (Cameroon), Sanaa Ashour (Palestine) and Dr. Zhaohua Li (China).

I am very much indebted to my brothers Gedefa Woldemariam and Zenebe Kebede, and their families, especially Tsigie Adugna and Geremu Negat, for their hospitality, moral support and kindness at all times. I thank Kefyalew Adugna, Lijalem Asrat and their families, who supported me in all means they could. Many more friends and relatives have supported me in different ways during my study. I am, indeed, thankful for their support.

This research would not have been possible without my sponsors, the Catholic Academic Exchange Service (KAAD), the Center for Development Research (ZEF), the Gottlieb Daimler and Karl Benz Foundation, and the Ethiopian Agricultural Research Organization (EARO). I would like to thank them for their kind assistance both financially and in helping with materials and logistics. The Illubabor Zone and the Yayu District department of agriculture and the District administration were very collaborative to facilitate my fieldwork.