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Montane rainforest with wild *Coffea arabica* in the Bonga region (SW Ethiopia): plant diversity, wild coffee management and implications for conservation

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ABSTRACT

The montane rainforests of Ethiopia are the center of origin and genetic diversity of *Coffea arabica* L. (Rubiaceae). They form part of the Eastern Afromontane biodiversity hotspot due to the high threat of deforestation. Concepts for conservation of these forests and their wild coffee populations are urgently needed.

For the present study, vegetation surveys were carried out in four forest fragments in the Bonga region (southwestern Ethiopia) situated between 1,560 and 2,280 m asl. A total of 309 vascular plant species including 16 endemics were recorded; 36 % of the species occur in all forest fragments, while 43 % are present in one fragment only. Ordination methods reveal that plant species composition is strongly influenced by the altitudinal gradient. The forest fragment Koma, which is located above 1,800 m asl, is characterized by high pterophyte diversity and high abundance of Afromontane endemics or near endemics. Forest below 1,800 m asl has a greater diversity of tree species and pytogeographical elements, and is further divided in a moister type (Mankira forest fragment) and a drier type (Kayakela forest fragment).

Many species of the understory are frequent and abundant, so that the representative species number for a forest fragment can be captured with 10 study plots. In contrast, many tree species and epiphytes have low frequency, and the recording of their representative species number in a forest fragment requires 29 study plots.

Wild coffee grows throughout the forest until 2,050 m asl except for extremely shaded and humid sites. Growth rates are very low, in particular during the main rainy season from July until October. Most wild coffee populations are utilized by local farmers. Three use types can be differentiated: (1) Unmanaged wild coffee has very low density in the shaded understory of undisturbed forest. Yields (clean coffee) are below 5 kg ha^{-1} a^{-1}. (2) Forest coffee systems with low management intensity have an undisturbed forest structure, but some undergrowth vegetation is removed systematically. Abundance and size of coffee trees increase, and yields can reach 15 kg ha^{-1} a^{-1}. (3) In semi-forest coffee systems, management intensity is high and forest structure is disturbed. Most undergrowth vegetation besides coffee is cleared at least once a year and some canopy trees are cut. Removal of competing plants and increased light penetration stimulate wild coffee growth. Yields average 35 kg ha^{-1} a^{-1}.

Low management intensity in forest coffee systems does not modify natural species composition. Abundance and distribution of tree species in unmanaged forest and forest coffee systems are currently governed by natural dynamics, but increasing demand for wood is likely to cause over-exploitation of some highly valued secondary forest and climax tree species.

In semi-forest coffee systems, slashing of vegetation and related modification of forest microclimate have a strong impact on species composition and species population structures. Most mature individuals of woody species are coppiced, which favors species that regenerate well vegetatively. Species richness increases due to high numbers of ruderal herbs, climbers and pioneer species adapted to regeneration in disturbed sites. In contrast, the number and abundance of typical forest species that require shade and humidity decline. This is most pronounced regarding tree species.

This study makes suggestions for a conservation concept that combines both protection of the original plant diversity of Afromontane forest and profitable use of wild coffee.

Bergregenwald mit wildem *Coffea arabica* in der Bonga-Region (Südwestäthiopien): Pflanzendiversität, Wildkaffeebewirtschaftung und Konsequenzen für den Waldschutz

KURZFASSUNG

Die Bergregenwälder Äthiopiens sind das Mannigfaltikeitszentrum von *Coffea arabica* L. (Rubiaceae). Aufgrund ihrer starken Gefährdung durch Abholzung sind sie Teil des „Östlichen Afromontanen Biodiversitätshotspots“. Schutzkonzepte für diese Wälder und ihre wilden Kaffeepopulationen sind dringend notwendig.

Für die vorliegende Arbeit wurden in vier Waldfragmenten der Bongaregion (Südwestäthiopien) Vegetationsaufnahmen in Höhenlagen zwischen 1.560 und 2.280 m NN durchgeführt. 309 vaskuläre Pflanzenarten, davon 16 endemische Arten, wurden erhoben. 36 % der Arten kommen in allen Waldfragmenten vor, wohingegen 43 % nur in einem Fragment auftreten. Ordinationsmethoden machen deutlich, dass die Zusammensetzung der Pflanzenarten stark durch den Höhengradienten beinflußt wird. Das Waldfragment Koma, das oberhalb 1.800 m NN liegt, ist durch eine hohe Pterophytendiversität sowie eine hohe Abundanz endemischer oder fast-endemischer Arten der afromontanen Region geprägt. Unterhalb von 1.800 m NN gelegener Wald hat eine höhere Diversität an Baumarten und phytogeographischen Elementen, und ist weiter untergliedert in einen feuchteren Typ (Waldfragment Mankira) und einen trockeneren Typ (Waldfragment Kayakela).

Viele Arten des Unterwuchses haben hohe Frequenz und Abundanz, so dass die repräsentative Artenzahl für ein Waldfragment mit 10 Untersuchungsflächen erfasst werden kann. Dagegen haben viele Baumarten und Epiphyten eine lückenhafte Verbreitung, weshalb 29 Aufnahmeflächen für die Erfassung ihrer repräsentativen Artenzahl in einem Waldfragment benötigt werden.

Mit Ausnahme von extrem schattigen und feuchten Standorten wächst wilder Kaffee bis zu einer Höhe von 2.050 m NN überall im Wald. Seine Wachstumsraten sind sehr niedrig, insbesondere während der großen Regenzeit von Juli bis Oktober. Die meisten wilden Kaffeepopulationen werden von ortsansässigen Bauern genutzt. Drei Nutzungstypen können unterschieden werden: (1) Unbewirtschafteter Kaffee wächst mit sehr geringer Dichte im beschatteten Unterwuchs ungestörten Waldes. Erntemengen (Rohkaffee) liegen unter 5 kg ha^{-1} a^{-1}. (2) Waldkaffeesysteme mit niedriger Bewirtschaftungsintensität haben eine ungestörte Waldstruktur, ein Teil des Unterwuchses wird jedoch systematisch entfernt. Abundanz und Größe der Kaffeebäume nehmen zu, und Erntemengen können 15 kg ha^{-1} a^{-1} erreichen. (3) In Semi-Waldkaffeesystemen ist die Bewirtschaftungsintensität hoch, und die Waldstruktur ist gestört. Wenigstens einmal im Jahr wird der überwiegende Teil des Unterwuchses außer Kaffee entfernt, und einige Kronenbäume werden geschlagen. Das Entfernen von konkurrierenden Pflanzen und erhöhter Lichteinfall stimulieren das Kaffeewachstum. Durchschnittliche Erntemengen liegen bei 35 kg ha^{-1} a^{-1}.

Niedrige Bewirtschaftungsintensität in Waldkaffeesystemen verändert die natürliche Artenzusammensetzung nicht. Abundanz und Verbreitung von Baumarten im unbewirtschafteten Wald und in Waldkaffeesystemen werden derzeit von natürlichen Dynamiken bestimmt. Steigender Holzbedarf wird jedoch wahrscheinlich zur Übernutzung einiger stark gefragter Sekundärwald- und Klimaxbaumarten führen.

In Semi-Waldkaffeesystemen haben das intensive Entfernen von Vegetation und die damit verbundenen Veränderungen des Waldmikroklimas eine starke Auswirkung auf die Artenzusammensetzung und auf die Populationsstruktur einzelner Arten. Ausgewachsene Individuen holziger Arten werden zum großen Teil abgeschlagen, was Arten fördert, die sich gut durch Stockausschlag regenerieren. Das Artenreichtum erhöht sich aufgrund der hohen Anzahl von ruderalen Arten der Krautschicht, Lianen und Pionierarten, die an Regeneration in gestörten Flächen angepasst sind. Dagegen verringert sich die Anzahl und die Abundanz von typischen Waldarten, die Schatten und Feuchte benötigen. Dies zeigt sich am deutlichsten in Bezug auf Baumarten.

Die vorliegende Arbeit macht Vorschläge für ein Schutzkonzept, das den Schutz der ursprünglichen Pflanzendiversität afromontanen Waldes und die wirtschaftliche Nutzung von wildem Kaffee miteinander verbindet.

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1 INTRODUCTION

1.1 Background and problem statement

Ethiopia is the homeland and center of genetic diversity of Arabica coffee (*Coffea arabica* L., Rubiaceae) (Vavilov 1951). The original habitat of coffee is the shaded understory of montane rainforests in southwestern and southeastern Ethiopia between 1,000 and 2,000 m asl. Indigenous communities have been utilizing wild coffee for centuries, and the art of preparing coffee is a central part of the Ethiopian culture. Until today, Ethiopian coffee is mainly produced in traditional coffee production systems. This means wild coffee is simply picked inside the forest, or managed inside the forest by removing competing undergrowth vegetation and some canopy trees (Demel Teketay 1999).

Arabica coffee started its triumphal procession around the world from Ethiopia in the 10th century, when coffee plants were taken to Yemen by Persian invaders. Later, coffee beans were shipped to Europe from the famous port of Mocca. Linnaeus, ignorant of the true origin of the coffee plant, hence named it *Coffea arabica* L. (Richard 1847; Demel Teketay 1999). In the 17th and 18th century, European merchants introduced coffee to India, Java, and finally to Latin America (Demel Teketay 1999). Today, Arabica coffee is cultivated in over 70 countries and is one of the most important raw goods on the world market (DKV 2004). For many developing countries, coffee is the main source of foreign currency. Ethiopia is the seventh largest coffee producer worldwide and ranks ninth in coffee export (EEA 2001). Coffee is its most important export crop contributing decisively to the country's foreign currency income with 41 % (FAO and WFP 2006).

International coffee breeding currently aims at increasing coffee productivity and the plant's resistance towards pests and diseases. Furthermore, there is an international demand for coffee cultivars adapted to sub-optimal environmental conditions, e.g., to drought or cold (ZEF and EARO 2002). The genetic base of the world's coffee plantations is very narrow, though, because the spread of Arabica coffee around the globe was based on a small number of trees (Tewolde Berhan 1990; Demel Teketay 1999). Plantation coffee therefore has a limited potential for the breeding of new varieties (Meyer 1965; Hein and Gatzweiler in press).

Wild Ethiopian coffee populations can play a crucial part in international coffee breeding. Owing to natural selection processes in their original forest habitat, genetically diverse coffee varieties have developed, which vary, for example, in drought resistance, light requirements, disease tolerance, coffee bean size and taste (Hindorf et al. 2004; Kassahun

Tesfaye 2006; Taye Kufa 2006; Beining in prep.). These coffee genetic resources constitute a tremendously valuable asset to Ethiopia (Hein and Gatzweiler in press). The discovery of three naturally decaffeinated coffee varieties underlines this great potential (Coghlan 2004).

Genetic information from wild varieties of cultivated species is, however, being lost at an alarming rate, in particular for tropical crops like *Coffea arabica* (Lovejoy 1995; Hein and Gatzweiler in press). The kryo-conservation of coffee seeds in gene banks is not yet developed to a satisfactory level. Hence, the genetic diversity of wild coffee populations can only be conserved through *ex situ* conservation in field gene banks or *in situ* conservation in their natural environment. *In situ* conservation is the preferable solution, because it sustains the mechanisms of natural selection and adaptation to changing site and environmental conditions (Charrier and Berthaud 1990; Tewolde Berhan 1990; DFSC and IPGRI 2001b; Tadesse Woldemariam 2003; Meilleur and Hodgkin 2004).

In the past three decades, large parts of the Ethiopian forest areas with wild coffee have been modified or destroyed by new settlements, agricultural activities and timber extraction (Reusing 1998; Million Bekele 2002). The population pressure on the remaining forests continues to grow and will cause further deforestation and fragmentation. This destruction of the original habitat of *Coffea arabica* will eventually lead to the loss of the wild coffee genetic resources.

The Ethiopian rainforests have special conservation value not only because of the presence of wild coffee, but also because of high numbers of endemic species and high floristic diversity. This great biodiversity coupled with the extreme threat caused by habitat destruction makes them part of the Eastern Afromontane biodiversity hotspot (Gil et al. 2004).

Ethiopia thus faces the challenge to conserve its last montane rainforests and the wild coffee genetic resources in a densely populated area. The livelihoods of local communities heavily depend on forest resources, and wild coffee production is the main source of income (Tadesse Woldemariam 2003; Urich 2005; Stellmacher in prep.). Conservation concepts therefore need to integrate protection and traditional uses of the forests. They also have to create incentives for the local population to participate in conservation measures and should guarantee the fair and equitable sharing of the benefits from the use of genetic resources as postulated by the internationally ratified Convention on Biological Diversity (CBD 2005).

Such comprehensive conservation concepts require accurate knowledge on the ecological and socio-economic situation in the region of concern. For this reason, the

Ethiopian Institute of Agricultural Research (EIAR) in Addis Ababa, Ethiopia, and the Center for Development Research (ZEF) in Bonn, Germany, jointly initiated the interdisciplinary research project "Conservation and use of wild populations of *Coffea arabica* in the montane rainforests of Ethiopia (CoCE)" (CoCE 2006). The project is divided into six interdisciplinary sub-projects covering issues on forest diversity, genetics, ecophysiology, pathology, socio-economy and institutions. The present thesis is written within the sub-project on forest diversity.

1.2 Objectives

This study has the objective to investigate the impact of selected environmental parameters and coffee management on the Afromontane rainforest with wild coffee in the Bonga region (southwestern Ethiopia). The forest in the study region is highly fragmented and the forest patches differ in size, altitude and degree of coffee management intensity. The ultimate goal of the study is the identification of the forest areas that are most crucial for the protection of wild coffee as well as for the conservation of the original plant diversity of the region. To meet this goal, it is necessary:

(1) to study the distribution of wild coffee in relation to environmental factors, and to examine the impact of coffee management on forest structure and on the wild coffee populations (Chapter 5),
(2) to investigate the effects of environmental parameters and coffee management on plant species diversity, floristic composition and vegetation structure of the forest (Chapter 6), and
(3) to identify the influence of human activities on abundance and distribution of canopy tree species (Chapter 7).

The results are used to develop a conservation concept for the Bonga region (Chapter 8).

2 WILD *COFFEA ARABICA* IN SOUTHWESTERN ETHIOPIA

2.1 Ecological requirements of *Coffea arabica*

Coffea arabica L. (Rubiaceae) grows naturally as bush or small tree in the shaded understory of montane rainforests in southwestern and southeastern Ethiopia (Figure 2.1). It occurs at altitudes between 1,000 and 2,000 m asl with the most suitable range being 1,500 – 1,800 m asl. Coffee tolerates annual rainfall between 900 and 1,300 mm yr^{-1}, but most appropriate are conditions above 1,300 mm yr^{-1} with an optimum at 1,600 – 1,800 mm yr^{-1} (Alemayehu Mamo 1992). The optimum average annual temperature for coffee is 18 – 24 °C with contrasting seasons.

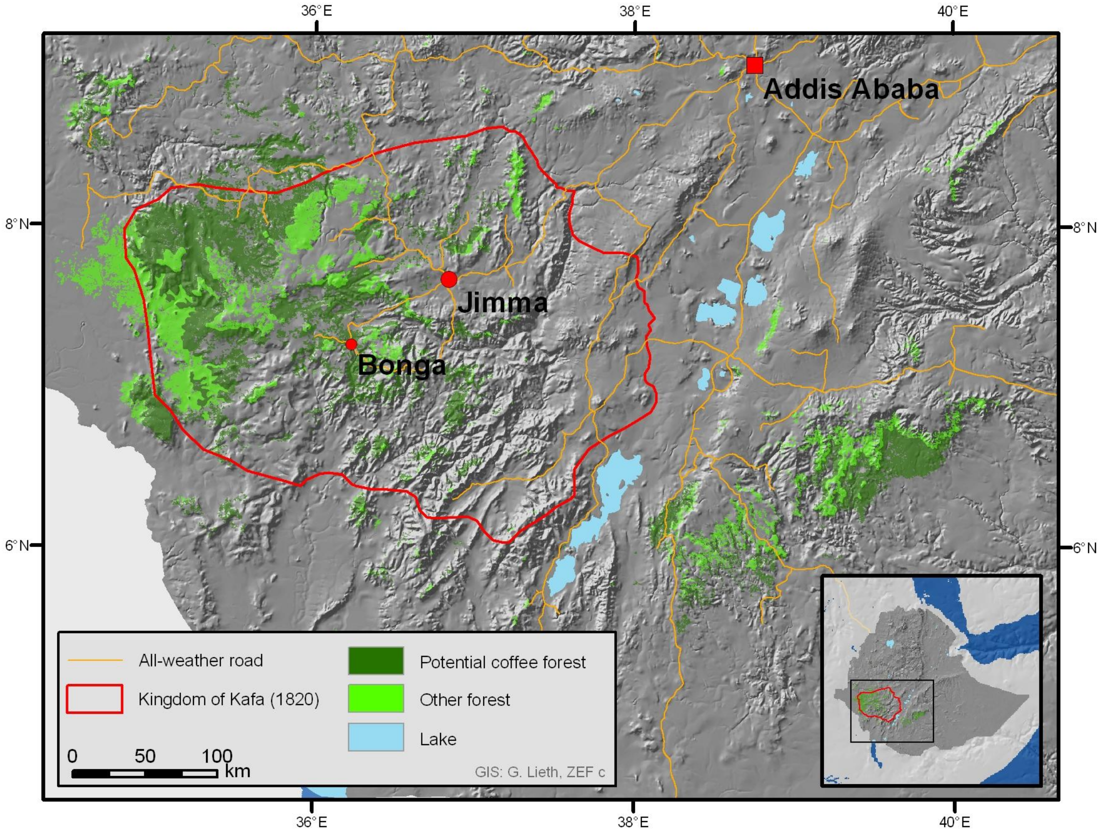

Figure 2.1 Forest cover in southwestern and southeastern Ethiopia with ecologically suitable areas for wild coffee growth (potential coffee forest) (Georg Lieth, unpubl. 2005) and the borders of the kingdom of Kafa in 1820 (Bieber 1923)

Coffee grown in plantations tolerates much wider altitude and rainfall ranges than coffee grown in its original habitat. Coffee plantations occur from sea level up to 2,800 m asl. Annual rainfall can be as low as 500 mm yr^{-1} if coffee is irrigated as, for example, in Harar (eastern Ethiopia) (Demel Teketay 1999).

Coffee grows on soils with varying acidity. Slightly acid soils, as present under montane forest in southwestern Ethiopia, are the most suitable (Krug and De Poerck 1968). Since coffee is an evergreen plant, it requires sub-soil water at all times. Thus, deep soils with good water-holding capacity are the most suitable environment for coffee growth. The soil structure must also allow good drainage because the surface feeding roots need a drier period for part of the year to slow down growth, ripen the wood and initiate flower buds (Demel Teketay 1999). In high rainfall areas such as southwestern Ethiopia, where the dry season is short and cloud cover is frequent, coffee grows successfully in shallow clay soils of 15 – 20 cm depth. Yields, however, can be remarkably reduced in years with excessive rainfall or an unusually long dry season (Alemayehu Mamo 1992).

Coffee is self-fertilizing, but fertilization by bees increases the yield substantially (Roubik 2002). Monkeys, birds and rodents relish the sweet pulp of ripe coffee fruits and disseminate the coffee seeds inside the forest (Sylvain 1955; Meyer 1968).

2.2 Traditional management and processing practices

Forest coffee is traditionally managed in forest coffee (FC) and semi-forest coffee (SFC) systems (Demel Teketay 1999). They constitute 14 % and 54 % of the total coffee production area in Ethiopia, respectively. In FC systems, only some competing undergrowth is removed. In SFC systems, most undergrowth is removed and some emergent trees are cut. In semi-forest plantations (17 % of the total coffee production area) farmers keep only few shade trees and plant additional coffee seedlings collected in adjacent areas as well as improved coffee varieties distributed by government extension workers and non-governmental organizations (NGOs). Home-garden coffee (9 %) and modern type plantations (6 %) only constitute small parts of the total coffee production area.

Coffee fruits consist of endosperm (beans) coated by testa (silverskin) and endocarp (parchment) surrounded by fleshy mesocarp (pulp). During wet coffee processing, the mesocarp is removed with water (pulping), and the remaining fruit is fermented and dried. Endocarp and testa are then removed mechanically (hulling) (Cannel 1983).

Traditionally, farmers harvest forest coffee by strip harvesting or by shaking trees and collecting the fruits from the ground. They thus obtain a mixture of ripe and immature fruits. These are dried on the soil or sometimes on mats (dry processing). Thereafter, pulp, parchment and silverskin are removed manually.

The quality of traditionally processed coffee beans is good enough for home consumption, but does not meet export standards. Foreign coffee experts have long complained that forest coffee should be harvested perfectly ripe, but not from the ground, should be mechanically pulped and hulled (wet processing), or dried on stools to avoid the smell of earth (Cecchi 1888; Branzanti 1942; Sylvain 1958; Fee 1961).

2.3 History of coffee production and trade in Kafa

Kingdom of Kafa

The ancient kingdom of Kafa is said to be the homeland of *Coffea arabica*. During its heyday in the 19th century, it comprised large parts of southwestern Ethiopia (Figure 2.1). The origins of the kingdom of Kafa can be traced back to the 14th century (Bieber 1920; Bieber 1923; Bahru Zewde 2002). Its history, though, is only poorly known, because the Kafa do not have a written language and travel reports by outsiders are scarce. In fact, the entry into southern Ethiopia, anytime from the beginning of the 17th century to the beginning of the 20th century was virtually impossible for Europeans (Meyer 1965). As a consequence, *Coffea arabica* growing concealed in the montane rainforests of Kafa kingdom was neither collected nor described from its place of origin until quite recently.

The Kafa kingdom was highly organized and closed its borders almost hermetically against the surrounding provinces of the Ethiopian empire. Its citizens and affiliated kingdoms had to pay taxes and tributes, such as ivory, civet oil, leopard skins, gold, musk, animal hides, honey and butter, which the king used in his external trade relations. For a long time, though, the most important items of export were slaves taken from tribes south of the kingdom (Assefa Gebremariam, pers. comm. 2005). In return, the king expected salt bars, glass, beads, cloth, ironware, and firearms.

The goods were transported along trade routes that had already been established during medieval times. Bonga, close to where the Kafa king had his residence, is considered as the starting point for trade routes to Massawa (Eritrea), Matamma (Sudan), Zeila and Berbera (Somalia) (Bahru Zewde 2002).

In the early Kafa kingdom, coffee was an important product for home consumption as well as for ceremonial and medicinal purposes. It was probably cultivated in home gardens and forest coffee systems (Beshir Abdella, pers. comm. 2004; Assefa Gebremariam, pers. comm. 2005). Even though coffee was only a minor trading commodity, slaves and merchants played an important role in disseminating the plant from Kafa to other provinces (Wrigley 1988; Berhanu Abebe 1998).

The trade activities of the Kafa kingdom reached their peak in the 19th century (Bahru Zewde 2002). Stimulated by international demand, coffee finally became a major product in the trade business in the second half of the 19th century (Berhanu Abebe 1998). In other parts of Ethiopia, e.g., Harar, coffee export goes back earlier than 1810.

One of the first scientific missions to southwestern Ethiopia carried out by a French team during the years 1839 – 1842 observed that *Coffea arabica* grew spontaneously throughout the whole Changalla region (i.e., southwestern Ethiopia) and was cultivated widely in the provinces of Énarrea (i.e., around the town of Jimma) and Caffa (Richard 1847). Most coffee from these provinces was taken to Massawa by caravans, shipped to Mokka and sold as Arabian coffee from there.

At the end of the 19th century, the Kafa kingdom was attacked by Emperor Menelik II and his allies. When Menelik II finally managed to overthrow the Kafa king after 12 years of war in 1897, the country was largely depopulated, because 60 % of the Kafa people had been killed or displaced (Bieber 1923; Strenge 1956; Meyer 1968). The wars of 1897 also eliminated the coffee trade and led to an abandonment of coffee cultivation (Di Fulvio and Chapman 1947).

Feudal Ethiopia

Under Menelik II (1889 - 1913), Kafa became a province of Ethiopia with Jimma as its administrative center. The emperor expropriated the Kafa nobility and distributed fertile land and forests to his own allies, mainly Amhara people. These feudal landlords had the right to impose taxes and to demand the workforce of the local peasants. In return, the landlords had the obligation to pay coffee as a tribute to the emperor. This obligation, coupled with a revival of the coffee trade business and the free workforce, led to an increase in coffee management. The feudal landlords established semi-forest coffee systems and transplanted coffee seedlings inside the forest as well as in home gardens (Assefa Gebremariam, pers. comm. 2005).

Transportation, however, made access to the international market difficult for the coffee producers of southwestern Ethiopia. Merchants needed 35 – 40 days to transport dried coffee on mule back to Addis Ababa (Southard 1918). In 1916, only 16 tons of coffee reached the international market via Addis Ababa and Djibouti. The establishment of a customs and trading station at Gambela was expected to clear the way for larger coffee exports from southern Ethiopia, which could be transported from Gambela via Khartoum to Port Sudan (Southard 1918). The route via Gambela did not gain any greater importance, though, because despite the low cost, it was apparently too long and dangerous (Spaletta 1917).

The building of the Addis Ababa - Djibouti railway in 1917 as well as the construction of the Jimma - Addis Ababa road in 1933 decreased transportation costs and contributed to the development of the coffee market. Starting from the 1920s, coffee exploitation became one of the main sources of income in the region. Even tenants who before collected coffee only for their landlords and for home consumption struggled for the right to trade coffee for their own profit on the market (Philippe 2003).

Jimma was the uncontested coffee trading center for exchanges between northern and southern Ethiopia as well as with the Arab world and Europe (Meyer 1965; Philippe 2003). While until 1923 almost all coffee exported from Ethiopia came from the Harar plateau, in 1933 the export of coffee derived from wild plants in southwestern Ethiopia reached the level of Harar coffee, and even overtook it in the later years up to the Italian war (Di Fulvio and Chapman 1947).

The coffee business attracted foreign merchants and investors to the southwestern of Ethiopia, e.g. Arabs, Armenians, Greeks, Italians, Swedish and Dutch, who were the first to establish small coffee plantations (van Doren, pers. comm. 2004). Modern coffee plantations were only established in the late 1950s (Krug and De Poerck 1968), for example in Agaro (Meyer 1965) and Wushwush (Fee 1961). At that time, 20,000 tons of forest coffee were harvested annually in Kafa, and especially Bonga was well known for its coffee production (Fee 1961). In the 1960s, Kafa contributed 27 % of the export coffee, i.e., more than any other province in Ethiopia (Krug and De Poerck 1968).

Since the Derg regime

In 1974, Emperor Haile Selassie was overthrown by the military, and the socialist-inspired Military Coordinating Committee known as the Derg assumed power. The Derg announced a land reform program, which destroyed the feudal system and proclaimed the nationalization of all the lands of Ethiopia. Peasant associations were put in charge of the land distribution (Philippe 2003). Foreign coffee plantations and coffee areas owned by feudal landlords were confiscated by the regime or redistributed amongst local peasants (Assefa Gebremariam, pers. comm. 2004).

Commercial coffee exploitation was one of the objectives of the new government. The peasant associations had the task to stimulate coffee production by disseminating modern management and marketing practices and by distributing seedlings of improved coffee varieties and fertilizer to farmers. In many parts of Kafa, however, farmers were not motivated or did not have the capacity to tend to the coffee plantations and semi-forest coffee systems as intensively as their former landlords. Thus, the general management intensity of forest coffee decreased (Assefa Gebremariam, pers. comm. 2004). This trend was emphasized by the decline in world coffee prices, which began in 1987. Paradoxically, at the same time, farmers started to be increasingly dependent on coffee economically, as it was becoming the major cash crop and the only income generating activity (Philippe 2003).

The Ethiopian Peoples Revolutionary Democratic Front (EPRDF) overthrew the Derg regime in 1991 and established a new administrative system in Ethiopia. The Kafa province was transformed into the Kafa zone within the Southern Nations National Peoples Regional State (SNNPRS). Governmental and non-governmental organizations (NGOs) continue to distribute improved coffee varieties and fertilizers to farmers in southwestern Ethiopia. Enthused by an increasing demand for wild coffee on the international market, in 2004 the Kafa Forest Coffee Farmers Cooperative Union gained the license to trade directly with foreign business partners. Farmers have thus profited from better prices and the intensity of forest coffee management is increasing again.

3 BIODIVERSITY AND ITS CONSERVATION

3.1 Biodiversity assessment

The term biological diversity, in short biodiversity, deals with the total variability of life on earth (Heywood 1995). As emphasized by the internationally ratified Convention on Biological Diversity (CBD), it includes genetic diversity, species diversity and diversity of ecosystems (CBD 2005).

The emerging of this broad biodiversity concept has contributed to the addressing of environmental issues in a holistic manner. The broad definition, however, has the shortcoming that the term biodiversity is often used casually and imprecisely (Vanclay 1998). One way to escape the vagueness associated with biodiversity is to pinpoint the components of biodiversity one is dealing with and to define measurable attributes or indicators for them (Noss 1990).

Biodiversity is more than simply the number of genes, species, ecosystems, or any other group of things in a defined area. It can be broken down into compositional, structural and functional attributes organized at multiple spatial and temporal scales. Ecological processes are crucial for ecosystem functioning and are thus an integral part of biodiversity, although they are as much biotic as abiotic (Noss 1990; CBD 2005). The three attributes of biodiversity, composition, structure and function, are intimately linked as Vogel (1972) put it aptly: “Structure without function is a corpse; function sans structure is a ghost” (cited in Ewel and Bigelow 1996).

In rainforests, vascular plants contribute most of the structure and biomass and are surely the single most fundamental rainforest component (Gentry 1992). In the following paragraphs, important methods for the evaluation of forest biodiversity regarding plant species composition, vegetation structure, and functional attributes are described:

(1) Floristic diversity is a compositional attribute of forest biodiversity. It refers to plant species richness, abundance, frequency, and distribution. Plant species diversity is often expressed in terms of diversity indices, initially derived from information theory, which combine species richness with a measure of evenness or relative abundance (Berger and Parker 1970; Hill 1973; Magurran 1988; Lande 1996; Smith and Wilson 1996; Vanclay 1998; Kent and Coker 2002; McCune and Grace 2002). The significance of these indices for biodiversity issues has been strongly questioned (Hurlbert 1971; Peet 1975; Noss 1990). The underlying assumption, for example, that species diversity as expressed by the Shannon index (H’), which was introduced to ecology as a stability index, is positively correlated with

ecosystem stability and functioning is far too simplistic (Walker 1992; Silver et al. 1995; Ewel and Bigelow 1996; Franc and Mai 1998; Lepš 2005). Within their limitations, though, diversity indices are demonstrative statistics for describing and comparing diversity (Magurran 1988; Vanclay 1998; Rennolls and Laumonier 2000).

Any attempt to explain patterns of floristic diversity needs to complement diversity indices with qualitative analyses that take into account actual species identities and their respective natures (Noss 1990; Ozinga et al. 2005). Ordination techniques help to identify relative continuities or discontinuities in species composition among sample stands without imposing the classification of discrete vegetation groups as done in vegetation classification (Mueller-Dombois and Ellenberg 1974). This is particularly useful for vegetation surveys that do not attempt the definition of plant communities, because little is known about the ecological requirements and distribution patterns of the studied plants.

(2) Vegetation structure is a structural attribute of forest biodiversity. It is the organization in space of the individuals that form a stand with growth form, stratification and coverage as primary elements (Dansereau 1957). Stratification can be done in terms of age classes, size classes or morphological attributes (Vanclay 1998). The qualitative analysis of structural biodiversity is possible with vegetation profiles (Dansereau 1958; Mueller-Dombois and Ellenberg 1974). At the landscape level, Dansereau's definition is extended to include the distribution pattern of forest patches (Noss 1990).

(3) Functional attributes of forest biodiversity constitute an important reference for the interpretation of floristic composition and vegetation structure. Knowledge on the life cycle and the ecological requirements of plant species, for example, helps to interpret distribution patterns and population structures. Vice versa, distribution patterns hint at underlying ecological processes such as seed dissemination, for example. Disturbance is the major trigger of vegetation dynamics, and has a crucial function in maintaining forest biodiversity (White and Pickett 1985; White and Jentsch 2001; Jentsch 2004; van der Maarel 2005).

3.2 Disturbance and tropical rainforest biodiversity

3.2.1 Definition of disturbance

"A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985).

This is a very broad definition reflecting the enormous variation in disturbance processes. The sources of variation include differences in ecosystem scale, differences in kinds of disturbances, and differences in disturbance regimes. The description of particular disturbance events thus requires a thorough specification of their temporal and spatial scales and the processes involved. The specification must also refer explicitly to the relevant community dimensions (White and Pickett 1985; Walker 1992; White and Jentsch 2001; Jentsch 2004; Pickett and Cadenasso 2005; van der Maarel 2005).

Disturbance is not defined here in a sense that is relative to the "normal" environment, because there are problems in defining "normal" for the environmental settings of natural systems, e.g., recurrent fire in boreal ecosystems. To underline that a disturbance event is indeed an explicitly defined departure from an explicitly defined normal state, behavior or trajectory, the term "perturbation" can be used (White and Pickett 1985).

Vegetation change after disturbance depends as much on the kind of disturbance as on the ecosystem itself. The ability of undisturbed vegetation or ecosystems to recover quickly from disturbance, i.e., to return to a pre-disturbance state, is called "resilience". The ability of undisturbed vegetation or ecosystems to resist disturbance is called "resistance" or "inertia" (Grime 1979; Lepš 2005).

The impact of human management activities on forest biodiversity depends on how different the disturbances caused by humans are from disturbances to which species have adapted over evolutionary time (Noss 1999). The felling of a tree, for example, is a disturbance event similar to the natural fall of senescent trees. A distinction can be made, however, between the immediate removal of the felled tree from the habitat, and the remaining of the fallen tree *in situ* (Grime 1979). Next to intensity, frequency of disturbance is an important aspect. While tree fall, for example, is an erratic event that allows for natural succession to take place, annual management activities and deforestation succeeded by agricultural activities impede natural succession.

3.2.2 Gap dynamics

Disturbance makes sites available by disrupting established vegetation, or by creating new surfaces (Pickett and Cadenasso 2005). Canopy openings in tropical forests, i.e., forest gaps (Runkle 1992), caused by different types of disturbance have a vital function in maintaining forest biodiversity. This was already realized by Aubréville in 1938 in his "mosaic theory of regeneration" (cited in Richards 1996).

The characteristics of a site following disturbance influence how plants can establish, grow and interact there. Even though the term forest gap was initially applied only to small gaps (< 0.05 ha) caused by the death of a canopy individual, it can also be extended to large canopy openings (> 3 ha) caused by hurricanes or fire (Runkle 1985; DFSC and IPGRI 2001a). According to their size, forest gaps vary in terms of soil disturbance, soil temperature fluctuations, vegetation cover, and light availability (Hubbell and Foster 1986; Vázquez-Yanes and Orozco-Segovia 1990; Grubb 1996; Turner 2001).

Plant species have developed different survival strategies to increase their competitiveness in this diverse environment, for example by the occupation of particular regeneration niches (sensu Grubb 1977). Based on certain characters such as reproduction, demography, growth, physiology, and degree of association with disturbance, tree species can be divided into pioneer, secondary forest and climax species. However, the pioneer-climax concept is to be regarded as a continuum, because any classification of species into distinct groups has to be done with more or less arbitrary break points (Grubb 1996; Turner 2001).

Pioneer species are light demanding. They are typically present in the early stages of vegetation succession in relatively large gaps. Pioneers show many characters typically associated with r-selection in plants (sensu MacArthur and Wilson 1967; Snow 1981; Brokaw 1985). Their seeds have specialized dormancy mechanisms, and this creates a soil seed bank in mature forest. Germination is cued to a disturbance indicator such as light or soil disturbance. Pioneers can be further divided into short-lived species that reach 20 - 50 years of age, and long-lived ones, also called late secondary forest species (Brokaw 1985; Vázquez-Yanes and Orozco-Segovia 1990; Turner 2001).

Climax tree species are adapted to regeneration in shaded, undisturbed forest parts. They show many characters typically associated with K-selection in plants (sensu MacArthur and Wilson 1967). Most climax tree seeds cannot be stored or dehydrated (Vázquez-Yanes and Orozco-Segovia 1990). Germination is regulated by soil moisture and air humidity, both being high under a closed canopy. The seedlings exist as suppressed juveniles in the comparatively noncompetitive understory, but show accelerated growth when a gap opens above (Brokaw 1985).

Thus, the creation of gaps through disturbance is as important for climax species as it is for pioneers. The important distinction to be made is gap size, because pioneers grow faster than climax species in large gaps, whereas climax species grow in gaps too small for pioneers (Brokaw 1985; Grubb 1996; DFSC and IPGRI 2001a). For large gaps, where regeneration is dominated by pioneer species, it takes longer for the forest to return to the pre-disturbance state than for small gaps.

3.2.3 Fragmentation

Large-scale disturbance such as forest conversion into agriculture results in the fragmentation of the originally continuous forest cover into isolated forest patches. Fragmentation has an important impact on forest biodiversity due to the reduction of habitat size, forest edge effects, reduced seed dissemination and higher-order effects (Turner and Corlett 1996; Debinski and Holt 2000; White and Jentsch 2001; Jentsch 2004; Murphy and Lovett-Doust 2004):

(1) Reduction of habitat size

Small forest fragments are only able to support small populations of most species, which are more likely to fluctuate to below demographic viability and to lose genetic diversity through genetic drift and in-breeding (Barrett and Kohn 1991; Bawa and Ashton 1991; Huenneke 1991; Menges 1991). Furthermore, forest fragments cannot comprise the same amount of habitat diversity as large forests. Species with particular ecological requirements, e.g., regarding regeneration, are therefore less likely to encounter sites suitable for establishment.

With decreasing forest fragment size, humans can easily access previously remote forest parts. Thus, intensity and frequency of human disturbance increase throughout small fragments and may lead to permanent changes in the natural species composition and structure of the forest.

(2) Forest edge effects

The internal microclimate near forest edges, particularly where they meet non-forest vegetation, is frequently hotter, drier and brighter than inside the forest (Turner and Corlett 1996; Murphy and Lovett-Doust 2004). These changes negatively affect typical forest species and can lead to increased tree mortality. Besides, the changes in microclimate enhance the invasion of pioneer, ruderal, and alien species that grow in open sites around forest fragments. If the fragments are small, invading species may eventually outcompete typical forest species. Additionally, increased predation of seeds at forest edges and in disturbed forest may lead to changes in tree species composition (Curran et al. 1999; Donoso et al. 2004).

(3) Reduced seed dissemination

Of the tropical woody forest species, 85 – 90 % require frugivorous mammals and birds for dissemination of their seeds (Howe 1990; Poulsen et al. 2002). Many rainforest animals, however, are reluctant to cross open areas or only have small action radii. This reduces the rate of immigration of individuals into isolated fragments, making re-establishment of extinct species unlikely and increasing the genetic isolation of fragmented populations. Also, within a small fragment, dispersal of seeds might be hampered because large fruit bats, fruit pigeons, and a wide range of other forest specialists survive only in the largest and most remote forest fragments (Turner and Corlett 1996; Corlett 2001).

(4) Higher-order effects

The loss of certain species within fragments may have knock-on effects on other species (Turner and Corlett 1996). The widespread decimation of seed dispersers by over-hunting or habitat degradation, for example, can have devastating long-term consequences on the plant species that depend on them (Howe 1990; Chapman and Oderdonk 1998; Loiselle and Blake 2002; McConkey and Drake 2002; Terborgh et al. 2002). Vice versa, the loss of “pivotal plant species” that bear fruits during annual periods of fruit scarcity will lead to the loss of the fruit-eating birds and mammals they maintain (Howe 1984).

3.3 Conservation of biodiversity

The initiation, implementation and operation of successful conservation programs require awareness of the basic elements of conservation: objective or principal target, management, and adequate support at local, national as well as international levels.

(1) Conservation objective

Any conservation program needs to clearly state the target of conservation (Frankel 1983; Groves et al. 2002). The objective “biodiversity conservation” is far too general, because biodiversity itself can be split up in numerous components that require different conservation strategies (see section 3.1).

In the 1990s, there was a shift from a species-based to an ecosystem-based approach in conservation (Franklin 1993; Poiani et al. 2000; Cowling et al. 2003). This approach puts an emphasis on maintaining ecosystem functioning and stability. It does not require the conservation of maximum species richness, which is also practically impossible in most cases, but aims to conserve viable populations of the species that are most representative for the ecosystem and crucial for ecosystem functioning. It also recognizes that long-term conservation of any particular biotope or species is only possible if the wider preconditions for persistence of the target are met, i.e., if the respective ecosystem is maintained (Frankel

1983; Magurran 1988; Noss 1990; Walker 1992; Lovejoy 1995; Silver et al. 1995; Ewel and Bigelow 1996; Chapman and Chapman 1999; Noss 1999; Chapman et al. 2002; Cowling et al. 2003).

Species with an important impact on the community or ecosystem are called “key stone” or “pivotal” species (Howe 1984; Caro and O'Doherty 1998; Newmark 2002). They are often used as surrogate species. The underlying assumption is that the protection of surrogates will contribute to the maintenance of ecosystem functioning and will automatically protect a large diversity of less conspicuous species. “Indicator species” are another type of surrogate species that help to track habitat destruction, population changes of other species, or pinpoint areas of high biodiversity (Pearson 1995). “Umbrella species” are species with large area requirements, for example. Their protection is assumed to protect a number of other species that depend on the same habitat. Furthermore, there are “flagship species”, which are popular, charismatic species that help to create conservation awareness and action (Noss 1999). The appropriateness of surrogate species in conservation schemes has to be thoroughly evaluated, however. It is crucial to know exactly which background species and ecosystem processes are protected if the surrogates are conserved (Caro and O'Doherty 1998; Spector and Forsyth 1998; Andelman and Fagan 2000).

Conservation also has to take a decision on size and location of reserve areas, because the complete spatial extent of an ecosystem can usually not be conserved (Franklin 1993; Noss 1999). The objective is the conservation of sites that represent the biological variation in a region (representativeness) and of sites that play a key role in maintaining certain species or ecosystem functions (irreplaceability). Usually, several sites are required to meet these objectives (complementarity) (Belbin 1995; Howard et al. 1998; van Jaarsfeld et al. 1998; Williams 1998).

Ultimately, conservation cannot be separated from sustainable development as was approved internationally at the Earth Summit in Rio de Janeiro in 1992. The Convention on Biological Diversity (CBD) is a key agreement of this summit and postulates three main goals, “the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources” (CBD 2005). The ecosystem approach, a comprehensive guideline for reaching the goals of the CBD, recognizes that humans, with their cultural diversity, are an integral component of ecosystems. Thus, the conservation and the sustainable use of ecosystems and their natural resources have to be two integral targets of any conservation project.

(2) Management

Management is a program and a procedure, executed or at least programmed in our time, with an impact intended to take effect on a measurable and predictable timescale (Frankel 1983). Each conservation project needs a management plan that clearly links the conservation objectives to defined management activities. Indicators have to be in place to measure the success of the management activities (monitoring) (Struhsaker 1990). Management plans should not be static, but should allow for continuous adaptations of the applied activities.

The conservation and sustainable use of ecosystems require that the protection area is broken down into area sub-sets with specific objectives and particular management activities, e.g., in core areas under strict protection and buffer zones with controlled utilization (Franklin 1993; Poiani et al. 2000; CBD 2005). Ideally, protected areas are linked with one another through corridors, which either remain under natural vegetation, or are managed to ensure that human land-uses are compatible with the maintenance of a high degree of biological connectivity. Socio-economic management aspects including, e.g., the involvement of local communities and other stakeholders as well as benefit sharing mechanisms, are as important as ecological ones.

(3) Support

The success of any conservation project depends on support from local communities directly affected by conservation activities, from governmental bodies in charge of implementation, and from international organizations often responsible for funding. These three levels mutually influence each other: local communities can appeal to organizations operating at the international level, while public attention at the international level can put pressure on national or local institutions. Root causes for the failure of conservation projects are often lack of capacity, poor co-ordination between agencies responsible for management of natural resources, and lack of awareness of the importance of biodiversity for local and regional economies (Struhsaker 1990; Cowling et al. 2003; Hayes and Ostrom 2005; Jacobs and Schloeder 2006).

Support is gained at the local level by involving all stakeholders in the planning process and by creating concrete incentives for individuals as well as communities to participate in the conservation measures (OECD 1997; Enters 1999). At the national level, the support of conservation projects is much more strongly motivated by political and economic issues than by the simple appreciation of biological diversity. Thus, economic benefits related to the conservation of genetic resources and political benefits related to increased international recognition through conservation projects are important. Public attention and financial support at the international level is most easily stimulated if the conservation project deals with internationally known ecosystems or flagship species (Caro and O'Doherty 1998; Noss 1999).

3.4 Biosphere reserves: a comprehensive conservation framework

International organizations and programs can constitute fundamental financial, logistic, technical, as well as idealistic support to conservation projects. Notable examples include the World Heritage Convention, the Ramsar Convention, the Critical Ecosystems Project (World Bank), the Global 200 Project (WWF), and the Parks in Peril initiative (The Nature Conservancy). The world network of biosphere reserves, established under the UNESCO Man and the Biosphere (MAB) Program is particularly well suited to reconcile conservation and sustainable use of ecosystems. The MAB program was launched at the Biosphere Conference in 1970 with the goal to enhance the sustainable use and conservation of biological diversity, and to improve the relationship between people and their environment globally, thus foreshadowing the CBD notion of sustainable development (UNESCO 2006). The three main functions of biosphere reserves are:

1. Conservation: contribute to the conservation of landscapes, ecosystems, species and genetic variation
2. Development: foster economic and human development, which is socio-culturally and ecologically sustainable
3. Logistic support: support for demonstration projects, environmental education and training, research and monitoring related to local, regional, national and global issues of conservation and sustainable development

The qualification of a conservation area for designation as a biosphere reserve depends on various factors. A biosphere reserve should:

(a) encompass a mosaic of ecological systems representative of a major biogeographic region, including a gradation of human intervention,
(b) be of significance for biological diversity conservation,
(c) provide an opportunity to explore and demonstrate approaches to sustainable development on a regional scale,
(d) have an appropriate size to serve the three functions of biosphere reserves,

(e) have an appropriate zoning system, with legally constituted core areas devoted to long-term protection, clearly identified buffer zones and an outer transition area, and

(f) provide organizational arrangements for the involvement and participation of a suitable range of *inter alia* public authorities, local communities and private interests in the design and the carrying out of the functions of a biosphere reserve.

Currently (June 2005), there are 482 biosphere reserves in 102 countries (UNESCO 2006). Out of these, 67 are located in Africa. In East Africa, there are five biosphere reserves in Kenya, three in Tanzania, one in Uganda, and one in Rwanda. Three of them cover the Afromontane vegetation type: Mount Kulal and Mount Kenya (Kenya) established in 1978, respectively, and East Usambara (Tanzania) established in 2000.

Biosphere reserves are international designations. For transparency and harmonization reasons, they should additionally be recorded under the protected area management categories developed by the IUCN World Commission on Protected Areas (WCPA). The IUCN scheme consists of six categories of protected areas, which are defined according to the main management objectives of the reserve (IUCN-WCPA and WCMC 1994):

I. Strict Nature Reserve/ Wilderness Area: wilderness protection
II. National Park: ecosystem protection and recreation
III. Natural Monument: conservation of specific natural features
IV. Habitat/ Species Management Area: conservation through management intervention
V. Protected Landscape/ Seascape: landscape/ seascape protection and recreation
VI. Managed Resource Protected Area: sustainable use of natural ecosystems

4 STUDY AREA AND SAMPLING DESIGN

4.1 Study area

4.1.1 Geographic location and topography

The Ethiopian highlands are separated into the northwestern and southwestern highland plateaus by the Great Rift Valley. The studied forests lie within the steeply dissected and rugged mountainous highlands west of the Great Rift Valley. They are located around the town of Bonga, the administrative center of the Kafa zone, Southern Nations Nationalities and Peoples Regional State (SNNPRS) (Figure 4.1). This zone is further divided into *woredas* (districts). The study area will be referred to as the Bonga region in a merely geographic sense, not to be confused with the administrative regions of Ethiopia. It comprises most of the Gimbo *woreda* and the north of the Decha *woreda*.

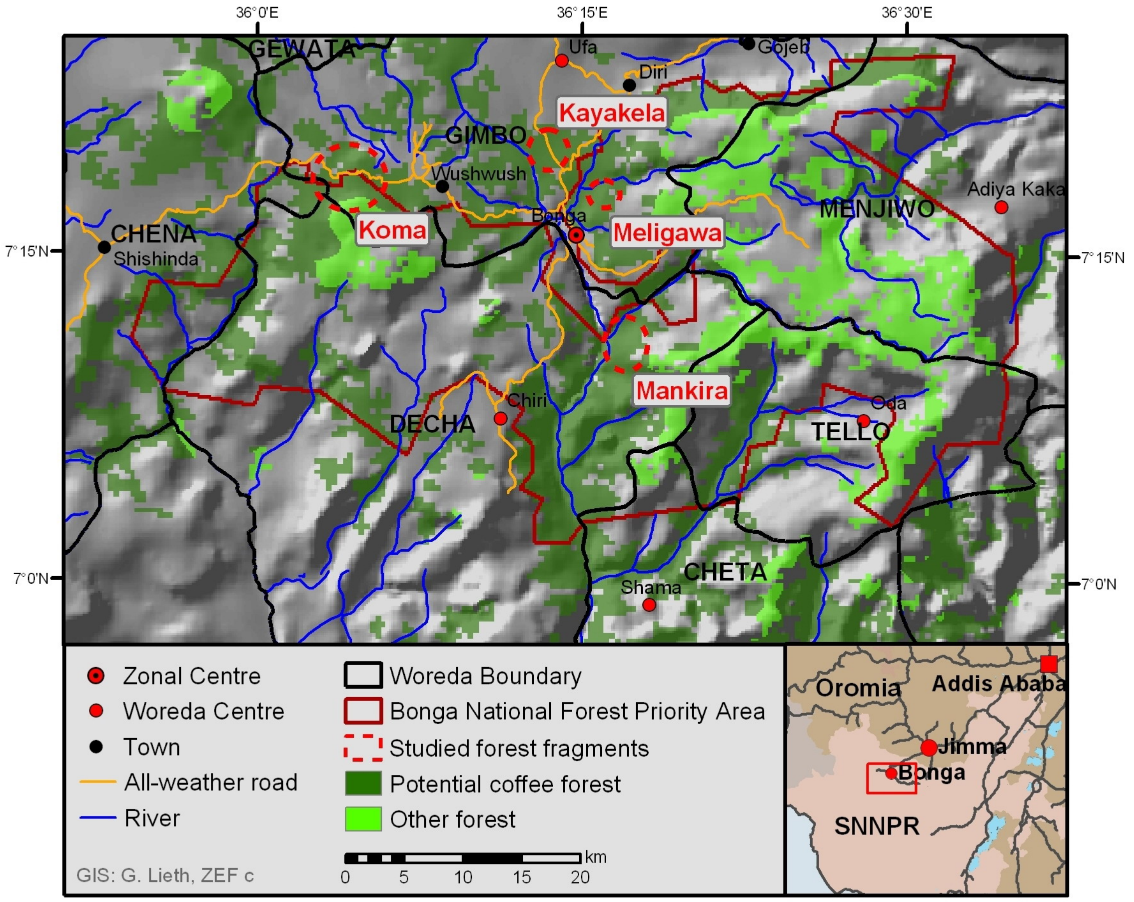

Figure 4.1 Location of the studied forest fragments in southwestern Ethiopia; potential coffee forest: ecologically suitable areas for wild coffee growth; other forest: forests above 2,000 m asl too high for wild coffee (Georg Lieth, unpubl. 2005)

The studied forest fragments, i.e., Koma, Kayakela, Meligawa and Mankira, are located at UTM 37 N 0792 000 – 0812 000; 0174 000 – 0202 000. Altitude varies from 1,450 – 2,370 m asl. The landscape is dissected by numerous small streams and has a highly diverse topography with flat plateaus, undulating to mountainous terrain and very steep slopes. Gojeb, Weshi, and Dincha are the main rivers in the region and belong to the Omo drainage system.

4.1.2 Geology and soils

In all of Ethiopia, pre-Cambrian rocks form a basement of extremely folded, metamorphosed sediments and igneous intrusions. It is overlain by Mesozoic rocks, mainly sandstone and limestone, and by Tertiary volcanic rocks, mainly basalts (Friis 1992).

The southwestern part of Ethiopia is characterized by a lithological succession of three different volcanites, i.e. Omo Basalts (Oligocene to Miocene), Jimma Volcanites (Oligocene to Miocene) and Wollega Basalts (Miocene to Pliocene). High rainfall up to more than 2,200 mm annually has had a masking effect on other soil-forming factors. Hence, very similar soils have developed on different parent materials (Tafesse Asres 1996).

Nitisols are the most dominant soils in southwestern Ethiopia, prevailing mainly in coffee and tea growing areas such as the Bonga region. Cambisols and regosols are also found. They have a tendency to occur on steep slopes such as escarpments and on undulating topography. Further soil types in southwestern Ethiopia are acrisols and vertisols (Bridges et al. 1998; Deckers et al. 1998; FAO et al. 1998).

4.1.3 Climate

The climate in Ethiopia is governed by the Inter-Tropical Convergence Zone (ITCZ), the humid southwestern monsoon and the dry northeastern trade winds (Liljequist 1986). This results in four seasons: dry season (December – February), small rainy season (March – May), main rainy season (June – August), and transitional period (September – December). Intensities and frequencies of rain are highly variable throughout Ethiopia depending on altitude and exposure of the area.

The Bonga region is humid and has a warm tropical rainy climate according to the Koeppen classification (Liljequist 1986). The rainfall is uni-modal with low rainfall from November to February and the wettest months between May and September. The coolest months are July and August in the middle of the main rainy season, while the hottest months are from February to May (Figure 4.2).

Climate data for the study region are provided by the meteorological stations of Bonga (7.13 °N, 36.17 °E; 1,725 m asl) and Wushwush (7.16 °N, 36.11 °E; 1,950 m asl) (Lemma Gonfa 1996). Precipitation data range from 1953 – 2001. Temperature data cover the years 1970 – 2001 for Bonga and 1954 – 1995 for Wushwush. The data have, however, been irregularly recorded and values are missing for several years. Data for 2004 are derived from measurements taken in Bonga (7.15 °N, 36.15 °E; 1,805 m asl) (Beining in prep.).

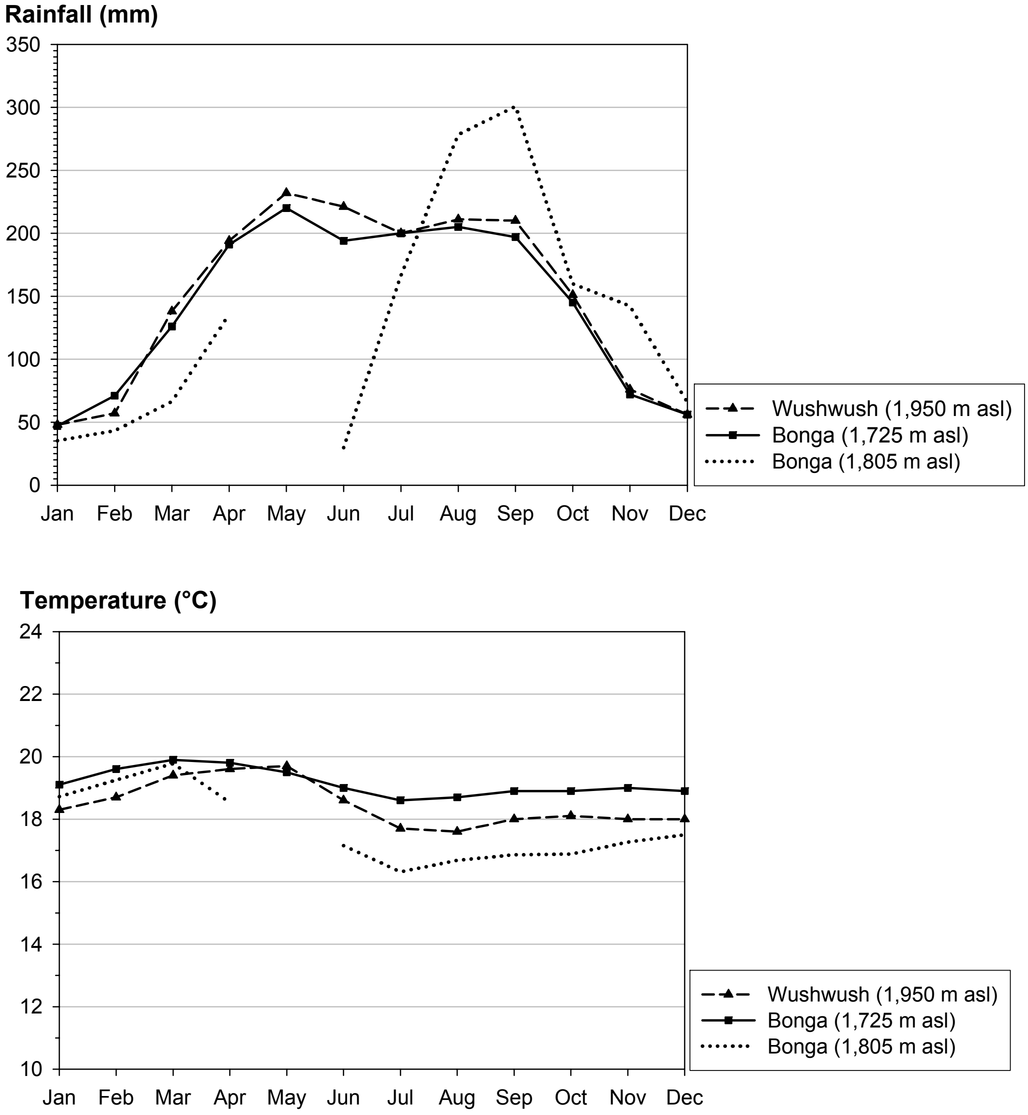

Figure 4.2 Annual rainfall (mm) and temperature (°C) distribution patterns at Wushwush (1,950 m asl) and Bonga (1,725 m asl) (source: Ethiopian Meteorological Service Agency 1953 – 2001); Bonga (1,805 m asl) represents data for the year 2004 (Beining in prep.)

The mean annual temperature at Bonga is 19.2 °C ranging from a mean annual minimum of 11.9 °C to a mean annual maximum of 26.4 °C. The mean annual rainfall is

1,723 mm yr^{-1} with high variations from year to year (1,259 – 2,569 mm yr^{-1}). In Wushwush, temperatures are slightly cooler and rainfall is slightly higher than in Bonga due to location at higher altitude. The mean annual temperature at Wushwush is 18.5 °C ranging from a mean annual minimum of 11.5 °C to a mean annual maximum of 25.5 °C. The mean annual rainfall is 1,794 mm yr^{-1} with variations from 1,356 – 2,445 mm yr^{-1}. In 2004, the main rainy season started quite late and rainfall was still exceptionally high in November. Additionally, the average monthly temperatures were quite low during that time.

Mean humidity in Bonga is 80 % as measured from July 2003 – June 2005 (Beining in prep.). Mean monthly humidity was lowest in February 2005 (61 %) and highest in June 2005 (89 %).

4.1.4 Forest vegetation

The forests in the Bonga region are classified as Afromontane rainforest (Friis 1992). White (1978) defined Afromontane vegetation as the "vegetation of the lower slopes of the highest mountains and the upper slopes of the lesser mountains in tropical Africa that is totally different from the surrounding lowlands". Lowland is referred to in a purely relative sense and can occur as high as 2,000 m asl.

The Afromontane region is an archipelago-like regional center of endemism. Its "islands" are very widely distributed on the African mainland and can be grouped into several regional mountain systems, e.g., Cameroon, South Africa, Tanzania and Ethiopia. Although many Afromontane species are local endemics, the majority, and especially the dominant species, are widely distributed within the Afromontane region (White 1981). The forests of Ethiopia are closely physiognomically and floristically related to the upland rainforests of Uganda and western Kenya, although they are floristically poorer (Friis et al. 1982).

In southwestern Ethiopia, Afromontane rainforests occur at altitudes between 1,500 and 2,600 m asl with mean temperatures of ca. 15 – 20 °C and mean annual rainfall between 700 and 1,500 mm yr^{-1}. In the Bonga region, where the average annual temperatures is 18 – 20 °C and the annual rainfall reaches more than 2,000 mm yr^{-1}, the warmer and wetter type of Afromontane forest is found (Friis 1992).

There are two other forest types described from southwestern Ethiopia, which occur at lower elevations and higher mean annual temperatures than in the Bonga region: dry peripheral semi-deciduous Guineo-Congolian forest at altitudes between 450 and 600 m asl, with mean annual temperatures of ca. 28 °C, and mean annual rainfall of 1,300 to 1,800 mm

yr^{-1}, and transitional rainforest between 500 and 1,500 m asl with mean annual temperatures of ca. 23 °C, and mean annual rainfall close to 2,000 mm yr^{-1} (Friis 1992).

The general classification of Ethiopian forest vegetation has been done on the basis of relatively detailed lists of woody plants that highlight important species but do not specify species quantities. The classification by Friis (1992) cited above is the most recent one. There are a number of earlier classifications as well as recent studies with more detailed analyses of forest types (Logan 1946; Pichi-Sermolli 1957; von Breitenbach 1963; Greenway 1973; Friis 1986; Lisanework Nigatu and Mesfin Tadesse 1989; Friis and Mesfin Tadesse 1990; Tafesse Asres 1996; Friis and Sebsebe Demissew 2001; Tadesse Woldemariam 2003; Feyera Senbeta 2006). In the Bonga region, few vegetation surveys have been carried out so far (Friis et al. 1982; Abayneh Derero 1998; Getachew Berhan 2001; Mateos Ersado 2001; Ensermu Kelbessa and Teshome Soromessa 2004).

4.1.5 Human population

The SNNPRS is the most ethnically and lingually diverse of all administrative regions in Ethiopia (Tafesse Asres 1996). The indigenous inhabitants of the Bonga region are the Kafa people, who are omotic language speakers. In the past, the Kafa society has been characterized by a highly rigid and complex class system, based on occupation, descent and status. The Manja, who make up between 5 and 10 % of the total population, are the largest minority class, which still faces prejudices and discrimination (Gezahegn Petros 1996; van Halteren 1996).

With a peak in the mid 1980s, there has been governmentally introduced and spontaneous resettlement of peoples from northern and central to southwestern Ethiopia (Million Bekele 2002). In the Bonga region, Amhara, Oromo and Gawata constitute the largest groups of new settlers (Stellmacher in prep.).

Bonga town is the administrative center of the Kafa zone and the major town in the area with 16,278 inhabitants (CSA 2002). Ufa (1,000 inhabitants) and Chiri (1,655 inhabitants) are the administrative centers of Gimbo and Decha *woreda*, respectively (Figure 4.1). The largest part of the population lives in hamlets or small villages in the countryside. In 2002, the average population densities of the Gimbo and Decha *woreda* were 103 and 33 inhabitants per km^2, respectively (CSA 2002).

4.1.6 Land-use types and land tenure

The Bonga region, i.e., the Gimbo *woreda* and the northern part of the Decha *woreda*, consists of a mosaic of different land-use types (Table 4.1). The south of Decha is dominated by woodland and inhabited by nomadic people.

Table 4.1 Land-use type distribution in the Gimbo and the Decha *woreda* (Kafa zone) (Bech et al. 2004)

		Land-use type (%)						
Woreda	**Size (ha)**	**Agri-culture**	**Undistur-bed forest**	**Distur-bed forest**	**Planta-tion**	**Grass-/ shrubland**	**Wet-land**	**Built-up area**
Gimbo	87,187	41.7	26.4	13.2	3.6	8.4	6.0	0.8
Decha	297,440	19.3	10.1	8.4	0.0	61.3	0.9	0.0

NB: undisturbed forest: > 90 % cover; disturbed forest: 50-90 % cover; plantation: Eucalyptus, Juniperus, tea, and coffee investment area

There is no industry in the Bonga region. A tea plantation (3,936 ha) and several small coffee investment areas (10 – 500 ha) are the main opportunities for employment (Bech et al. 2004). The major occupation in the Bonga region is agriculture, though people also engage in homestead animal husbandry. The main agricultural crops are ensete (*Ensete ventricosum*), maize (*Zea mays*), and tef (*Eragrostis tef*).

Non-timber forest products (NTFPs) such as honey, false cardamom (*Aframomum corrorima*) and wild pepper (*Piper capense*) are important means of income, in particular for the indigenous Kafa population. Furthermore, the forests are a source for fuel wood, charcoal, and timber (Million Bekele 2002; Ensermu Kelbessa and Teshome Soromessa 2004). Coffee collected and managed inside the forest and planted in home gardens is the most important cash crop (Tafesse Asres 1996; Urich 2005). In 2003/04, the Kafa Forest Coffee Farmers Cooperative Union marketed 131 tons of coffee from forest coffee and semi-forest coffee systems with the Gimbo and the Decha *woreda* contributing 50 % and 30 %, respectively (Kafa Union 2004).

The government is the sole owner of land in Ethiopia. Farmers have use rights that can be revoked from the government at any time. In most parts of southwestern Ethiopia, the average land holding per family is between 1.25 and 2.0 ha (Tafesse Asres 1996). In the Bonga region, it may vary between 0.8 and 2.5 ha. Forest is considered *de jure* as a common good even though *de facto* the Kafa communities have complex traditional systems of forest-use rights (Urich 2005; Stellmacher in prep.).

Most forest in the Bonga region is part of the Bonga National Forest Priority Area (NFPA) (Figure 4.1). It was first demarcated in 1985 and further expanded in 2002 (Million

Bekele 2002; MoA 2002). NFPAs were established by the Ethiopian government as an attempt to stop forest degradation and the conversion of forest into agricultural land. The control of NFPAs has been very weak, however, related to financial short-comings and to unresolved matters of competence between the administrative regions and the national state (Reusing 2000; Bech et al. 2004; Stellmacher in prep.). A new Proclamation on Forest Development and Conservation is currently being reviewed by the Ethiopian Council of Ministers (Tadesse Woldemariam pers. comm. 2006).

4.2 Sampling design

4.2.1 Location of plots

After preliminary inspection of most forest fragments in the Bonga region, four fragments were selected for this study (Figure 4.1). They all contain areas of unmanaged forest with wild coffee as well as managed forest areas with semi-forest coffee (SFC) systems. Altitude varies between 1,560 and 2,280 m asl. The fragments are between 5 and 30 km apart and are separated by patches of disturbed and undisturbed forest, fields, grassland and villages. Three fragments, namely Koma, Meligawa and Mankira, are located within the Bonga National Forest Priority Area (NFPA).

The number of study plots each measuring 20 m x 20 m within a forest fragment varies according to the size of the fragment (Table 4.2). In total, 85 plots were studied. If possible, plots were located every 300 m along transects, which were spaced 1 km apart. Otherwise, plots were placed subjectively in order to capture a representative variety of altitudinal ranges and different management intensities (Figure 5.7). Kayakela comprises four plots from a pilot survey located 4 km south of the fragment, which fall into the same altitudinal range and have vegetation similar to study plots in Kayakela.

Table 4.2 Geography of the studied forest fragments, number of plots and study period

Forest fragment	**Koma**	**Kayakela**	**Meligawa**	**Mankira**
Woreda	Gimbo	Gimbo	Gimbo	Decha
Size (ha)	1,700	700	600	1,100
Number of study plots	34	22	12	17
Altitude range of plots (m asl)	1,830 – 2,280	1,610 – 1,750	1,710 – 1,920	1,560 – 1,810
Study period	May 03 – March 04	March 04	June 04	January 05

4.2.2 Vegetation survey

In each plot, all vascular plant species were identified. Species that could not be identified in the field were pressed and taken to the National Herbarium of Ethiopia at the Addis Ababa University, and in the case of some selected specimens, to the Herbarium of the Royal Botanic Gardens, Kew (UK). Identification was done according to the Flora of Ethiopia and Eritrea (Hedberg and Edwards 1989; Edwards et al. 1995; Edwards et al. 1997; Edwards et al. 2000; Hedberg et al. 2003), the Flora of Tropical East Africa, in particular ferns (Verdcourt 2001a; Verdcourt 2001b; Verdcourt 2002a; Verdcourt 2002b), and according to reference specimens at the herbaria in Addis Ababa and Kew.

Herbs, grasses, ferns and fern-allies were recorded with presence-absence data. Ground layer species and epiphytes, as visually observed from the ground, were listed separately. In this study, epiphytes are defined as ferns, fern-allies or herbs that grow predominantly on woody plants. Woody plants that start their life cycle as epiphytes are listed with trees or woody climbers.

For woody plants and climbers, height was measured for individuals with height $\geq$ 0.5 m, and diameter at breast height (dbh) was recorded if dbh $\geq$ 2 cm. Woody plant and climber species were assigned to five different growth forms (Mueller-Dombois and Ellenberg 1974; Jacobs 1981; Ewel and Bigelow 1996). The designation was done according to own observations in the field, and according to species descriptions in the Flora of Ethiopia and Eritrea and at the National Herbarium of Ethiopia.

Shrub:	Woody plant having several stems arising from the base and lacking a single trunk; shrubs are usually less than 5 m tall, even though few individuals fall into the height class 5 - 15 m
Small tree:	Woody plant with a single trunk that reaches a maximum height of 15 m; three *Dracaena* species and one tree fern (*Cyathea manniana*) are included in this group
Tree:	Woody plant with one main trunk and rather distinct and elevated head that grows larger than 15 m; one palm (*Phoenix reclinata*) is included in this group
Woody climber:	Climbing plant with woody stem; synonym: liana
Herbaceous climber:	Climbing plant without woody stem

Six vegetation profiles covering a length of 50 m each, and their respective projection transects were drawn in different forest parts. Projection transects were 7 m wide;

for the vegetation profiles the first 2 m of the projection area were considered. The position of plants (> 0.5 m) along the vegetation profile, their diameter, height, crown shape and crown mass were estimated visually.

4.2.3 Site factors

The following site factors were recorded for all 85 study plots:

- estimation of the percentage cover of four vegetation layers: ground layer (< 0.5 m), shrub layer (0.5 – 5 m), lower canopy (5 – 15 m), upper canopy (> 15 m),
- altitude (m asl) with GPS 72 (Garmin),
- slope inclination (%) with clinometer (Silva),
- exposition with compass (Silva),
- number of coppiced woody plants including tree stumps, and
- moss index.

Exposition data were assigned into four classes: 1 = NW – NE; 2 = NE – SE; 3 = NW – SW; 4 = SW – SE (Figure 4.3). The higher the exposition class, the sunnier and warmer, and thus drier the study plot.

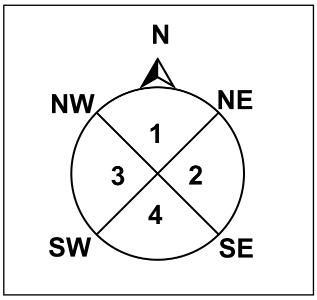

Figure 4.3 Classification of exposition data

Coppiced woody plants are a sign for human management activities in the forest. Hence, the higher the number of coppiced plants, the higher the intensity of human management inside a study plot.

The moss index is used as an indicator of humidity, since the direct measurement of humidity would not have been feasible. Mosses are suitable indicators of humidity, because dense moss layers on trees as well as abundant moss festoons are usually observed in highly shaded and humid forest parts (Jacobs 1981; Taylor 1999). Moss festoons are mosses that hang down from branches reaching lengths of at least 5 cm up to 20 cm and more in the Bonga region. Identification of moss species was not possible, but based on visual inspection the same species were present throughout the forest.

The moss index for each study plot was calculated from an estimation of:

- percentage of woody plants (dbh $\geq$ 2 cm) inside the plot covered with moss (<u>%-trees</u>),
- percentage of moss cover on trunks and branches of these plants (<u>%-trunk cover</u>), and
- percentage of these plants with moss festoons (<u>%-festoons</u>).

$$\text{Moss index} = \left[\frac{(\%\text{-trees})*(\%\text{-trunk cover})}{100}\right] + \left[\frac{(\%\text{-trees})*(\%\text{-festoons})}{100}\right] / 2$$

Composite soil samples were taken at a depth of 0 – 20 cm from 37 of the 85 study plots. Soil was sampled from the four corners and the middle of each plot and subsequently mixed. The samples were dried and analyzed by the Analytical Services Laboratories of the International Livestock Research Institute in Addis Ababa (Ethiopia). The following analyses were carried out according to standard procedures (Landon 1984; AG Boden 1994):

- pH (H_2O): 1:2.5, potentiometric method,
- pH (KCl): 1 M KCl, potentiometric method,
- organic matter (OM) (%): titrimetric determination after Walkley and Black,
- total N (%): Kjeltec method,
- available P (ppm): Bray II method, and
- exchangeable K (meq 100 g^{-1}): ammonium acetate method.

Additionally, 6 representative soil profiles for the study region were described.

5 WILD COFFEE PRODUCTION SYSTEMS AND WILD COFFEE ECOLOGY

5.1 Introduction

Wild Arabica coffee (*Coffea arabica*) has recently become a buzzword on the international coffee specialty market. Little is known, however, about the actual abundance and distribution of wild coffee in its indigenous habitat. Southard (1918) was impressed by "great forests of the wild coffee, which have not yet been touched". Subsequently, researchers have questioned whether wild coffee exists at all, because centuries of human activities in the forests of southwestern Ethiopia might have strongly modified the natural occurrence of so-called wild coffee populations (Cifferi 1940; Sylvain 1955; Strenge 1956; Meyer 1965; Meyer 1968). Until today, an official and internationally recognized definition of wild coffee does not exist.

Reams of studies have been published on the ecological requirements of coffee, coffee growth performance and coffee yields in plantations worldwide, but wild coffee in its natural habitat has hardly received any attention (Tewolde Berhan 1986; Alemayehu Mamo 1992; Tadesse Woldemariam 2003; Feyera Senbeta 2006). Most descriptions of coffee phenology and growth patterns in Ethiopian rainforests stem from early coffee researchers (Branzanti 1942; Strenge 1956; Sylvain 1958; Meyer 1965; Meyer 1968). Sketchy characterizations of wild coffee management systems exist, but systematic studies on performance and yield of coffee in these systems are lacking (Demel Teketay 1999). Furthermore, conservation planning for the last Ethiopian rainforests with wild coffee requires good knowledge on the actual impact of wild coffee management on coffee populations and forest vegetation.

This chapter, therefore, has the objective

- to characterize wild coffee management systems in terms of forest structure, coffee population structure and coffee yields,
- to monitor growth and regeneration of wild coffee in managed and unmanaged forest,
- to identify soil and environmental factors that influence the distribution and abundance of wild coffee,
- to develop a definition of wild coffee, and
- to draw conclusions for its conservation.

5.2 Material and methods

5.2.1 Data set

Coffea arabica populations, soil and environmental factors were surveyed in 85 study plots each measuring 20 m x 20 m in four forest fragments in the Bonga region. The location of the study plots and the studied site factors are described in detail in section 4.2.

5.2.2 Survey of coffee populations

Coffea arabica is classified as a small tree. Height was measured for coffee individuals $\geq$ 0.5 m, and diameter at breast height (dbh) was recorded if dbh $\geq$ 2 cm. Additionally, butterfly seedlings and seedlings up to 10 cm height were counted in each study plot. Butterfly seedlings are coffee seedlings with two cotyledons, but still without leaves.

Estimation of coffee yield

The number of fruits per coffee tree was counted in the study plots, which were surveyed during the ripening period of coffee (June – December). In some of these plots, the yield per coffee tree was only estimated: low yield = ca. 30 fruits per tree; high yield = ca. 200 fruits per tree. Additional fruit counts were carried out in two 10 m x 10 m plots and four 50 m x 7 m plots.

For calculation of the weight conversion rate from fresh fruits to dried beans (clean coffee), 20 coffee fruits from four different plots were weighed, pulped, dried, hulled and weighed again.

Regeneration and growth rate

Regeneration and growth of coffee populations were monitored in six study plots in the Koma forest fragment. The plots were located in forest areas representative for different coffee management types. Five of the plots measured 5 m x 5 m. For one plot, size was reduced to 2.5 m x 5 m due to very high coffee density.

Within each plot, butterfly seedlings were counted. All other coffee individuals were tagged. Dbh $\geq$ 1 cm and height were measured for the first time in December 2003. Counting and measuring were carried out at 8-week intervals until January 2005. Butterfly seedlings that developed leaves during that period of time received additional tags and were included in the monitoring activities.

Two further sites were selected for seedling monitoring in the Koma forest. At each site, 35 butterfly seedlings were labeled in December 2003. Subsequently, butterfly seedling height was measured, and leaves and cotyledons counted every month from January 2004 until January 2005.

5.2.3 Data analysis

Statistical analyses were carried out with SPSS for Windows, version 13.0. The following tests were computed: multivariate ANOVA (mANOVA), univariate ANOVA and one-way ANOVA with Bonferroni test (post hoc) for quantitative data, and Kruskal-Wallis test for ranked data. Spearman's rho (r_S), suitable for parametric and non-parametric data, was used as correlation coefficient. Box plots and scatter plots were created with Sigma plot for Windows, version 7.0.

5.3 Results and discussion

5.3.1 Soil and environmental properties

Environmental factors and soil properties differ considerably between the four forest fragments. Koma is located above 1,830 m asl, whereas Kayakela and Mankira are situated below that altitude (Table 5.1). Meligawa has an intermediate position. The moss index, which is an indicator of humidity, is significantly higher in Koma and Mankira than in Meligawa. Slope inclination is highly variable in all fragments.

Table 5.1 Differences in environmental factors between the four studied forest fragments

	Koma (34 plots)			**Kaya (22 plots)**			**Meli (12 plots)**			**Mank (17 plots)**			**Sign.**
	Ave.	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**Ave.**	**Min.**	**Max.**	**diff.**[1]
Altitude (m asl)	**1,942**	1,830	2,280	**1,691**	1,610	1,750	**1,817**	1,710	1,920	**1,665**	1,560	1,810	1>3 >2,4
Moss index (%)	**37.5**	4.5	82.5	**32.2**	0	77.9	**13.4**	0	40.6	**50.4**	12.5	90	1,4 >3
Slope (%)	**24.4**	0	55	**16.6**	0	40	**23.2**	5	60	**18**	0	40	-

[1] *Significant difference at level 0.05 as determined by the Bonferroni test (one-way ANOVA): 1 = Koma, 2 = Kayakela (Kaya), 3 = Meligawa (Meli), 4 = Mankira (Mank)*

The pH (H_2O) is low to medium in all four fragments and lies between 4.08 and 6.3 (Table 5.2). In all fragments, organic matter (OM) contents are high, and C/N values are mostly below 10, which is typical for tropical soils (Landon 1984). Total N and exchangeable K are medium to high. It has to be taken into account, though, that plant availability of N and K strongly depends on pH, and can be impeded at pH values lower than 5. Available P is low in all fragments and may be a limiting factor for plant growth.

The range of values in this soil analysis corresponds with previous soil analyses in southwestern Ethiopia (Alemayehu Mamo 1992; Quinkenstein 2004). Although the values for most soil parameters are significantly lower in Koma than in Mankira, these differences are probably too small to cause practically relevant variations in nutritional status between the forest soils in these two fragments.

Table 5.2 Differences in soil parameters between the four studied forest fragments

	Koma (16 plots)			**Kaya (6 plots)**			**Meli (5 plots)**			**Mank (10 plots)**			**Sign.**
	Ave.	**Min**	**Max**	**Ave.**	**Min**	**Max**	**Ave.**	**Min**	**Max**	**Ave.**	**Min**	**Max**	**diff.[1]**
pH (H_2O)	5.1	4.21	5.91	5.4	5.02	5.74	5.3	4.08	5.89	5.5	4.58	6.3	-
	low (low-medium)			low (low-medium)			low (low-medium)			medium (low-med.)			
pH (KCl)	4.3	3.49	4.87	4.6	4.04	4.99	4.8	3.7	5.32	4.9	3.98	5.48	1<4
OM (%)	6.28	3.61	9.92	7.09	4.75	8.76	8.29	5.38	11.93	8.37	6.69	10.56	1<4
	high (medium-high)			high (medium-high)			high (high-very high)			high (high-very high)			
Total N (%)	0.42	0.31	0.6	0.43	0.3	051	0.45	0.34	0.6	0.52	0.43	0.68	1<4
	medium (med.-high)			medium (med.-high)			medium (med.-high)			high (medium-high)			
C/N	8.8	5.1	10.3	9.5	7.9	10.5	10.5	9.2	11.5	9.3	8.8	10.0	1<3
Avail. P (ppm)	1.08	0.31	2.22	2.91	0.95	5.38	4.97	1.5	8.44	1.63	0.54	3.18	1<2,3 3>4
	low			low			low			low			
Exch. K (meq/100g)	0.5	0.16	0.95	1.21	0.48	2.2	0.96	0.31	1.87	1.21	0.35	2.09	1<2,4
	medium (low-high)			high (medium-high)			high (medium-high)			high (medium-high)			

[1] Significant difference at level 0.05 as determined by the Bonferroni test (one-way ANOVA): 1 = Koma, 2 = Kayakela (Kaya), 3 = Meligawa (Meli), 4 = Mankira (Mank)
Classification of values (low to very high) (Landon 1984; AG Boden 1994)

Random sampling by soil auger indicated that parent material and soil types are similar throughout the whole study region. Six soil pits, representing typical variations in soil type were dug in Koma. They were classified as: nitisols (rhodic or haplic) with effective soil depth > 150 cm, cambisols (ferric or humic) with effective soil depth up to 90 cm, and regosols (dystric) with effective soil depth up to 50 cm.

Water tables were not observed in any of the soil pits. All soil types are well drained and highly permeable with seasonal run-off. They are clayey throughout the horizon and therefore have good water-holding capacity. Organic matter content, biological activity and amount of roots are highest in the A_h (average depth 0 - 27 cm), but quickly decline with increasing soil depth. Throughout the Bonga region, the parent material is colluvial (sedimentary) material containing Fe. Hence, the chemical properties of the soils are rather similar. Older (deep) and younger (shallow) soils occur close together. Erosion of topsoil from slopes through landslides in the prehistoric past presumably created the relatively young regosols.

The soils in the Bonga region are ideal for coffee growing, because they are rich in humus, are well drained, and have good water-holding capacity (Fee 1961; Demel Teketay 1999). In fact, Ethiopian coffee forest soils are similar to the best soils on which Arabica coffee is cultivated in other parts of the world, i.e., deep red to brown red, lateritic loams or clay loams of volcanic origin with high or medium fertility, and with pH values ranging from 5.3 to 6.6 (Krug and De Poerck 1968). The pH values of soils in the Bonga region are at the lower end of this range (Table 5.2). This corresponds to the fact that coffee favors slightly acid soils in Ethiopia (Demel Teketay 1999) and grows well on soils with pH between 4.37 and 6.78 (Alemayehu Mamo 1992).

Summary

- Forest soils in the Bonga region are generally suitable for coffee growing, and there are only minor differences in soil properties between the four studied forest fragments.

5.3.2 Levels of forest disturbance

The Bonga region is a mosaic of forest, farmland and small villages, which are often situated at forest edges. Local communities use the forest as forage area for cattle, for the collection of non-timber forest products (NTFPs), the collection of fire wood, the cutting of large trees, poles and lianas for house, furniture and beehive construction, and the cutting of buttress roots for plough construction. They also remove vegetation to increase the productivity of wild coffee (coffee management).

Intensive coffee management and cutting of large trees are usually carried out at the forest edges and along small footpaths criss-crossing the forest. Less intensive coffee management, cutting of poles and putting up of beehives, for example, are done throughout the whole forest. In fact, signs of human activities are visible even in the most remote parts of the studied forest fragments.

Owing to these human activities, the forest is a patchwork of areas with primary and secondary floristic composition and vegetation structure. Natural events such as the fall of senescent trees also contribute to a heterogeneous forest aspect. Transitions between old-growth forest and disrupted forest parts are often indistinct. Besides, it is often not possible to tell whether forest modification was caused by natural or anthropogenic events. In this study, the differentiation between disturbed and undisturbed forest is done according to the pattern of forest vegetation structure at the time of the vegetation survey.

Old-growth forest has dense upper and lower canopies. Due to shady conditions in the understory, the shrub layer is not well developed, and the ground layer usually has less than 50 % cover. In some cases, however, there is either a dense shrub layer or a dense ground layer: Dense shrub layers, composed of *Justicia schimperiana*, *Dracaena afromontana*, *Dracaena fragrans*, or *Phoenix reclinata* completely shade the ground or produce a large amount of litter, so that the ground layer is hardly developed. In contrast, if the shrub layer is very open, the percentage cover of the ground layer can be high.

In disturbed forest, however, both shrub and ground layer are well developed due to increased light penetration as compared to old-growth forest. This is caused by the fall or felling of trees of the upper and lower canopies. In intensively managed coffee forests, coffee forms a dense but tall (3 – 5 m high) shrub layer, which only moderately shades the forest floor and also allows for the development of a dense ground cover.

Based on the vegetation surveys carried out in the Bonga region, disturbed forest is defined as forest where the sum of the percentage cover estimate of shrub and ground layer (cover index) is equal to or larger than 105. The two main causes of forest disturbance, tree fall and intensive coffee management, can have relatively similar disturbance intensities, but tree fall is a localized, infrequent event whereas coffee management occurs annually on a larger spatial scale (Table 5.3).

Table 5.3 Main causes of forest disturbance

Descriptor	**Tree fall**	**Intensive coffee management**
Ecological dimension	population, community	population, community
Spatial scale	< 0.05 ha	0.05 – 2 ha
Time needed to return to pre-disturbance state	1 – 100 years	1 – 100 years
Frequency	once in 10 – 100 years	annually
Intensity	disruption of vegetation structure; selective removal of woody vegetation if human caused	disruption of vegetation structure and selective removal of woody vegetation

The vegetation profiles and projection transects illustrate the differences in the pattern of the vegetation structure in disturbed and undisturbed forest (Figure 5.1, Figure 5.2). Both cover a length of 50 m with projection transects having a width of 7 m and vegetation profiles considering the first 2 m of the projection area. Figures signify plant species in both profiles and transects, and different lines and symbols are used to indicate the size of plants in the transects (Table 5.4). In the profiles, coffee plants are indicated by the green color. Ferns, epiphytes and mosses are drawn too large considering the scale applied.

Table 5.4 Plant species and plant size in the six vegetation profiles and projection transects (see Figures 5.1 – 5.6)

Figures in vegetation profiles and projection transects refer to the following plant species:

No.	Species	No.	Species	No.	Species
1	*Coffea arabica*: green color in profiles	18	*Erythrococca trichogyne*	35	*Maytenus gracilipes*
		19	*Clausena anisata*	36	*Teclea nobilis*
2	*Dracaena fragrans*	20	*Vepris dainellii*	37	*Pavetta abyssinica*
3	*Rothmannia urcelliformis*	21	*Schefflera abyssinica*	38	*Fagaropsis angolensis*
4	*Milletia ferruginea*	22	*Celtis africana*	39	*Vernonia ssp*
5	*Prunus africana*	23	*Bersama abyssinica*	40	*Ficus sur*
6	*Olea welwitschii*	24	*Polyscias fulva*	41	*Deinbollia kilimandscharica*
7	*Trichilia dregeana*	25	*Ekebergia capensis*	42	*Elaeodendron buchananii*
8	*Ficus thonningii*	26	*Lepidotrichilia volkensii*	43	*Psychotria orophila*
9	*Embelia schimperi*	27	*Albizia ssp*	44	*Allophylus abyssinicus*
10	*Acacia brevispica*	28	*Canthium oligocarpum*	45	*Euphorbia ampliphylla*
11	*Landolphia buchananii*	29	*Piper capense*	46	*Oxyanthus speciosus*
12	*Galineria saxifraga*	30	*Aframomum corrorima*	47	*Trilepisium madagascariense*
13	*Dracaena afromontana*	31	*Croton macrostachys*	48	*Phyllanthus limmuensis*
14	*Chionanthus mildbraedii*	32	*Ehretia cymosa*	49	*Dracaena steudneri*
15	*Phoenix reclinata*	33	*Sapium ellipticum*	50	*Pouteria adolfi-friederici*
16	*Rytigynia neglecta*	34	*Syzygium guineense*	51	*Justicia schimperiana*
17	*Maytenus arbutifolia*	^{d}	dead (profile)	^{c}	coppiced (profile)

Illustration of plant size in projection transects:

Height (m)	Illustration
0.5 – 5 (shrub layer):	simple figure; *Coffea arabica*: crown diameter < 1 m = dot; crown diameter > 1 m = asterix
5 – 15 (lower canopy):	figure underlined; crown cover = simple line
> 15 m (upper canopy):	trunk and crown diameters = bold lines if trunk outside transect: crown diameter = bold dotted line

In undisturbed forest, upper canopy (height: > 15 m) and lower canopy (height: 5 – 15 m) almost completely shade the understory (Figure 5.1). As a consequence, the shrub layer (height: 0.5 – 5 m) is patchy besides some parts with dense *Justicia schimperiana* (51). The ground layer receives very little light and consists of only a few fern individuals. Due to the shaded environment, tree trunks have a dense moss and fern cover.

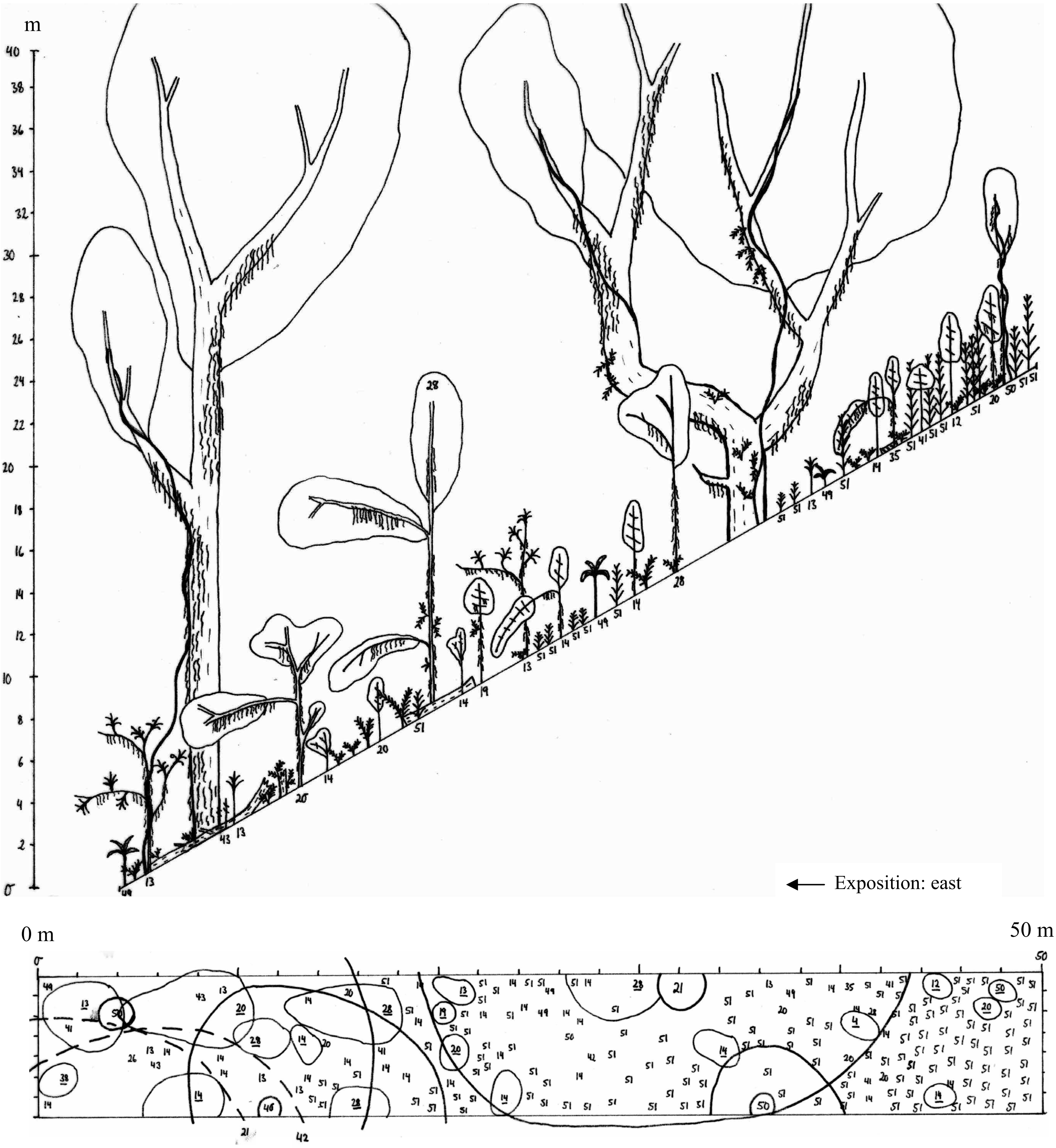

Figure 5.1 Undisturbed forest without wild coffee; for further explanation see text and Table 5.4

The transect through disturbed and undisturbed forest underlines the differences in vegetation structure between these two forest types (Figure 5.2). The undisturbed forest on the left side of the transect is characterized by dense upper and lower canopy, patchy shrub layer and little ground cover. In contrast, the disturbed forest on the right side of the transect has reduced canopy cover, dense shrub layer (dominated by coffee) and dense ground cover. In this case, the disturbed forest structure is caused by annual coffee management.

Figure 5.2 Transect through disturbed and undisturbed forest with wild coffee; coffee plants are indiated by the green color; for further explanation see text and Table 5.4

Summary

- In this study, disturbed forest is defined as forest with cover index $\geq$ 105;
  cover index (CI) = percentage cover (shrub layer) + percentage cover (ground layer)

5.3.3 Characterization of wild coffee management systems

The forest in the Bonga region is classified into five management types according to degree of disturbance and abundance of coffee as observed in the respective study plots (Table 5.5).

Table 5.5 Wild coffee management types: no management (NM), forest coffee (FC) system, and semi-forest coffee (SFC) system types 1 and 2; density refers to number of individuals per study plot

	NM / un-disturbed	**NM / disturbed**	**FC**	**SFC 1**	**SFC 2**
No. of representative study plots	29	9	24	13	10
Management category (Wiersum 1997)	uncontrolled utilization		controlled utilization	purposeful regeneration	
Coffee management intensity	zero	zero	low	high	high
Forest structure[1]	undisturbed	disturbed	undisturbed	disturbed	disturbed
Average density of coppiced plants	4	11	8	12	31
% of coffee individuals[2]	< 20	< 20	> 20	> 50	< 50
Average density of small coffee trees ($\geq$ 0.5 m, dbh $\leq$ 3 cm)	31	57	335	1106	215
Average density of large coffee trees (> 1.5 m, dbh > 3 cm)	1	3	6	24	17
Average density of coffee seedlings (< 0.1 m)	49	84	338	843	295
Planting of coffee seedlings	no	no	no	possibly	possibly

[1] *undisturbed: cover index < 105; disturbed: cover index $\geq$ 105 (see section 5.3.2)*

[2] *[number (coffee individuals $\geq$ 0.5 m)/ number (all plant individuals $\geq$ 0.5 m)] * 100 per plot*

(1) No management / undisturbed

This is unmanaged forest with an undisturbed forest structure. The understory is deeply shaded and consists mostly of shrub and small tree species that are more competitive than coffee under these conditions. Coffee density is very low, and the individuals are sparsely distributed in the undergrowth (Table 5.5). They are spindly and produce few fruits. Due to the low number of mother trees and due to low productivity, there are only few seedlings. In some forest parts, there are no mature mother trees at all, and seedlings stem from seeds dispersed by birds or mammals. If the forest is extremely shaded and humid, no coffee individuals are observed (Figure 5.1).

Local farmers sometimes remove woody plants from these forest parts, but there are no regular coffee management activities. They collect green and red coffee fruits at the same time because the cherries ripen asynchronously in the shaded forest, yields are low, and the walking distance from the villages is usually large. Some remote coffee trees are not visited annually, but on a more arbitrary basis.

This management intensity is the very first step in the domestication process of wild trees. It is classified as "uncontrolled utilization" if the coffee fruits are only collected casually or as "controlled utilization" if the collection is more or less systematic. In both cases, though, there is no transformation of the natural vegetation composition and structure, and propagules are only incidentally dispersed (Wiersum 1997).

(2) No management / disturbed

This is forest with disturbed vegetation structure and low coffee density. The disturbance is caused by natural fall of trees or by people who remove poles and trunks to meet their needs for wood and timber, but there is no explicit coffee management. The coffee individuals have the same physiognomy as in unmanaged and undisturbed forest, and their yields are also low. The fruits are picked by farmers on a casual basis.

(3) Forest coffee system

This is forest with low coffee management intensity. Local farmers remove some shrubs and small trees that compete with coffee, but the overall vegetation structure remains undisturbed. As result of the management, coffee trees have more space and are less shaded. The density of coffee individuals as well as the number of large coffee trees is therefore higher than in the unmanaged forest types (Table 5.5, Figure 5.3). Coffee yields also increase (compare section 5.3.4).

Local farmers visit forest coffee (FC) systems at least once a year to remove competing undergrowth vegetation and systematically collect coffee fruits. The FC systems are considered as owned by individual farmers according to traditional land-use perceptions (Stellmacher in prep.). Thieving occurs, however, and therefore farmers prefer to harvest early, i.e., even green fruits, in order to be ahead of thieves.

The production of coffee in FC systems is classified as "controlled utilization" involving systematic collection and the limited transformation of forest structure to reduce competing vegetation (Wiersum 1997).

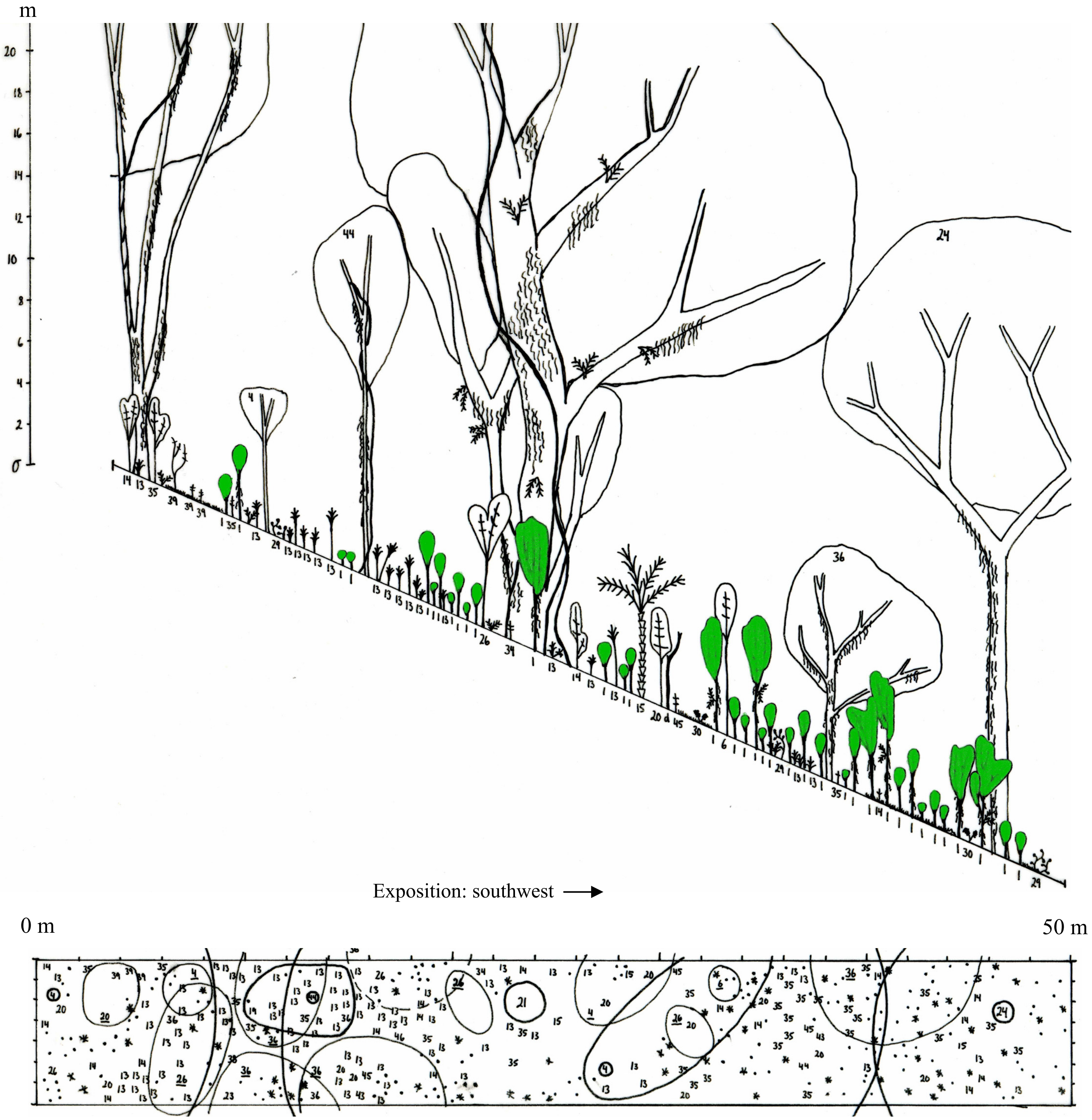

Figure 5.3 Forest coffee system with undisturbed forest structure: closed upper and lower canopies; patchy shrub layer dominated by coffee, but few large coffee trees; ground layer is not well developed; relatively dense moss and fern cover on trees; coffee plants are indiated by the green color; for further explanation see text and Table 5.4

(4) Semi-forest coffee system, type 1

In semi-forest coffee (SFC) systems type 1, farmers remove some of the canopy trees and most of the undergrowth vegetation that competes with coffee (Figure 5.4). As a result, coffee density is extremely high and coffee constitutes more than 50 % of all plant individuals per plot (Table 5.5). The numbers of small and large coffee trees as well as seedlings are much higher in SFC systems type 1 than in the other management types.

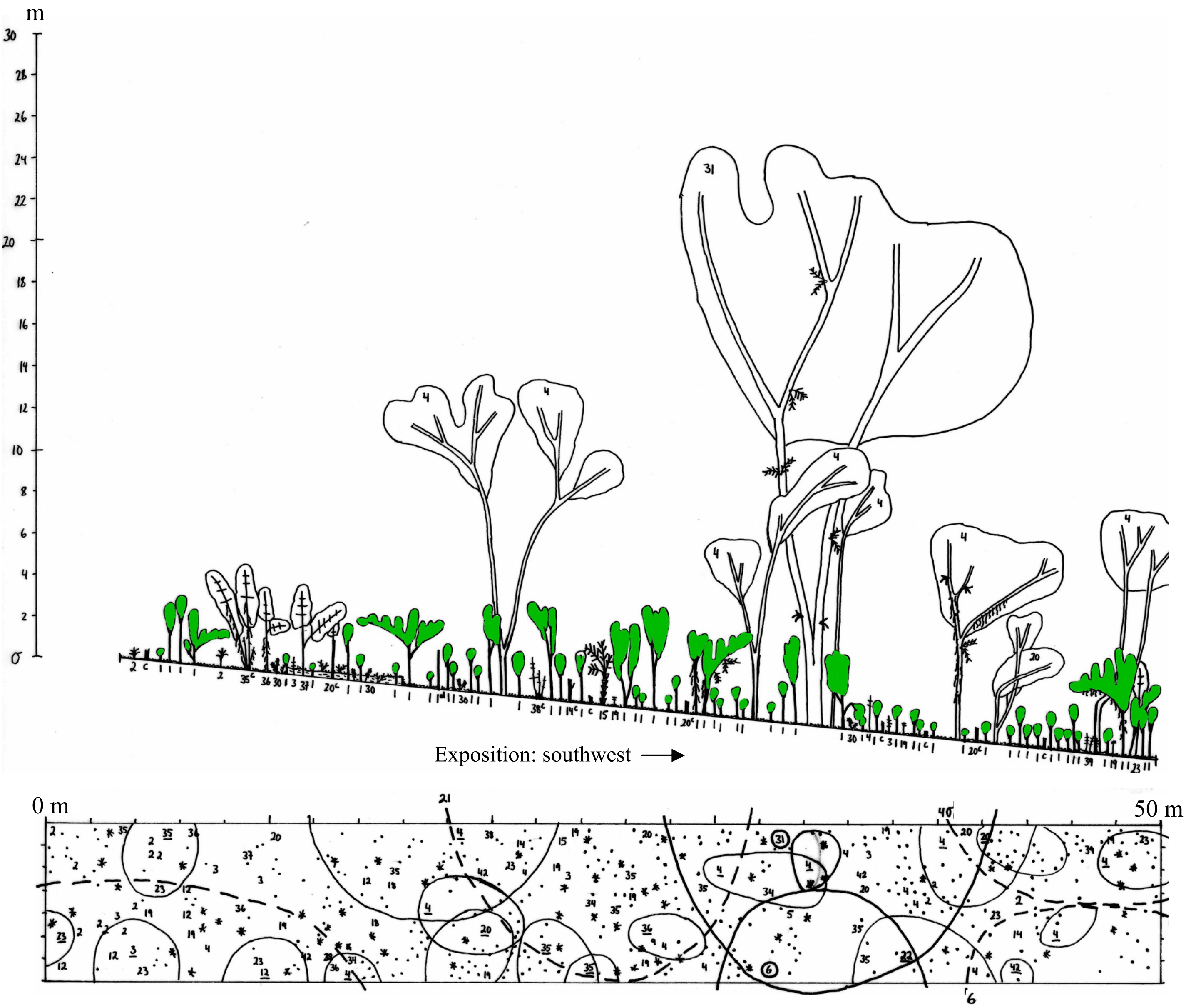

Figure 5.4 Semi-forest coffee system type 1 with disturbed forest structure: upper and lower canopies are reduced; dense shrub layer dominated by large coffee trees; ground is densely covered by herbs and grasses; moss and fern cover on trees is low; coffee plants are indiated by the green color; for further explanation see text and Table 5.4

(5) Semi forest coffee system, type 2

In SFC systems type 2, farmers not only remove some canopy trees and competing undergrowth, but also reduce coffee density. The forest understory, therefore, is very open and the shrub layer consists of few but large coffee trees (Figure 5.5).

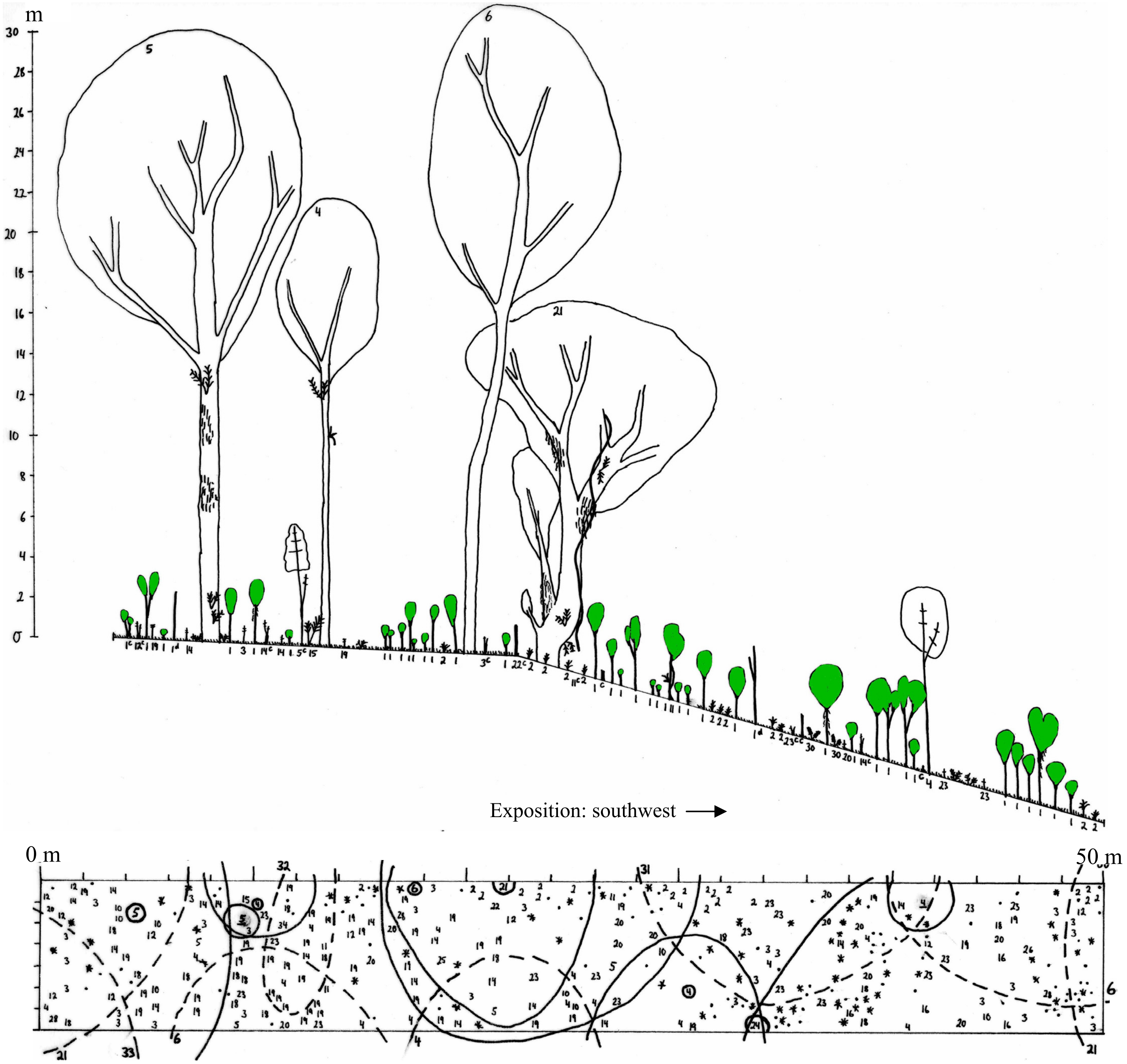

Figure 5.5 Semi-forest coffee system type 2 with disturbed forest structure: upper and lower canopies are reduced; patchy shrub layer dominated by large coffee trees; ground is densely covered with herbs and grasses; moss and fern cover on trees is low; coffee plants are indiated by the green color; for further explanation see text and Table 5.4

The SFC systems of type 2 are considered as semi-forest coffee plantations (SFP) if the planting of coffee seedlings was obviously carried out systematically on a large scale and management eliminated almost all woody vegetation besides coffee (Figure 5.6).

Figure 5.6 Semi-forest coffee plantation with disturbed forest structure: canopy is dominated by *Milletia ferruginea* (4); very large coffee trees dominate lower canopy and shrub layer; ground layer quite dense; moss cover on coffee trees is high; coffee plants are indiated by the green color; for further explanation see text and Table 5.4

Forest managed as a SFC system is considered as owned by individuals according to traditional land-use rights (Stellmacher in prep.). They are managed as SFC type 1 or 2 according to the individual preferences of the owner. The cutting of competing vegetation is done once to several times per year. It is usually organized as a traditional work party, where a group of neighbors or relatives works together for up to three days (*dabbo* system).

Many SFC systems have a long management history that can reach back as far as the beginning of the 20th century (section 2.3). Enrichment planting with wild coffee seedlings (wildings) from the surrounding forest was probably done in the past and is still being carried out today. The farmers' practice of planting wildlings at unequal spacing makes it impossible to distinguish spontaneously established coffee from transplanted coffee. At the same time, it is difficult to get precise information on the forest history from local farmers, because they cannot give a precise timescale, only gained their forest plots at the time of the Derg regime, moved to the area only recently, or are reluctant to answer questions concerning forest management practices.

The SFC systems are classified as "purposeful regeneration" (Wiersum 1997), i.e., the cultivation of wild trees by transplanting wildlings within the forest and by transforming the forest structure. The genetic integrity of wild coffee populations is maintained as long as there is seed left for natural regeneration (DFSC and IPGRI 2001b). A true domestication process only takes place if coffee is cultivated outside the forest, e.g., in tree-crop plantations, and if particular genotype or phenotype variants are propagated as is the case in Ethiopian home garden systems.

In the past, seedlings of improved coffee cultivars were distributed to farmers by governmental and non-governmental organizations in the Bonga region. In Mankira, however, farmers are hesitant to plant these coffee cultivars because they consider them as less productive and less vigorous than wild coffee varieties (Alemayu Alemu pers. comm. 2003). The amount of planted coffee cultivars in SFC systems in Koma is also estimated to be negligibly low (Stellmacher in prep.). In Meligawa, 66 % of the farmers practice transplanting of coffee seedlings in SFC systems, but only 5 % of those use improved varieties (Urich 2005).

In all studied forest fragments, the SFC systems are usually located close to villages and footpaths (Figure 5.7). The FC systems can be located deep inside the forest, but are mostly within one hour walking distance from the next village. Undisturbed forest plots are generally found in remote forest parts.

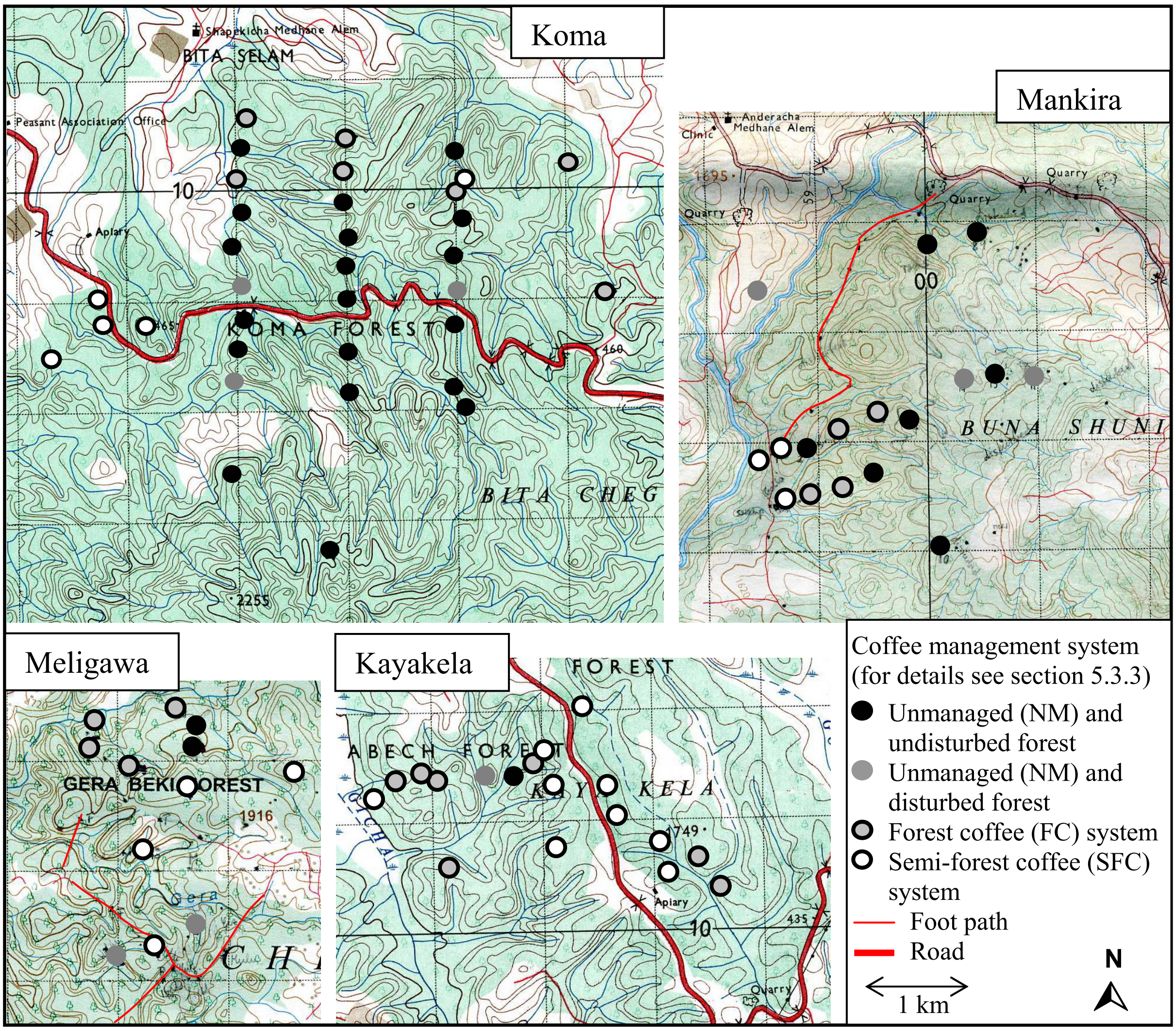

Figure 5.7 Location and coffee management system of study plots in the forest fragments Koma, Mankira, Meligawa and Kayakela

Summary

- Unmanaged forest and FC systems have undisturbed forest structure. Coffee density is much lower in unmanaged forest than in FC systems.
- In SFC systems, forest structure is disturbed due to high management intensity. Density of coffee, including large coffee trees is high.
- In unmanaged, but disturbed forest, disturbance of vegetation structure has other causes than coffee management, and coffee density is low.

5.3.4 Estimation of coffee yields

Yield calculations are based on counts and estimates of the number of coffee fruits in selected study plots. In the following, the coffee marketing terminology will be employed, i.e., the coffee fruit is called cherry and the coffee seed is called bean. Clean coffee (cc) refers to the dried beans without pulp and parchment.

Number of cherries was converted to weight of clean coffee by using the average weight of 20 cherries sampled from four different plots (Table 5.6).

Table 5.6 Average weights (fresh and clean) of 20 coffee cherries from unmanaged and undisturbed forest (NM), forest coffee (FC) system, and semi-forest coffee (SFC) system type 1

Average weight (g)	NM	FC	SFC 1	SFC 1	Average	Conversion rate
Fresh cherries	1.48	1.48	1,71	1.39	1.51	22 %
Clean cherries	0.31	0.34	0.37	0.32	0.33	

For the yield calculations, the average weight of 0.33 g per clean cherry was used besides for the 4 plots, from which the cherries were actually sampled. For these plots, the weight as indicated in Table 5.6 was taken. The estimated yields for the different coffee management types are shown in Table 5.7.

Table 5.7 Estimated clean coffee (cc) yields for five wild coffee management types: no management (NM), forest coffee (FC) system, and semi-forest coffee (SFC) system types 1 and 2

	NM/ undisturbed	NM/ disturbed	FC	SFC 1	SFC 2
Management intensity	zero	zero	low	high	high
Number of study plots	19	3	7	6	4
Range of yield for studied plots (kg cc ha $^{-1}$)	0 - 3	0 - 0.5	1 – 15	3 – 54	20-40
Estimated yield (kg cc ha^{-1} a^{-1})	< 5	< 5	< 15	+/- 40	+/- 30

The estimated coffee yields are quite close to the yields stated by the farmers who live in the study region. In Meligawa, farmers reported bad yields from forest coffee with 0 – 7 kg cc ha^{-1} a^{-1} and good yields with 4 – 29 kg cc ha^{-1} a^{-1} (Urich pers. comm. 2005)[1]. In Koma, the average yield for forest coffee as indicated by farmers is 24 kg cc ha^{-1} a^{-1} (Stellmacher pers. comm. 2005). It was not clear, though, if farmers referred to simple coffee

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[1] Farmers indicate yield of dried coffee, which is converted to clean coffee by multiplying with 0.5 (FAO 2001).

collection, FC or SFC systems. In Kayakela, one farmer estimated his yield from the SFC system type 1 as 42.5 to 70.8 kg cc ha^{-1} a^{-1} in bad to good years, respectively.

Some farmers in Meligawa reported their yields from forest coffee to be above 150 kg cc ha^{-1} a^{-1} (Urich pers. comm. 2005). It is possible that they referred to very intensively managed semi-forest coffee plantations (SFP, section 5.3.3). In Kayakela, farmers mentioned equally high yields from SFPs.

The differences between yield estimates for study plots and yield estimates by farmers are due to three main reasons: 1) farmers may have mentioned lower yields than they actually had because they are afraid of negative implications caused by their statements, e.g., having to pay higher taxes, 2) plots were studied in one year only, but coffee yields vary from year to year, and 3) it is difficult to extrapolate yield estimates from study plots to one hectare because the forest is very heterogeneous. In intensively managed forest, for example, some parts are dominated by lianas, *Phoenix reclinata* or shrubs while other parts consist of large and high-yielding coffee trees. In unmanaged forest, coffee is also very unequally distributed within one hectare. Thus, the estimated yields can be too low or too high depending on which section of the forest was covered by the study plot.

Generally, coffee yields in the study region are very low when compared to literature statements. For forest and semi-forest coffee systems, for example, yields are mentioned to range from 150 to 250 kg cc ha^{-1} a^{-1} (Agrisystems Ltd. 2001) and from 100 to 350 kg cc ha^{-1} a^{-1} (Taye Kufa pers. comm. 2005). These differences arise because there are no commonly recognized definitions of coffee forest management types. High yields possibly refer to very intensively managed semi-forest coffee plantations. Other authors indicate low yields for forest coffee with less than 30 kg cc ha^{-1} a^{-1} (Demel Teketay 1999), which is close to the estimates in this study.

Yields from coffee estates are usually much higher than yields from forest coffee. They vary from 500 (- 800+) kg cc ha^{-1} a^{-1} in an organic coffee plantation (Green Coffee Plantation pers. comm. 2005) to an average of 750 kg cc ha^{-1} a^{-1} (Agrisystems Ltd. 2001) to over 1,200 kg cc ha^{-1} a^{-1} (Demel Teketay 1999).

Yields in coffee plantations are high because the coffee trees there are high-yielding varieties, fertilized, spaced adequately, pruned and coppiced after ca. 15 years when yields start to drop (Green Coffee Plantation pers. comm. 2005). Farmers usually do not have the means to buy fertilizer. With very few exceptions, they are also reluctant to carry out pruning and to remove old coffee trees, even though fruit production of large old trees is low as was already observed by early coffee researchers (Branzanti 1942; Strenge 1956; Sylvain 1958).

The management strategy of farmers may be related to the fact that for them continuous low yields are more favorable than uncertain high yields, which can even lead to over-bearing, i.e., plant death caused by high productivity (Demel Teketay 1999). Besides, if the canopy cover is not reduced as is the case in forest coffee systems, coffee grows slowly and there will be a gap in productivity between the coppicing of large trees and the first yield of re-sprouting ones.

Summary

- Wild coffee yields are extremely low in unmanaged forest and increase with increasing coffee management intensity.
- Semi-forest coffee systems produce higher wild coffee yields than unmanaged forest and forest coffee systems, but are much less productive than semi-forest coffee plantations and coffee estates.

5.3.5 Growth and regeneration of coffee

Two monitoring experiments were carried out in the Koma forest fragment from December 2003 – January 2005. In the first, coffee height was monitored in six plots at 2-month intervals while in the second, seedling growth was observed each month.

The six plots for the 2-monthly monitoring were located in unmanaged forest (disturbed and undisturbed), forest coffee (FC) systems and semi-forest coffee (SFC) systems. In all six plots, the coffee populations were dominated by individuals taller than 1.5 m. On average, seedlings (0.05 - 0.3 m) made up 32 %, saplings (0.3 – 1.5 m) made up 47 % and trees (1.5 – 3.5 m) made up 18 % of the populations. Large trees (> 3.5 m) were infrequent and on average constituted only 3 % of the populations. They were not measured throughout the monitoring because they have several growth axes (Table 5.8).

The total number of coffee plants was smallest in plots 2 and 3. A single large mother tree in plots 1 and 4 was responsible for large numbers of butterfly seedlings and additional coffee seedlings in both of these plots. In plots 5 and 6, coffee was very dense because competing vegetation had been removed during management.

Generally, there is plenty of regeneration, i.e., additional coffee seedlings, except for plot 2 due to the absence of a tall mother tree (Table 5.8). The number of dead and diseased coffee individuals per plot was usually smaller than the number of additional seedlings. Diseased coffee individuals are plants that displayed negative growth, i.e., their height at the last measurement in January 2005 was smaller than in December 2003. This could be due to diseases affecting the growth bud, to trampling and bending by humans and animals, and foraging.

Table 5.8 Structure and growth performance of coffee populations in six plots in Koma forest fragment monitored from December 2003 to January 2005; no management (NM), forest coffee (FC) system, and semi forest coffee system type 1 (SFC 1)

	Plot 1	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**
Coffee management type (see section 5.3.3)	NM/ disturbed	NM/ un-disturbed	FC	NM/ un-disturbed	SFC 1	SFC 1
No. of coffee plants taller than 3.5 m (height not monitored)	1	-	1	1	4	6
No. of coffee plants shorter than 3.5 m (monitored since Dec 2003)	9	21	31	71	115	211
No. of additional coffee seedlings[1]	178	1	56	67	45	179
No. of dead/ diseased coffee plants out of plants monitored since Dec 2003	0	1	7	12	8	38
Ratio of dead/ diseased coffee plants to plants monitored since Dec 2003	0 %	4.8 %	21.9 %	16.7 %	6.7 %	17.5 %

[1] *average number of butterfly seedlings per plot over all measurements plus total number of additional seedlings tagged after the first measurement in December 2003*

NB: Plot size is 5 m x 5 m except for plot 6 with 2.5 m x 5 m

The monitoring results show that coffee plants increased very little in height during one year and changes in diameter did not take place during this short period of time. In all plots, coffee growth patterns were rather similar, even though sample sizes and average initial sizes of the coffee plants varied greatly (Figure 5.8). Saplings and in particular seedlings showed very irregular growth patterns. In most plots, their height could decrease during two measuring intervals due to disease or foraging, but they usually recovered and showed an overall height increase by the end of the experiment.

During the course of the experiment, the average height increase of seedlings, saplings and trees was 3.3 cm, 6.5 cm and 15.5 cm, respectively. Seedlings had the highest average growth rate (height in January 2005 versus height in December 2003) with 15 %, while the height of saplings and trees only increased by 12 % and 9 %, respectively. The maximum height increase for individual seedlings, saplings and trees during the course of the experiment was 11.5 cm, 51 cm, and 48 cm with maximum growth rates of 75 %, 64 %, and 24 %, respectively. Such great differences between average and maximum growth rates are characteristic for young trees in tropical rain forests (Clark and Clark 2001).

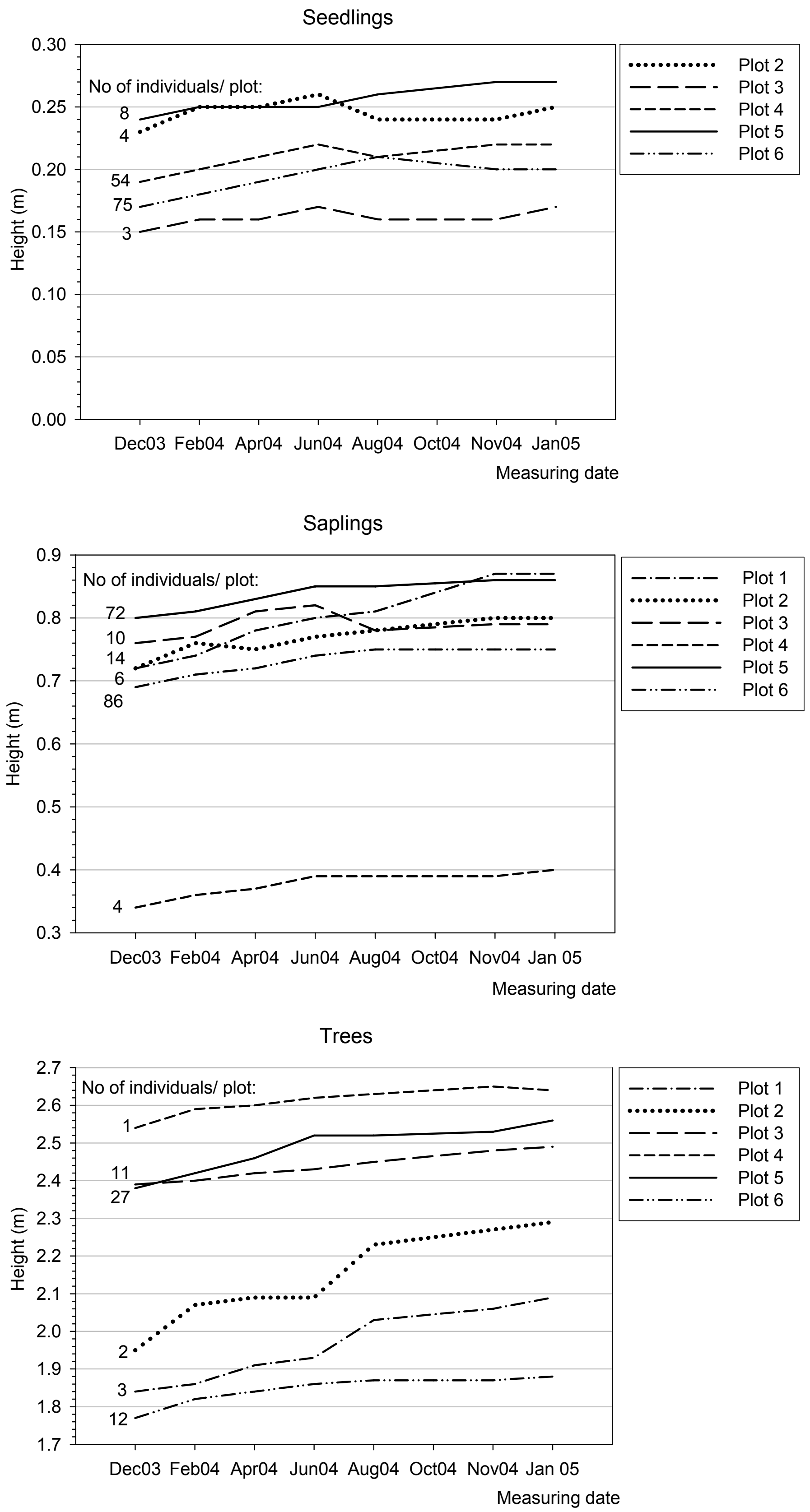

Figure 5.8 Height increase of coffee seedlings (0.05 – 0.3 m), saplings (0.3 – 1.5 m), and trees (1.5 – 3.5 m) in six study plots from Dec 2003 – Jan 2005; measurement interval was 8 weeks (values for Oct 2004 extrapolated)

The height increase during the main rainy season (July 2004 – October 2004) was low for seedlings saplings and trees (Figure 5.8). Accordingly, their relative growth rates between two measurement intervals declined sharply after the onset of the main rainy season in July 2004 (Figure 5.9). In 2004, the months July through October clearly had the highest precipitation and the lowest average temperatures of that year (Figure 4.2). It can thus be assumed that wet and cold conditions as well as high cloud cover during the rainy season are unfavorable for coffee growth.

The relative growth rates for December 2004 – January 2005 were much lower than the relative growth rates for January 2004 – February 2004 (Figure 5.9). This is probably related to the fact that the main rainy season lasted longer than usual in 2004, and that average temperatures in December 2004 and January 2005 were comparatively low (Beining in prep.). These annual climatic variations underline that monitoring needs to be carried out continuously over several years in order to understand the growth pattern of coffee.

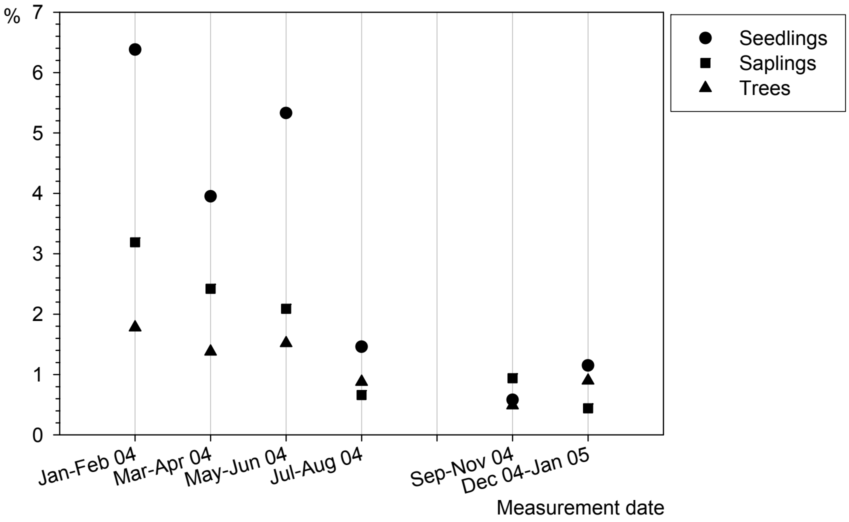

Figure 5.9 Relative growth rates (%) of coffee seedlings (0.05 - 0.3 m), saplings (0.3 - 1.5 m), and trees (1.5 – 3.5 m) from Jan 2004 – Jan 2005; measurement interval was 8 weeks (values for Oct 2004 are missing)

In the second monitoring experiment, 35 butterfly seedlings were monitored in two sites at monthly intervals. Both sites were located in SFC systems of type 1. Of the seedlings 80 % (28 out of 35 in both sites) survived during the time span of the experiment. The loss of seedlings was probably caused by disease infection, foraging and human disturbance during the coffee harvest. The results of both sites are averaged for the following analyses, because environmental conditions in both sites are relatively similar and growth patterns and height increase of the seedlings were almost the same. Within one year (January 2004 – January

2005), the surviving seedlings grew from an average height of 7.3 cm to an average height of 10.2 cm, lost both cotyledons and gained 5 leaves (Figure 5.10).

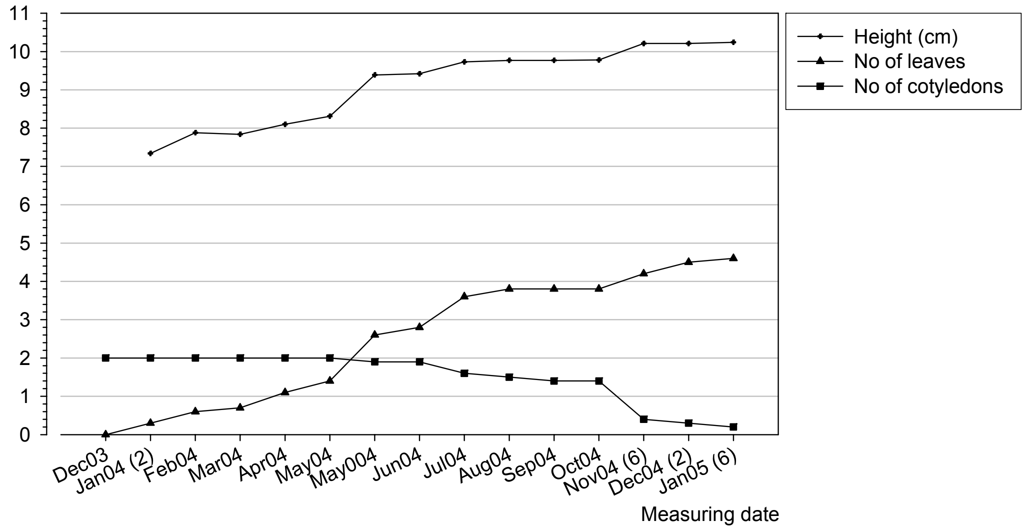

Figure 5.10: Height increase, number of leaves and number of cotyledons of 56 coffee seedlings from Dec 2003 – Jan 2005; measurement interval was 4 weeks, except for months with numbers in brackets, where intervals were 2 or 6 weeks

The results for seedlings in the first monitoring experiment match the results in the second experiment. In the former, the average height increase of seedlings over the total time span of the experiment was 3.3 cm (min: 0 cm; max 11.5 cm), and in the latter it was 2.9 cm (min: 0 cm; max: 5.5 cm). Average growth rates (height in January 2005 versus height in December 2003), however, differ between 15 % in the first monitoring experiment and 42 % in the second. This is related to the fact that the butterfly seedlings in the second experiment had a smaller initial size than the seedlings in the first one.

The strongest mean height increase in the second experiment was in May 2004 (Figure 5.10). On average, the seedlings also gained two leaves from May – July 2004. During the rainy season from July – October 2004 seedling growth stagnated and the number of leaves and cotyledons did not change. Concordantly, the relative growth rates of the seedlings between two measurement intervals were low from August – October 2004 (Figure 5.11). This confirms the observation already made above that coffee growth is inhibited during the main rainy season. Since most seedlings lost the second cotyledon in November 2004, it is assumed that they need about one year to fully retrieve nutrient and energy requirements through the root system and photosynthesis.

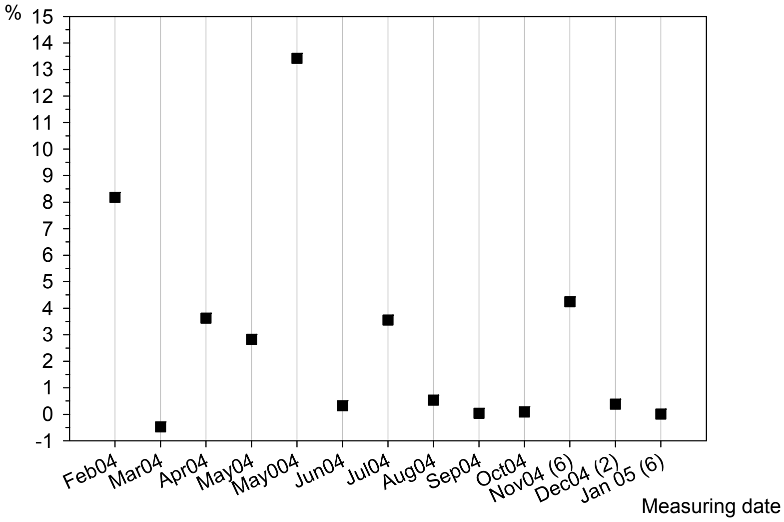

Figure 5.11 Relative growth rate (%) of 56 coffee seedlings from Feb 2004 – Jan 2005; measurement interval was 4 weeks, except for months with numbers in brackets, where intervals were 2 or 6 weeks

Both experiments emphasize that coffee grows very slowly under natural conditions. No differences in growth patterns between unmanaged, moderately and intensively managed plots were observed. One reason could be that coffee densities in intensively managed plots are very high, and coffee individuals thus experience interspecific competition, e.g., for nutrients or sunlight. Besides, the time span of the experiment was probably too short to point out differences in growth patterns between different management regimes.

For comparison, in nurseries, coffee seedlings can reach heights around 30 cm already after six months. In plantations, coffee trees attain heights of almost 2 m after 2 years and yield the first crop. Within 6 years they grow into large and mature trees (Green Coffee Plantation, pers. comm., 2005). In a greenhouse experiment conducted in Jimma, the relative growth rate for seedlings was 27 % in December 2004 and 29 % in January 2005, which is much higher than the highest relative growth rate observed in the forest (13.4 %, May 2004, butterfly seedling monitoring) (Taye Kufa 2006).

Dark light conditions caused by dense canopy layers are an important factor for the slow growth of most coffee individuals. The physiognomy of the coffee trees clearly indicates the shaded conditions in forest undergrowth: the lower branches are almost leafless, but the top branches have many, well developed and healthy leaves (Figure 5.12). This was already noticed by early coffee researchers (Branzanti 1942; Strenge 1956; Sylvain 1958). They described the undisturbed forest as quite dark. Coffee trees were characterized as spindly, which refers to very etiolated growth, long lateral branches limited to the terminal part of the plant, very long internodes, leaves of great dimensions and a considerable height. These coffee trees have few flowers and only produce just enough fruits to insure the survival of the species. The above-mentioned researchers also observed that trees that are accidentally better exposed to the sun have higher yields. They regarded this fact as the first incentive for coffee management.

Fig. 5.12 Top of coffee tree in shaded forest

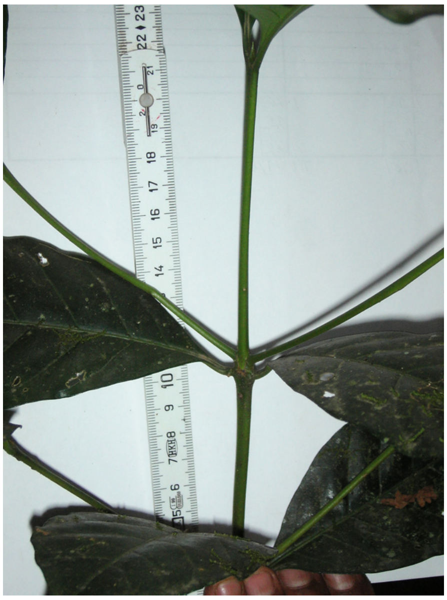

Fig. 5.13 Elongated internode of coffee tree

Fig. 5.14 Coffee tree (unmanaged forest)

Fig. 5.15 Pruned coffee tree (plantation)

Long internodes were also observed during this experiment (Figure 5.13). Internodal growth can be quite fast and led to the considerable height increase between two measuring dates, e.g., trees in plot 1 and plot 2 between June and August 2004 (Figure 5.8). This growth pattern was observed in all plots, but only with individual plants.

In Figure 5.14 and Figure 5.15 the difference between a spindly coffee tree in unmanaged forest and a pruned 6-year old plantation tree that has branches with well developed healthy leaves at ground level can be clearly seen. The age of the forest coffee tree is difficult to estimate due to the slow and irregular growth of wild coffee as pointed out above.

As for coffee, very slow growth of seedlings and saplings was observed in an ancient boreal montane forest, where 100-year old individuals of large tree species were less than 1 m in height (Antos et al. 2005). The authors argue that conditions in the understory, e.g., low light and limiting nutrients, can greatly limit growth. Low light is considered a stress factor and not a result of competition (sensu Grime 1979), because this limitation to growth can be as intense as any abiotic stress and is typically chronic (Wilson and Lee 2000). To cope with these environmental conditions, climax tree species form seedling banks that are pools of suppressed individuals waiting for improved growing conditions (Silvertown and Lovett Doust 1993). Tree species exhibiting this growth pattern are regarded as facultative stress tolerators, because they have the ability to persist in habitats where resource availability is low, but also have the potential to grow rapidly in favorable microsites, e.g., in large gaps.

The growth pattern of coffee only partly fits into this picture: Similar to the above-mentioned species, coffee seedlings and saplings grow very slowly in dense forest, but grow quickly under improved conditions, e.g., in gaps exposed to sunlight, and in a greenhouse or nursery. This is probably caused by low light availability in the forest, but also by other factors, e.g., high population density of coffee (plots 5 and 6), competing root systems, or allelopathy. In the long run, however, direct exposure to sunlight and increased productivity under good light conditions render coffee plants more susceptible to some diseases and may result in their losing vigor and dying off (over-bearing) (Demel Teketay 1999). This is not the case for the above-mentioned facultative stress tolerators that grow into large mature trees. Thus, it could be hypothesized that coffee has two growth strategies: First, a spindly coffee tree that persists in the natural forest for a long time producing just enough fruits for the survival of the species, and second a fast-growing tree in a forest gap producing a lot of fruits in a short time, but dying soon because of direct exposure to sunlight and over-bearing.

Summary

- Wild coffee has much lower growth rates than coffee in nurseries and plantations, which is presumably caused by deep shade in undisturbed forest and by high coffee densities in semi-forest coffee (SFC) systems.
- Coffee growth rates are particularly low during the main rainy season (July – October), due to high cloud cover, high precipitation and low temperatures.

5.3.6 Environmental versus management impacts on coffee

The abundance of coffee is significantly higher in Kayakela than in the other forest fragments (Table 5.9). The majority of study plots in Kayakela was located in SFC systems of type 1, whereas the majority of plots in the other forest fragments was located in unmanaged or little managed forest. This suggests that high coffee abundance in Kayakela is related to management intensity, because coffee abundance was shown to be highest in SFC systems of type 1 (section 5.3.3). High coffee abundance in Kayakela could, however, also be related to the low altitude of this forest fragment (1,610 – 1,750 m asl), because coffee has its ecological optimum between 1,500 and 1,800 m asl (Demel Teketay 1999).

Table 5.9 Coffee density (number of coffee plants with height > 0.5 m per study plot), altitude and main coffee management type in four forest fragments; NM: no management; FC: forest coffee system; SFC: semi-forest coffee system

	Koma (34 plots)			**Kaya (22 plots)**			**Meli (12 plots)**			**Mank (17 plots)**			**Sign. diff.**[1]
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	
Coffee density	**205**	0	1,899	**664**	41	1,901	**255**	11	1,098	**119**	3	308	2>1,3, 4
Altitude (m asl)	**1,942**	1,830	2,280	**1,691**	1,610	1750	**1,817**	1,710	1,920	**1,665**	1,560	1,810	1>3> 2,4
Management type	NM/ undisturbed (56 % of plots)			SFC 1 (45 % of plots)			FC (33 % of plots)			NM/undisturbed (41 % of plots)			

[1] Significant difference at level 0.05 as determined by the Bonferroni test (one-way ANOVA): 1 = Koma, 2 = Kayakela (Kaya), 3 = Meligawa (Meli), 4 = Mankira (Mank)

In fact, there is a negative correlation between coffee abundance and altitude in this study (r_S = - 0.360; significance level 0.01). The high-altitude plots, however, are mainly in the little managed Koma forest, while the low-altitude plots are dominating in intensively managed Kayakela. This leads to the question whether coffee abundance is more strongly influenced by differences in soil and environmental conditions between forest fragments, e.g. altitude, or by the prevalent coffee management type.

It is first hypothesized that soil and environmental conditions have a stronger influence on coffee abundance than management intensity. This would mean that SFC plots have more favorable soil and environmental conditions for coffee than plots with less intensive management. Presumably, these conditions are rather homogeneous throughout all SFC plots in all fragments.

To test this hypothesis, a multivariate ANOVA (mANOVA) is used to compare the differences in environmental and soil parameters between the four forest fragments and three management intensities. The environmental parameters tested are altitude, slope, and moss index. The tested soil parameters are listed in Table 5.2. Management intensities are: (1) no management = unmanaged and undisturbed forest; (2) low = forest coffee (FC) systems; (3) high = semi-forest coffee (SFC) system types 1 and 2 (compare section 5.3.3). Unmanaged but disturbed forest is not considered, because the disturbance is not related to coffee management. One plot located at 2,280 m asl is also not taken into account because coffee was generally not observed above 2,040 m asl. Two separate mANOVAs are run for environmental and soil parameters, because the two data sets differ in sample size.

The first hypothesis cannot be accepted, because soil and environmental conditions vary much more strongly between forest fragments than between management intensities. For soil parameters, the fragment effect is significant ($p = 0.002$; partial Eta squared = 0.586), but differences between management intensities are not significant ($p = 0.535$; partial Eta squared = 0.335). For environmental factors, the fragment effect is highly significant ($p < 0.000$; partial Eta squared = 0.815), whereas the management effect is not significant ($p = 0.778$; partial Eta squared = 0.008).

Therefore, a second hypothesis is formulated, i.e., managed and unmanaged plots do not differ in soil and environmental conditions. As a consequence, high coffee abundance in managed plots must be stimulated by other factors, e.g., by the removal of competing vegetation. This hypothesis is tested separately for each forest fragment except Meligawa, which is not considered due to its small sample size.

The second hypothesis can be accepted in terms of soil parameters, exposition and altitudinal ranges of the forest fragments. In none of the tested fragments is there a significant difference in these variables between plots with different management intensities. [2]

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[2] In Mankira, the altitude was significantly higher in unmanaged plots than in SFC plots, average values being 1,689 and 1,573 m asl, respectively. Both values lie within the optimal altitudinal range of coffee. The statistical significance therefore has no practical implication.

The moss index is significantly higher in unmanaged plots than in SFC plots in Koma (45 % versus 20 %, respectively; p = 0.012, F = 5.253). This confirms that high levels of shade and humidity are unfavorable for coffee growth as was already pointed out in the previous section. Being an indicator of humidity, the moss index is lower in intensively managed plots because they are generally sunnier and drier than unmanaged ones due to the removal of shading trees. In Kayakela and Mankira, values follow the same trend as in Koma. Results are not significant, though, because the values are highly variable in all management types, and high moss covers persist even in some intensively managed plots.

The results for slope are not significant in any fragment, but there is a general tendency for slopes to be flatter in intensively managed plots than in unmanaged ones (Figure 5.16).

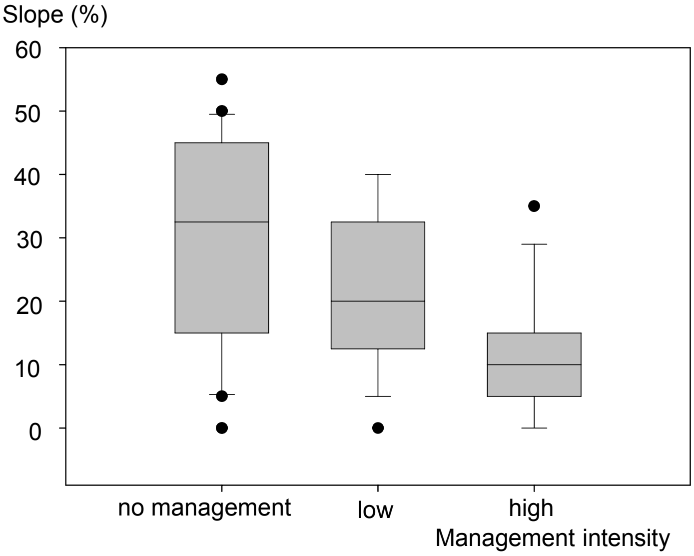


Figure 5.16 Slope inclination (%) in plots with no management, low (forest coffee systems) and high (semi-forest coffee systems) management intensity in Koma, Kayakela and Mankira; lower box boundary = 25th percentile, line within box = median, upper box boundary = 75th percentile; upper and lower whiskers = 90th and 10th percentiles, respectively; dot = outlier.

This observation indicates an ecological preference of coffee for flat terrain, on the one hand. As a consequence it is more abundant there, and farmers generally tend to manage coffee where it is already naturally abundant. On the other hand, as coffee management activities are more tedious on steep slopes, farmers prefer to manage coffee in flat terrain, and these management activities could be the main reason for the increase in coffee abundance on flat terrain.

The study plots in Koma underline the difficulty in separating the effects of management and environment on coffee abundance. In Koma, the number of coffee individuals is negatively correlated with the moss index (r_S = - 0.614; significance level 0.01) and slope (r_S = - 0.455; significance level 0.05), but is also related to management intensity: The number of coffee individuals is highest in SFC systems with a relatively low moss index and slope inclination (Figure 5.17), while it is lowest in unmanaged forest where both moss index and slope are highly variable and reach maximum values.

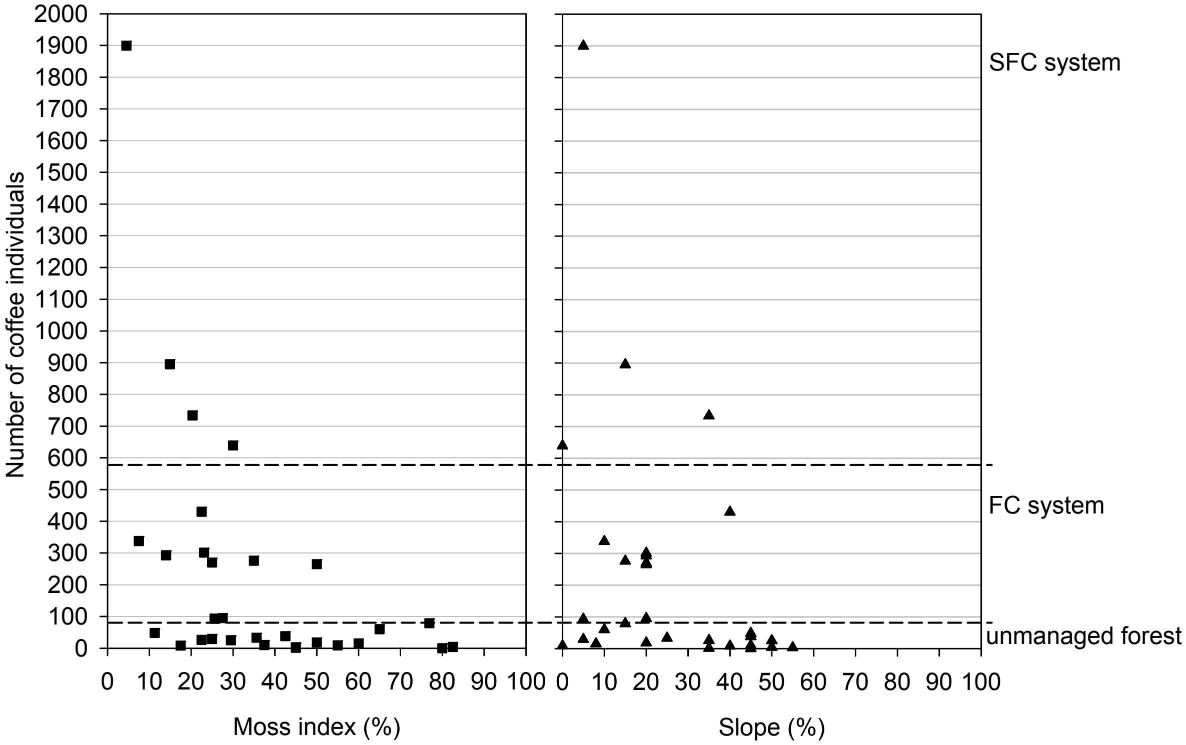


Figure 5.17: Relation between number of coffee individuals and moss index (%) and slope (%) in Koma forest fragment

It is assumed that intensive management in SFC plots has a positive impact on coffee abundance by reducing interspecific competition and by reducing shade and humidity as indicated by the moss index. This notion is confirmed by the correlation of coffee abundance with soil and environmental parameters in unmanaged forest. For unmanaged plots in Mankira, there is a strongly negative correlation between number of coffee individuals and moss index (r_S = - 0.821; significance level 0.05). For unmanaged plots in Koma, the moss index is not significantly correlated with coffee abundance. Coffee is, however, positively correlated with southern exposition (r_S = 0.649; significance level 0.01). Similar to the moss index, southern exposition is an indicator of relatively light and dry site conditions.

Correlations between coffee individuals and slope inclination in unmanaged forest are not significant in any of the fragments. Steep slopes, however, may accentuate effects of high plot humidity and northern exposition. The only plot without any coffee in unmanaged forest is on a steep slope (45 %), has a high moss cover (moss index = 80 %) and northwestern exposition.

In unmanaged forest in Koma, coffee abundance is positively correlated with soil organic matter (SOM) ($r_S = 0.673$; significance level 0.05) and total N content ($r_S = 0.711$; significance level 0.05). The correlation with SOM content does not have a practical meaning, though, because SOM values range from 5 to 10 % and can generally be considered as high (AG Boden 1994). The same is true for the total N content, which ranges from 0.3 to 0.6 % and can generally be considered as medium to high (Landon 1984).

Summary

- The hypothesis that managed plots do not differ in soil conditions from unmanaged ones is accepted. It is concluded that the studied soils are generally suitable for coffee, and other factors than soil are more important for coffee abundance.
- The hypothesis that managed plots do not differ in environmental conditions from unmanaged ones is accepted for altitude and exposition. The tendency for highly managed semi-forest coffee (SFC) plots to be flatter than unmanaged plots is probably related to the fact that farmers prefer to work on flat terrain.
- In unmanaged forest, coffee abundance is negatively correlated with moss index (Mankira) and positively correlated with southern exposition (Koma). This ecological preference of coffee has to be seen in the context of the montane rainforest where sites with high moss index and northern exposition are extremely shady and humid.
- Since high shade and humidity have negative effects on coffee, it is assumed that management enhances coffee abundance not only by reducing direct competition with other vegetation, but also by modifying the microclimatic conditions of the site. This is most apparent in the case of Koma, where intensively managed plots have lower moss index values than unmanaged ones.
- Generally, it is assumed that variations in altitude, slope, exposition, humidity, and management intensity have synergetic effects on coffee abundance, which may blur the effect of each factor considered on its own.

5.4 Definition of wild coffee and implications for conservation

This study shows that *Coffea arabica* occurs throughout forests in the Bonga region until 2,040 m asl, except for extremely shaded and humid sites. The low abundance and low density of coffee in unmanaged forest is substantially increased by local management practices. Due to past and present coffee collection and management interventions in the Bonga region, it is difficult, however, to clearly separate the management impacts from the environmental impacts on coffee density and distribution in the forest.

Wild plants are by definition native plants and their seeds that grow in their natural state within their habitats. This definition is not applicable to the Bonga region, because the natural state of most coffee populations has probably been modified by human activities in terms of abundance and spatial distribution. The transition from the natural state to domestication of plant species is, however, a gradual process (Wiersum 1997; DFSC and IPGRI 2001b). The simple collection of coffee and coffee management up to the level of SFC systems do not automatically lead to the production of domesticated coffee trees.

Wild coffee is, therefore, defined as coffee plants that grow and regenerate spontaneously in their natural habitat. These plants also have to be genetically different from known cultivars (Kassahun Tesfaye 2006). Wild coffee can be subject to different levels of management reaching from simple collection of coffee fruits in undisturbed forest to intensive management in SFC systems. Coffee in SFC systems is considered wild as long as the majority of coffee plants regenerates spontaneously and only limited amounts of coffee wildlings are transplanted.

This definition comes very close to the local farmers' perception of wild coffee. They differentiate between wild coffee that grows and regenerates spontaneously, i.e., "yäwof säräsch"/ sown by birds, and improved varieties distributed by extension workers. Wild coffee can be "yätämänätärä"/ managed or "yaltämänätärä"/ unmanaged. In contrast to the above definition, though, coffee wildlings transplanted in or outside the forest are also considered as wild.

The universal occurrence of wild coffee in the Afromontane forest of the Bonga region makes it a suitable flagship species to draw attention to the high conservation value of this forest. Differences in altitude, humidity and soil parameters between the studied forest fragments emphasize the importance of conserving all remaining forest parts, because these differences presumably lead to a variety of natural selection processes and thus to high genetic diversity of wild coffee (DFSC and IPGRI 2001b).

Over-exploitation of wild coffee is not a danger in the Bonga region, since coffee management in fact increases coffee abundance. The introduction of improved coffee cultivars is, however, a danger to the genetic diversity of wild coffee, because interbreeding can erode its original genetic make-up. Coffee is self-pollinating, but pollination by bees, that travel distances of up to 6.5 km, is also important (Roubik 2002; Klein et al. 2003; Beedata 2006). Wild coffee in SFC systems, which are often located at forest margins, is likely to experience genetic contamination through pollen from coffee cultivars planted in nearby coffee plantations and home gardens. As a consequence, the unique genetic character of wild coffee can only be conserved if the planting of cultured cultivars is prohibited within a distance of 6.5 km from the forest.

The marketing of wild coffee is advertised by several governmental and non-governmental organizations in the Bonga region. The Kafa Forest Coffee Farmers Cooperative Union, for example, has recently started to sell wild coffee at relatively high prices on the international specialty market. Increased revenues from wild coffee help farmers to improve their livelihoods and can enhance local development processes.

This study shows, however, that unmanaged wild coffee has extremely low yields. High prices for wild coffee are strong incentives for farmers to raise coffee yields by increasing coffee management intensity. As a consequence, the promotion of wild coffee marketing can jeopardize efforts to conserve the natural forest ecosystem in the Bonga region.

The reconciliation of wild coffee use and forest conservation can be achieved by delineating forest parts for intensive coffee management and for forest conservation. Semi-forest coffee (SFC) systems should be restricted to already disturbed forest areas, and should not be extended further into undisturbed forest. Forests on steep slopes are important for conservation because they are unsuitable for intensive coffee management activities.

Farmers could be encouraged to participate in conservation measures through training in modern coffee management practices. Pruning and thinning out of coffee plants in already existing SFC systems, for example, will increase coffee yields considerably and is likely to reduce the motivation of farmers to manage wild coffee in remote forest parts. Additionally, the intensification of coffee management in currently unmanaged forest or FC systems could be discouraged by compensating low coffee yields from these production systems with higher prices. In this case, the employed management interventions have to be controlled. The assignment of production ceilings can be a means to restrict fraud. This study shows that low coffee management intensity as should be applied in FC systems is unlikely to yield more than 15 kg cc ha^{-1} a^{-1}. Production ceilings can be calculated for individual FC areas on the basis of this maximum yield. The planning and implementation of conservation concepts for the Bonga region are discussed in detail in Chapter 8.

6 PLANT DIVERSITY AND IMPACT OF WILD COFFEE MANAGEMENT

6.1 Introduction

The Afromontane forests with wild coffee in southwestern and southeastern Ethiopia belong to the biodiversity hotspots of the world because they comprise high numbers of endemic species and high floristic diversity, but are severely threatened by anthropogenic activities (Gil et al. 2004). This is apparent in the Bonga region where the Afromontane forest is highly fragmented due to conversion into settlements and agricultural land.

Protection of the total remaining forest area in the Bonga region is practically impossible. The determination of number and size of protected areas needed for long-term conservation of the original plant diversity requires knowledge on species distribution patterns (Franklin 1993; Belbin 1995; Howard et al. 1998; van Jaarsfeld et al. 1998; Williams 1998; Noss 1999). So far, however, the forest vegetation of the Bonga region has only been studied on the basis of plant collections (Friis et al. 1982) and a few systematic vegetation surveys (Abayneh Derero 1998; Mateos Ersado 2001; Ensermu Kelbessa and Teshome Soromessa 2004).

Large forest areas in the Bonga region are subject to wild coffee management. There are to date no studies on the impact of these management activities on species composition and forest structure, although they are necessary to identify the role of wild coffee management in forest conservation.

This chapter, therefore, has the objective

- to characterize four forest fragments in terms of species diversity and species composition, and
- to study the impact of wild coffee management on the species composition and vegetation structure of natural forest.

6.2 Material and methods

6.2.1 Data set

In four forest fragments in the Bonga region, vegetation and environmental factors were recorded in 85 study plots each measuring 20 m x 20 m. The location of the study plots and methods of vegetation and site factor surveys are described in detail in section 4.2.

6.2.2 Ordination methods

Ordination techniques help to identify relative continuities and discontinuities in species composition among sample stands (Mueller-Dombois and Ellenberg 1974). There are two approaches in ordination, i.e., indirect (unconstrained) and direct (constrained) gradient analysis (ter Braak and Šmilauer 2002). In the indirect analysis, the ordination axes are theoretical gradients and the environmental data are subsequently used to interpret the ordination. Thus, the position of the plots within the multidimensional ordination space is solely based on similarities in species composition. The unconstrained ordination captures the main part of the variability in species composition, but can miss the part of variability that is related to the measured environmental variables. In contrast, in the direct ordination, the ordination axes are aggregates of the environmental variables that best explain the species data. This technique captures the main part of the variability explained by the environmental variables, but can miss the main part of a variability that is *not* related to the measured environmental variables. The two approaches are complementary and should both be used (Lepš and Šmilauer 2003).

Both methods are based upon eigenanalysis techniques: axes are found one by one, maximising the fit of residual variation (not accounted for by previously extracted axes) in species abundances to a model for species responses to underlying (direct analysis) or hypothetical (indirect analysis) environmental gradients (Økland 1999).

Each axis is characterized by an eigenvalue, λ, which measures the importance of each of the axes (ter Braak and Šmilauer 2002). In the direct analysis, the eigenvalue of an axis represents the amount of species data explained by this axis, while in the indirect analysis, the amount explained is given by r^2 * eigenvalue with r the species-environment correlation. It is important to note that in both types of analysis the species-environment correlation measures the strength of the relation between species and environment for a particular axis, but high correlations do not imply that an appreciable amount of the species data is explained by the environmental variables. In constrained methods, the species-environment correlation is often misleadingly high and should not be used as criterion for success of ordination (McCune 1997). In this respect, the cumulative percentage variance of species data and the cumulative percentage variance of species-environment relation explained by the axes are more important criteria.

However, the interpretation of these statistics requires some caution, because usually there is a large percentage of unexplained variance in ordination models of plant communities. This unexplained variance is attributed to the notion that species data are often very noisy, that there is inherent stochasticity in the location of individual plants and that only a reduced number of explanatory variables is used. Besides, a high proportion of unexplained variation is inherent in presence-absence data, since the probability of occurrence at specific sites translates into a binary pattern, and in abundance data with many zeros (Clark et al. 1999; ter Braak and Šmilauer 2002; Lepš and Šmilauer 2003; Ozinga et al. 2005). In constrained methods, unexplained variation in normal field data is usually low (and lower than in unconstrained models) because lack-of-fit of data to the response model is likely and thus, the amount of compositional variation extracted on ecologically interpretable ordination axes is underestimated (Økland 1999).

The high amount of unexplained variation does not mean, however, that the corresponding ordination diagrams cannot be interpreted ecologically (Økland 1999). There is often a well-interpretable structure, even if the amount of the explained variability is less than 10% (ter Braak and Šmilauer 2002; Lepš and Šmilauer 2003). Furthermore, the significance of species-environment relations can be analyzed with statistical tests. T-value biplots, for example, indicate which environmental variables contribute significantly to the regression of any particular species or, vice versa, which species react significantly to any particular environmental variable. These biplots are based on reduced-rank regression. They approximate the t-values of the regression coefficients of (weighted) multiple regressions between each of the species and each of the environmental variables. Environmental variables that have t-values larger than two in absolute value in the multiple regression of a particular species are inferred to be statistically significant in the regression for that particular species (ter Braak and Looman 1994; ter Braak and Šmilauer 2002).

In direct analyses, the statistical significance of the relation between the species and the whole set of environmental variables can be evaluated with Monte Carlo permutation tests, which means that statistical significance is tested by repeatedly shuffling (permuting) the samples (ter Braak and Šmilauer 2002). This procedure selects the environmental variables in order of the variance each explains, without considering the other environmental variables (marginal effects, λ_1), and in order of their inclusion in the model after successive selection of the most important variables (conditional effects, λ_A). The latter analysis gives the additional variance each variable explains, significance of the variable (p-value) and the test statistic (F-value) at time of inclusion in the model.

6.2.3 Analysis of species composition

Species frequency data (ground layer and epiphytes) and species abundance data (woody species and herbaceous climbers) were analyzed with CANOCO for Windows, version 4.52 and CanoDraw for Windows, version 4.12 (ter Braak and Šmilauer 2002).

Both indirect and direct ordination methods were used in a complementary way. Initial tests with detrended component analysis (DCA) indicated a linear rather than a unimodal response of the data because ß-diversity as expressed in units of standard deviations of species turnover (SD) was < 4 for all axes (Clark et al. 1999; Økland 1999; ter Braak and Šmilauer 2002). As a consequence, linear models, i.e., principal component analysis (PCA) for the indirect and redundancy analysis (RDA) for the direct method, were selected.

Abundance data were log transformed to account for the large differences in species abundances. The ordination diagrams were most coherent if species data tables were standardized by samples and centered by species (ter Braak and Šmilauer 2002).

In the PCA, t-value biplots were used to identify the environmental factors that explain a significant amount of variation of a particular species on their own. The region of the plot where the species lie that react significantly to a particular environmental variable is indicated by two circles, the so-called Van Dobben circles (ter Braak and Looman 1994). They have as their diameter the line segment that joins the environmental point and the mirror image of that point, respectively, and the origin. Species positively correlated with this environmental variable are enclosed by the positive circle (i.e., circle adjacent to the arrow-tip of the environmental variable), while those negatively correlated with the environmental variable have their arrow tips enclosed by the negative (mirror) circle (ter Braak and Šmilauer 2002).

The RDA ordination was constrained by the same set of environmental parameters as that used for the PCA ordination. They were entered in the RDA model by automatic forward selection and tested for deviation from randomness by Monte-Carlo permutation tests (number of unrestricted permutations = 499) (ter Braak and Šmilauer 2002).

6.2.4 Analysis of species diversity

Whittaker's three kinds of diversity were calculated for each forest fragment (McCune and Grace 2002):

1) α-diversity as average species richness per plot (= species density),

2) ß-diversity as measure of heterogeneity calculated with the ratio of the total number of species to the average number of species (γ over α),

3) γ-diversity as landscape-level diversity, i.e., the total number of species across plots.

Significance of variations in α-diversity between fragments was tested with one-way ANOVA and Bonferroni test (post hoc) in SPSS for Windows, version 13.0.

Shannon's diversity index [(H') = $- \Sigma^{i=1/s} \rho_i * \ln \rho_i$] and Shannon's evenness [(E) = H'/ln (number of species)] were calculated for each fragment using presence-absence data (ground layer species and epiphytes) and abundance data (woody species and climbers) (Magurran 1988).

Species-area curves were used to evaluate the adequacy of sample size. They are based on aggregates of differing numbers of study plots as created by the built-in subsampling procedure (500 times) of PC-ORD for Windows, version 4.2 (McCune and Mefford 1999).

6.3 Results and discussion

6.3.1 Overall species richness

Within 85 study plots in the Bonga region, 309 plant species, including 16 endemics, were recorded: 112 species of the ground layer, 39 epiphytes and 158 woody species and climbers (Table 6.1, Table A 1). A further 18 species, including 3 endemics, were recorded outside the study plots.

Table 6.1 Number of species in 85 study plots listed by growth form

Growth forms:	**Herb**	**Orch.**	**Fern**	**Grass**	**herC**	**wooC**	**Shr.**	**SmT**	**Tree**	**Total**
Ground layer species	75	4	21	12						112
Epiphytic species	4	16	19							39
Woody species/ climbers					35	26	27	25	45	158

Herb: herbs other than orchids; Orch.: orchids; Fern: ferns and fern-allies; Grass: grasses and sedges; herC: herbaceous climbers; wooC: woody climbers; Shr.: shrubs; SmT: small trees; Tree: trees

Most of the ground layer species are widely distributed in Ethiopia, tropical Africa, or are even pantropic. The majority of the epiphytes is common in tropical Africa (Hedberg and Edwards 1989; Edwards et al. 1995; Hedberg and Edwards 1995; Edwards et al. 1997;

Edwards et al. 2000; Cribb et al. 2002; Hedberg et al. 2003). Of the epiphytes found during this study 45 % had not been recorded during earlier forest surveys in the Bonga region (Friis et al. 1982). Many of the woody species and climbers also occur in the upland rainforests of Sudan, Uganda and Kenya (Friis et al. 1982) or in all of the Afromontane archipelago. Few are common in lowland forests of tropical Africa, too (White 1978; Lovett 1993).

The species richness of the Bonga region is quite low when compared to forests in the wetter areas of western Central Africa. In Cameroon, for example, vascular plants comprise 1100 species at Mount Cameroon (7.25 ha), 2297 at Campo Ma'an (14.7 ha), and 2433 in Korup National Park (50 ha) (Mbatchou 2004). In tropical forests outside Africa, the number of woody species in 50 ha plots is also considerable higher than in the Bonga region: 817 and 1171 in Malaysia, 251 in Thailand (Plotkin et al. 2000), and 303 in Panama (Hubbell and Foster 1986). On a global scale, the highest numbers of plant species are found in South American, Afro-Madagascan, and Malaysian rainforests (Gentry 1992).

Summary

- 309 vascular plant species, including 16 endemics were recorded from 85 study plots.

6.3.2 Ubiquitous species

Out of the 309 species recorded in the Bonga region, 110 (36 %) occur in all four forest fragments, 29 (9 %) in three, 37 (12 %) in two, and 133 (43 %) in one of the fragments only. While the majority of the ground layer species is only present in one fragment, many epiphytes, woody species and climbers occur in all forest fragments (Table 6.2).

Table 6.2 Percentage of species occurring in the four studied forest fragments

Occurrence (number of fragments)	**1**	**2**	**3**	**4**
Ground layer species (%)	**54.5**	13.4	10.7	21.4
Epiphytic species (%)	33.3	12.8	5.1	**48.7**
Woody species and climbers (%)	37.3	10.8	9.5	**42.4**

The most common species are similar in all forest fragments, because most species that are very frequent in one fragment (> 90 %) are also frequent in the other fragments (Table 6.3).

Table 6.3 Species with frequency > 90 % in at least one of the forest fragments: Koma (34 study plots), Kaya: Kayakela (22 study plots), Meli: Meligawa (12 study plots), Mank: Mankira (17 study plots); Total (all 85 study plots)

Species	**Family**	**GF**	**Frequency (%)**					**Ab. > 1,000***
			Total	**Koma**	**Kaya**	**Meli**	**Mank**	
Ground layer species								
Desmodium repandum	Fabac.	H	**98**	97	100	92	100	
Oplismenus undulatifolius	Poac.	G	**94**	94	86	100	100	
Piper capense	Piperac.	H	**84**	82	82	67	100	
Sanicula elata	Apiac.	H	**80**	76	77	75	94	
Poecilostachys oplismenoides	Poac.	G	**75**	79	41	100	94	
Pteris catoptera	Pteridac.	F	**75**	59	82	83	94	
Achyranthes aspera	Amaranthac.	H	**75**	62	91	83	76	
Aframomum corrorima	Zingiberac.	H	**75**	74	91	42	82	
Tectaria gemmifera	Aspidiac.	F	**72**	76	45	67	100	
Brillantaisia grotanellii	Acanthac.	H	**20**	0	0	0	100	
Epiphytes								
Peperomia tetraphylla	Piperac.	H	**98**	97	95	100	100	
Asplenium sandersonii	Aspleniac.	F	**93**	85	95	100	100	
Peperomia abyssinica	Piperac.	H	**92**	94	82	92	100	
Loxogramme lanceolata	Polypodiac.	F	**69**	59	55	83	100	
Arthropteris monocarpa	Oleandrac.	F	**69**	76	45	92	71	
Woody species and climbers								
Landolphia buchananii	Apocynac.	wC	**100**	100	100	100	100	x
Vepris dainellii	Rutac.	sT	**100**	100	100	100	100	x
Maytenus gracilipes	Celastrac.	S	**98**	94	100	100	100	x
Coffea arabica	Rubiac.	sT	**98**	94	100	100	100	x
Jasminum abyssinicum	Oleac.	wC	**96**	97	95	100	94	
Bersama abyssinica	Melianthac.	T	**95**	97	95	92	94	
Hippocratea goetzei	Celastrac.	wC	**94**	91	91	100	100	
Chionanthus mildbraedii	Oleac.	sT	**93**	97	77	100	100	x
Clausena anisata	Rutac.	sT	**89**	91	86	92	88	x
Oxyanthus speciosus	Rubiac.	sT	**88**	94	86	75	88	x
Rothmannia urcelliformis	Rubiac.	sT	**88**	79	91	92	100	x
Tiliacora troupinii	Menispermac.	wC	**82**	65	86	100	100	
Galiniera saxifraga	Rubiac.	sT	**81**	88	68	92	76	x
Dracaena fragrans	Agavac.	sT	**80**	56	95	92	100	x
Psychotria orophila	Rubiac.	sT	**80**	100	77	33	76	x
Embelia schimperi	Myrsinac.	wC	**75**	59	86	75	94	
Lepidotrichilia volkensii	Meliac.	sT	**73**	94	55	75	53	
Deinbollia kilimandscharica	Sapindac.	sT	**71**	82	41	58	94	x
Oncinotis tenuiloba	Apocynac.	wC	**62**	50	68	42	94	
Trilepisium madagascariense	Morac.	T	**58**	0	95	92	100	
Culcasia falcifolia	Arac.	hC	**42**	38	18	25	94	
Turraea holstii	Meliac.	S	**19**	0	0	0	94	

GF (growth form): H: herb; F: fern; G: grass; wC: woody climber; hC: herbaceous climber; S: shrub; sT: small tree; T: tree

** Abundance: more than 1,000 individuals in all study plots taken together*

Common species, however, constitute but a small percentage of the total species richness: only 7 % of the ground layer species and epiphytes, respectively, and 10 % of the woody species and climbers occur in more than 75 % of all study plots. In contrast, 54 % of the ground layer species, 33 % of the epiphytes and 29 % of the woody species and climbers are restricted to one or two study plots.

For woody species and climbers, the total number of individuals per species ($\geq$ 0.5 m) varies from one individual up to 26,669 individuals for *Coffea arabica*, which is the most abundant species in this study (Table A 3). Altogether, there are only 14 species (9 %) with more than 1,000 individuals, whereas the bulk of species (71 %) has less than 100 individuals in all plots taken together. Most highly abundant species are small trees, which also have high frequencies (Table 6.3). *Dracaena afromontana* and *Justicia schimperiana* have more than 1,000 individuals, but low frequency because they occur rather clumped in few plots. Small palms like *Dracaena afromontana* and *Dracaena fragrans* often have extraordinarily high densities in the shaded understory, because they exploit scant light resources very effectively (Ewel and Bigelow 1996).

While many woody climbers and small trees are frequent and abundant, this is not the case for trees. *Bersama abyssinica* and *Trilepisium madagascariense* are the only tree species with frequencies higher than 90 % in at least one of the forest fragments (Table 6.3). *Milletia ferruginea*, the most abundant tree species with 608 individuals, is clearly less abundant than the most common woody climbers or small trees with over 1,000 individuals.

Most tree individuals are saplings. Only 33 out of 45 tree species have mature individuals taller than 15 m in the canopy layer. *Olea welwitschii* and *Trilepisium madagascariense* dominate the canopy above 30 m, and were observed to grow up to 40 m high. *Pouteria adolfi-friederici* with individuals as tall as 42 m is the only other tree species reaching at least 40 m height. Canopy individuals (> 15 m) of *Olea welwitschii* and *Schefflera abyssinica* are relatively frequent in all fragments (Table 6.4). For all other species, the number of canopy individuals varies considerable between fragments. On average, seven canopy individuals (> 15 m) fit into one study plot.

Table 6.4 Frequency of canopy individuals (height > 15 m) of tree species with more than 10 canopy individuals: Koma (34 study plots), Kaya: Kayakela (22 study plots), Meli: Meligawa (12 study plots), Mank: Mankira (17 study plots); Total (all 85 study plots)

Species	**Family**	**Frequency (%)**					**Total**
		Total	**Koma**	**Kaya**	**Meli**	**Mank**	**abundance**
Olea welwitschii	Oleac.	**47**	56	45	33	41	79
Schefflera abyssinica	Araliac.	**42**	35	36	42	65	43
Milletia ferruginea	Fabac.	**34**	35	45	42	12	64
Trilepisium madagascariense	Morac.	**33**	0	59	33	65	94
Sapium ellipticum	Euphorbiac.	**31**	12	50	33	41	45
Syzygium guineense	Myrtac.	**25**	35	9	33	18	50
Phoenix reclinata	Arecac.	**24**	9	36	17	41	30
Croton macrostachys	Euphorbiac.	**19**	6	23	50	18	27
Polyscias fulva	Araliac.	**16**	21	5	8	29	14
Elaeodendron buchananii	Celastrac.	**15**	29	0	0	18	36
Pouteria adolfi-friederici	Sapotac.	**11**	12	0	8	24	13
Ocotea kenyensis	Laurac.	**8**	6	0	17	18	13
Ilex mitis	Aquifoliac.	**6**	15	0	0	0	11

Summary

- The most common species have high frequencies in all forest fragments, but constitute less than 10 % of the total species richness.
- Most species with high abundances and frequencies throughout the Bonga region are woody climbers and small trees, whereas tree species, in particular canopy individuals (height > 15 m), are quite irregularly distributed.

6.3.3 Species diversity distribution

This section points out differences in species diversity between the forest fragments and evaluates the impact of intensive coffee management on species diversity. Koma is the species richest fragment and also has the highest number of species observed in a single fragment (Table 6.5). This is partly due to the large sample size in Koma.

Table 6.5 Species richness of forest fragments

	Koma (34 plots)	**Kayakela (22 plots)**	**Meligawa (12 plots)**	**Mankira (17 plots)**
Species richness (γ-diversity)	221	188	157	168
No. of species only found in this fragment	63	38	10	22

It will be demonstrated that differences in species richness between forest fragments vary considerably for the ground layer, epiphytes, woody plants and climbers. Besides, coffee management leads to conspicuous changes in species diversity between intensively managed semi-forest coffee (SFC) systems and natural forest, i.e., unmanaged forest (disturbed and undisturbed) and forest coffee (FC) systems (see section 5.3.3). In the following, the study plots from natural forest and study plots from SFC systems will, therefore, be analyzed separately.

Ground layer in natural forest

Out of the 80 ground layer species sampled in the natural forest, 18 (23 %) occur in all forest fragments. The number of shared species is highest between Koma and Meligawa and Koma and Mankira (Table 6.6).

Species richness is clearly higher in Koma than in the other fragments, but evenness is lowest due to a high number of infrequent species. Many of these rare species are ferns, a growth form particularly common in Koma (Table A 2). In Mankira, evenness is high because many species are frequent in this fragment. This is also reflected by the 5 ground layer species occurring in all plots in Mankira (Table 6.3). Kayakela has the lowest species richness despite the fact that more plots were sampled in Kayakela than in Meligawa.

Table 6.6 Number of study plots and species diversity patterns for ground layer vegetation in the four studied forest fragments

	Koma	**Kayakela**	**Meligawa**	**Mankira**
No. of study plots (all forest)	34	22	12	17
Species richness (γ-diversity)	70	59	47	47
No. of study plots (natural forest)	29	11	8	14
Species richness (γ-diversity)	61	27	33	43
Species density (α-diversity)*	14.9	12	15.5	18.3
ß-diversity (γ/α)	4.16	2.25	2.13	2.35
Evenness	0.85	0.91	0.93	0.91
Shannon index	3.49	3.00	3.25	3.43
Number of shared species (natural forest): 18 species (23 %) occur in all fragments				
Koma	-	22	28	28
Kayakela		-	22	25
Meligawa			-	23

** Significantly higher in Mankira than in Koma and Kayakela ($p < 0.05$, Bonferroni test, one-way ANOVA)*

The comparatively low Shannon index underlines the low species richness of the Kayakela forest fragment. For Koma and Mankira, the Shannon indices are almost similar, even though species richness is much higher in Koma than in Mankira. This reflects the difference in species evenness, because the Shannon index underestimates diversity in large samples if a lot of rare species are present as is the case for the Koma forest fragment (Franc and Mai 1998; McCune and Grace 2002).

Differences in species richness, species density, and ß-diversity are reflected by species-area curves (Figure 6.1). High species richness but low species density leads to a high ß-diversity in the Koma forest fragment. As a result, the respective species-area curve has a steep slope. This indicates that species richness in Koma is probably underestimated despite the large number of study plots. In contrast, the slopes of the species-area curves for Kayakela and Mankira are quite flat and align towards a maximum value. It can thus be assumed that the majority of the ground layer species was sampled in Mankira and Kayakela with 14 and 11 study plots, respectively. Meligawa is not discussed due to the small sample size in this fragment.

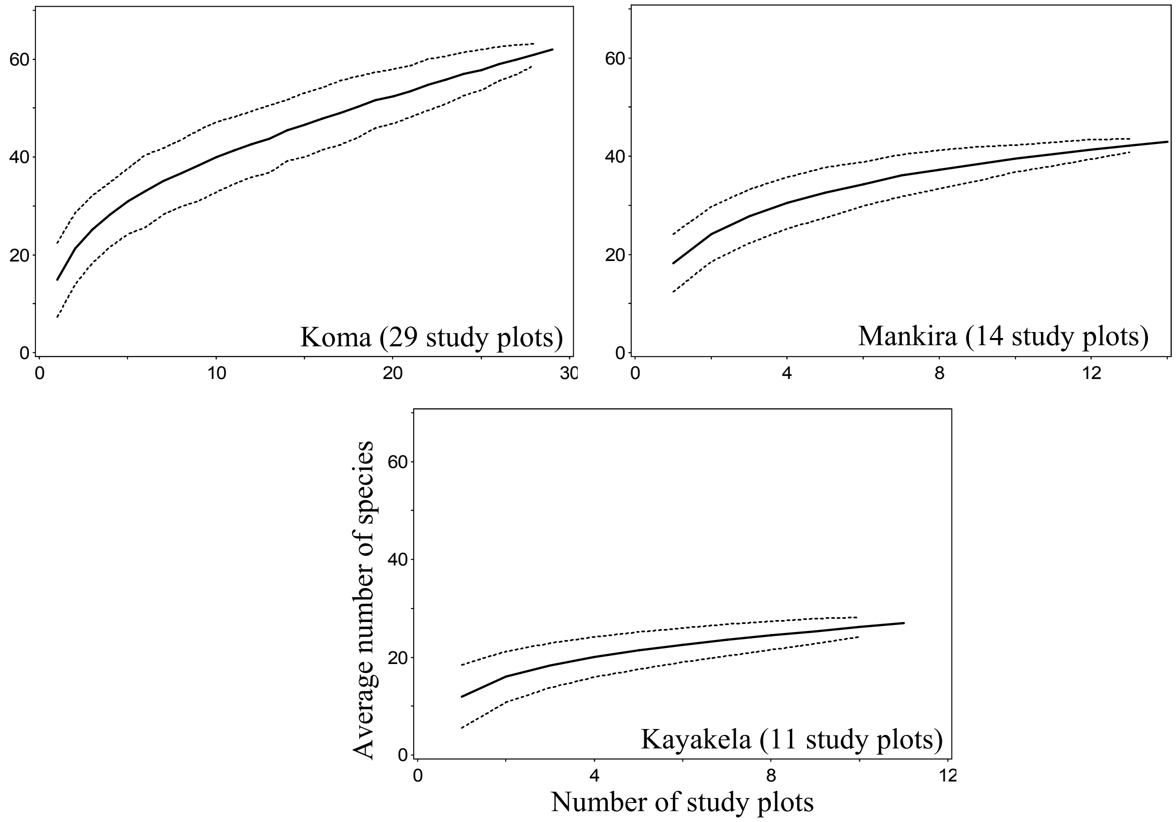


Figure 6.1 Species-area curves with confidence bands (+/- 1 standard deviation) for the ground layer vegetation in natural forest at Koma, Mankira and Kayakela

Epiphytes in natural forest

Out of the 35 epiphytic species sampled in the natural forest, 16 (46 %) occur in all forest fragments (Table 6.7). Thus, differences in species composition between fragments are less pronounced for epiphytes than for ground layer vegetation, where only 23 % of the species occurred in all fragments.

Species richness is highest in Koma and Mankira despite the large differences in sample size. Evenness and Shannon indices are also almost similar for these two fragments. As for the ground layer vegetation, the Shannon index is lowest for Kayakela, reflecting low species richness and comparatively low evenness in this fragment.

Table 6.7 Number of study plots and species diversity patterns for epiphytes in the four studied forest fragments

	Koma	**Kayakela**	**Meligawa**	**Mankira**
No of study plots (all forest)	34	22	12	17
Species richness (γ-diversity)	30	23	25	27
No of study plots (natural forest)	29	11	8	14
Species richness (γ-diversity)	27	21	19	27
Species density (α-diversity)*	11.1	7.8	10.9	11.5
ß-diversity (γ/α)	2.43	2.69	1.74	2.35
Evenness	0.91	0.90	0.96	0.92
Shannon index	2.99	2.75	2.83	3.02
Number of shared species (natural forest): 16 species (46 %) occur in all fragments				
Koma	-	18	18	21
Kayakela		-	16	20
Meligawa				18

** Significantly lower in Kayakela than in Koma and Mankira ($p < 0.05$, Bonferroni test, one-way ANOVA)*

The species-area curve for Koma is quite flat, indicating that a considerable amount of epiphytic species richness is captured by the 29 sampling plots (Figure 6.2). In Mankira and Kayakela, the number of sampling plots was much lower than for Koma, and the steep curves for these fragments suggest that more sampling effort is needed there. In the case of Kayakela, the steep curve is related not only to the low number of sampling plots, but also to low species density.

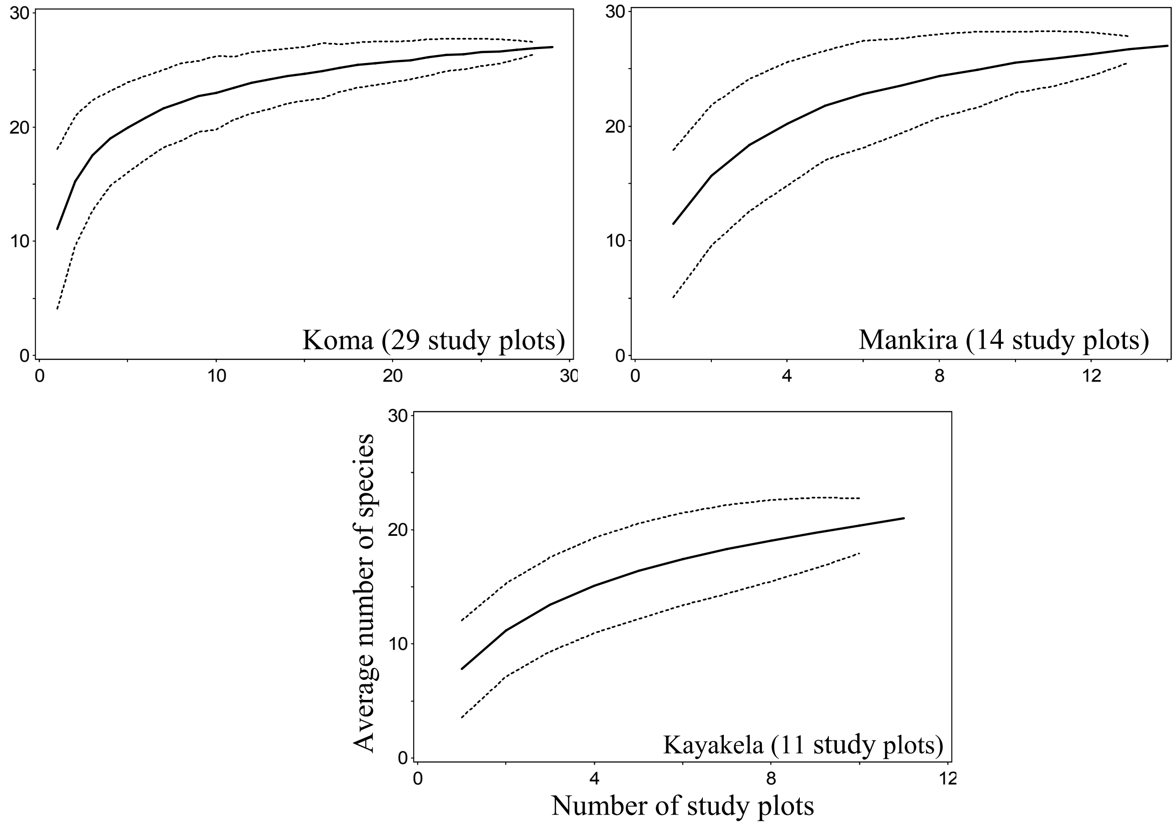


Figure 6.2 Species-area curves with confidence bands (+/- 1 standard deviation) for epiphytes in natural forest at Koma, Mankira and Kayakela

Woody plants and climbers in natural forest

Out of the 140 woody plant and climber species sampled in the natural forest 57 (41 %) occur in all fragments. The number of shared species between pairs of fragments is quite similar and varies between 66 and 71 (Table 6.8).

Table 6.8 Number of study plots and species diversity patterns for woody plants and climbers in the four studied forest fragments

	Koma	**Kayakela**	**Meligawa**	**Mankira**
No. of study plots (all forest)	34	22	12	17
Species richness (γ-diversity)	121	106	85	94
No. of study plots (natural forest)	29	11	8	14
Species richness (γ-diversity)	114	87	74	87
Species density (α-diversity)*	42.0	38.4	40.4	45.1
ß-diversity (γ/α)	2.71	2.27	1.83	1.93
Evenness	0.70	0.55	0.61	0.65
Shannon index	3.30	2.44	2.63	2.89
Number of shared species (natural forest): 57 species (41 %) occur in all fragments				
Koma	-	69	68	71
Kayakela		-	66	69
Meligawa			-	66

* *Species density in Mankira is higher than in Kayakela ($p < 0.05$, Bonferroni test, one-way ANOVA)*

Bonga stands out as the most diverse forest fragment with highest species richness, evenness and Shannon index (Table 6.8). In Mankira, species density is very high, which is reflected by the fact that many woody plant and climber species occur in all plots of this fragment (Table 6.3). Mankira and Kayakela have the same species richness, but the Shannon index is higher for Mankira due to higher evenness in Mankira than in Kayakela. The evenness is low in Kayakela because *Coffea arabica* is extremely abundant amongst the small trees and *Trilepisium madagascariense* is dominant amongst tree species. This is also indicated by low Shannon indices for the respective growth forms in Kayakela (Table 6.9).

A detailed analysis of the different growth forms reveals that Koma has highest species richness and Shannon index regarding climbers, shrubs and small trees only (Table 6.9). For trees, the Shannon index is highest in Mankira and the number of species in Koma is comparatively low considering the large sample size for this fragment.

Table 6.9 Species richness (γ-diversity) and Shannon index for woody growth forms and climbers in natural forest of four forest fragments, respectively

		Forest fragment			
		Koma (29 plots)	**Kayakela (11 plots)**	**Meligawa (8 plots)**	**Mankira (14 plots)**
Herbaceous climbers	Species richness	**18**	9	4	8
	Shannon index	1.59	**1.81**	0.54	0.60
Shrubs	Species richness	**17**	11	8	11
	Shannon index	**1.25**	0.82	0.87	0.58
Small trees	Species richness	**22**	20	19	19
	Shannon index	**2.36**	1.66	1.80	1.97
Woody climbers	Species richness	**23**	14	15	17
	Shannon index	**2.22**	1.97	2.14	2.18
Trees	Species richness	**34**	33	28	32
	Shannon index	2.79	2.50	2.69	**2.84**
Upper canopy (trees > 15m)	Species richness	18	18	13	**20**
	Shannon index	2.32	1.92	2.39	**2.59**

The differences in tree species diversity between the fragments become even more apparent if canopy tree individuals taller than 15 m are considered separately (Table 6.9). Mankira has the highest species richness and the highest Shannon index. The diversity of the canopy layer is also shown by the fact that individuals of 4 species constitute 50 % of the individuals in the canopy: *Trilepisium madagascariense* (17 %), *Sapium ellipticum* (13 %), *Schefflera abyssinica* (13 %), and *Olea welwitschii* (12 %). In Koma, 3 species make up 50 % of the canopy individuals: *Olea welwitschii* (22 %), *Elaeodendron buchananii* (17 %), and *Syzygium guineense* (14 %). Kayakela has the lowest Shannon index because *Trilepisium* *madagascariense* alone represents 50 % of the canopy tree individuals. This species has a narrow crown and individuals can grow very close to each other.

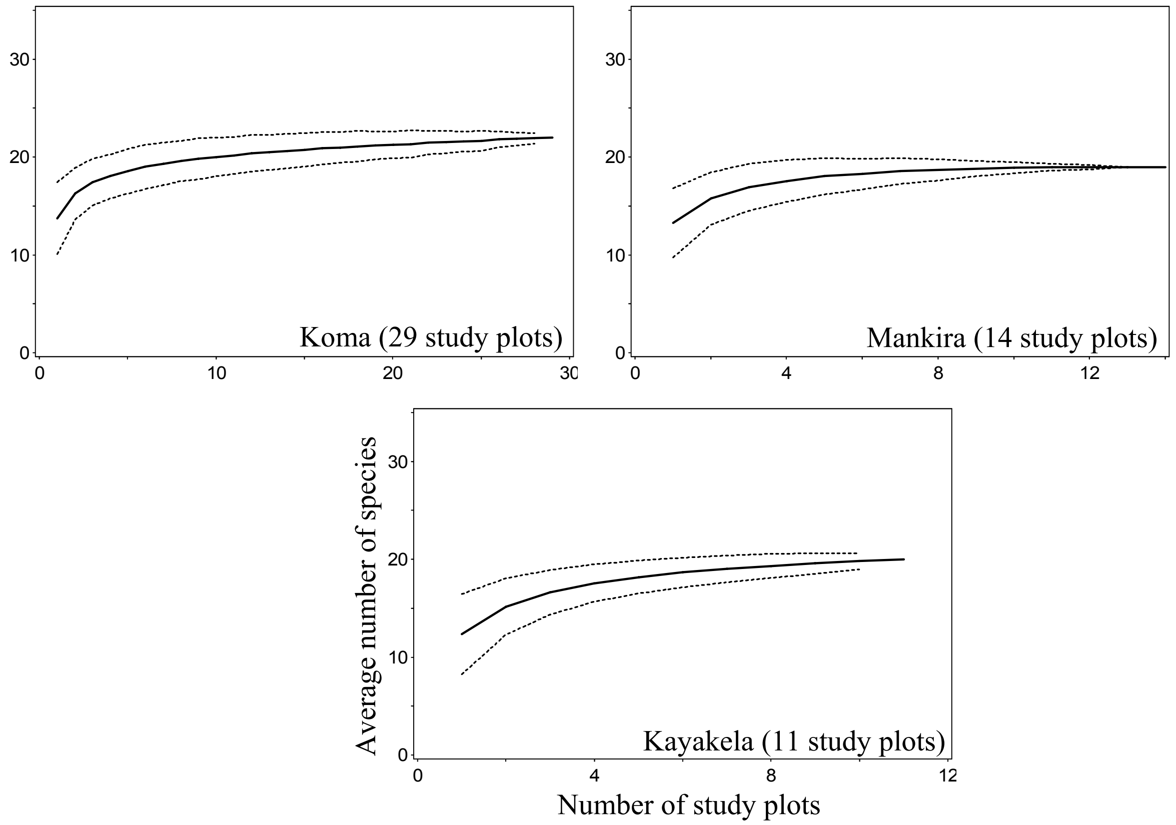
The species-area curves illustrate differences in species diversity patterns between fragments and growth forms (Figure 6.3). Curves for herbaceous climbers and shrubs are not shown, because many of these species are ruderals that encroach into the natural forest. Most of these species have low abundances while few are dominant, e.g., the climber *Culcasia falcifolia* and the shrub *Maytenus gracilipes*, which results in extremely small Shannon indices (Table 6.9).

For small trees, species richness ranges from 19 species in Mankira and Meligawa up to 22 species in Koma. These figures are remarkably close despite large differences in sample size (Table 6.9). Furthermore, the species-area curves for small trees are extremely flat for all fragments (Figure 6.3). They suggest that 10 study plots are enough to record a representative number of small tree species in a forest fragment in the Bonga region. The determination of understory species richness in tropical forests generally requires smaller spatial scales than the determination of tree species richness (Gentry 1992; Cadotte et al. 2002).

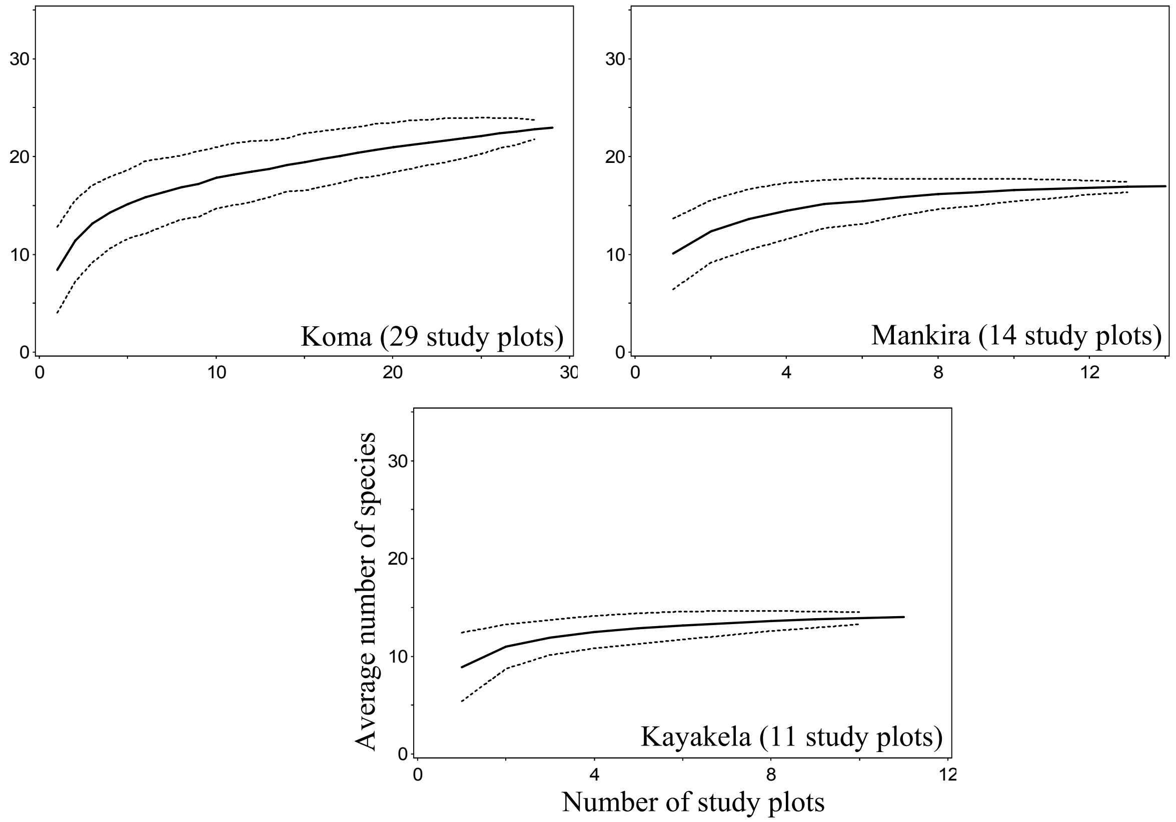
In contrast to the small trees, the number of woody climbers is much higher in Koma than in the other fragments. For Kayakela and Mankira, the flat species-area curves suggest that a representative number of woody climber species can be sampled within 10 study plots (Figure 6.3). For Koma, though, the steep slope of the species-area curve indicates that more than the 29 study plots are needed to sample all woody climber species in this fragment.

Regarding tree species, the species-area curve for Koma flattens out and 29 plots seem an appropriate sample size for trees in this fragment. For Kayakela and Mankira, however, the curves are steeper than for Koma, in particular for Kayakela. The number of study plots in these fragments was much lower than in Koma. Hence, the curves confirm that the sampling of tree species requires high sampling effort. Generally, it can be assumed that the large majority of the tree species occurring in the Bonga region was sampled. Three other vegetation studies conducted in the Bonga region mention only a few additional tree species, but did not record up to 15 tree species found during this study (Friis et al. 1982; Abayneh Derero 1998; Mateos Ersado 2001).

Small trees



Woody climbers



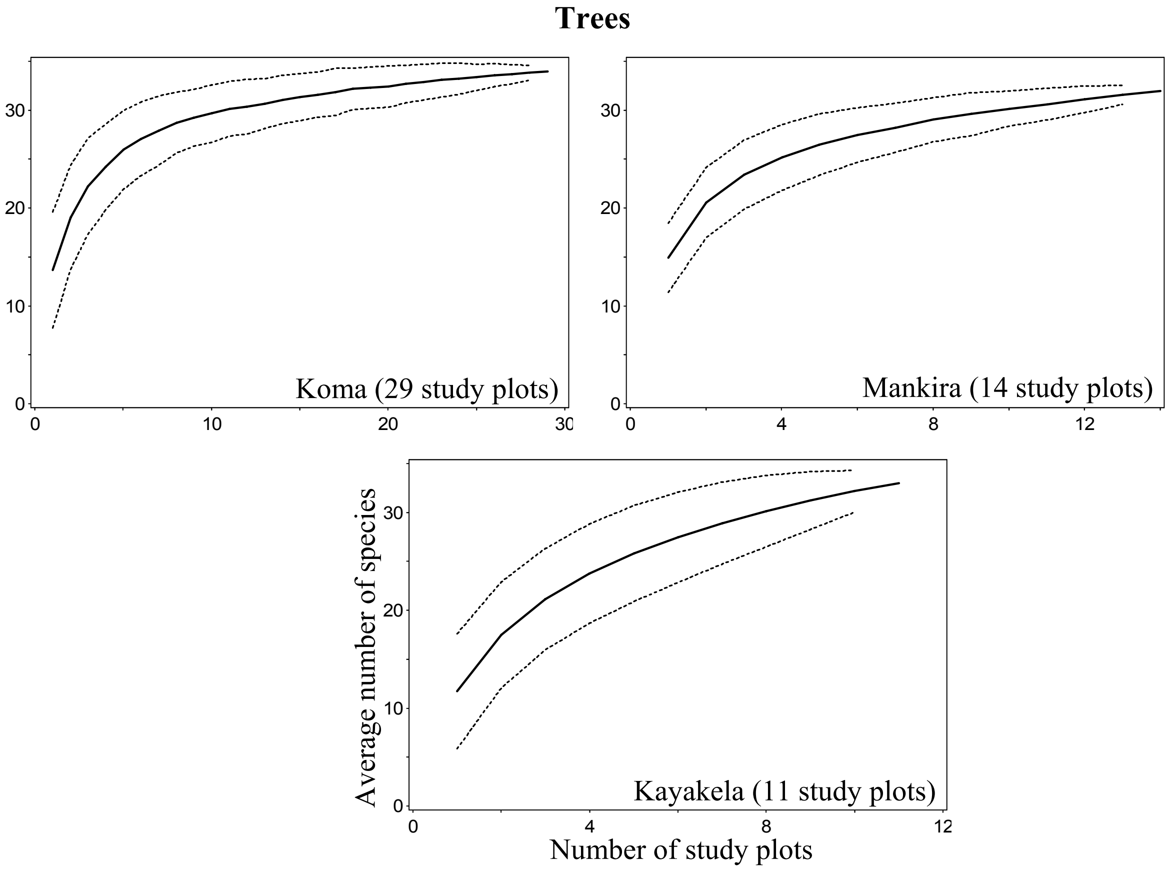


Figure 6.3 Species-area curves with confidence bands (+/- 1 standard deviation) for small trees, woody climbers and trees in natural forest at Koma, Kayakela and Mankira

Impact of coffee management on species diversity

Kayakela is suited best to show the impact of intensive coffee management on species diversity, because in this fragment the number of study plots is similar in natural forest and in intensively managed semi-forest coffee (SFC) systems.

The average cover of the ground layer is higher in the SFC systems (52 %) than in the natural forest (27 %), because intensively managed plots are less shaded (see section 5.3.3). Intensive coffee management leads to a strong increase in species richness and Shannon index of the ground layer vegetation, but does not have significant impact on species density (Table 6.10). Generally, the number of species and percentage of cover for ground herbs is markedly higher in forest gaps than in undisturbed forest (Hall and Swaine 1976; Brokaw 1985; Richards 1996). In contrast, the number of epiphyte species is slightly reduced and the Shannon index for epiphytes is also lower in SFC systems as compared to natural forest.

Table 6.10 Species diversity patterns for ground layer vegetation and epiphytes in natural forest (NF) and intensively managed semi-forest coffee (SFC) systems in Kayakela forest fragment

	Ground layer vegetation		**Epiphytes**	
	NF (11 plots)	**SFC (11 plots)**	**NF (11 plots)**	**SFC (11 plots)**
Species richness (γ-diversity)	27	55	21	18
Species density (α-diversity)*	12	15.7	7.8	7.5
ß-diversity (γ/α)	2.25	3.5	2.69	2.4
Evenness	0.91	0.91	0.90	0.93
Shannon index	3.00	3.64	2.75	2.68

** Difference is not significant for both ground layer vegetation and epiphytes (one-way ANOVA)*

As for the ground layer, coffee management has a positive impact on species richness of woody plants and climbers (Table 6.11). Despite high species richness in the SFC systems, evenness and Shannon index are lower than for natural forest, because coffee is dominant. The splitting up of species richness by growth forms shows that species richness increases for shrub and climber species, which are typical growth forms of disturbed habitats. In contrast, the number of tree species in the upper canopy (individuals > 15 m) is reduced by management interventions.

Table 6.11 Species diversity patterns for woody plants and climbers in natural forest and intensively managed semi-forest coffee (SFC) systems in Kayakela forest fragment

	Natural forest (11 plots)	**SFC system (11 plots)**
Species richness (all woody plants and climbers)	87	97
Species density (α-diversity)*	38.4	43.7
ß-diversity (γ/α)	2.27	2.22
Evenness	0.55	0.38
Shannon index	2.44	1.75
Species richness (herbaceous climbers)	9	14
Species richness (woody climbers)	14	17
Species richness (shrubs)	11	14
Species richness (small trees)	20	19
Species richness (trees)	33	33
Species richness (upper canopy, trees > 15m)	18	13

** Difference is not significant (one-way ANOVA)*

Thorough interpretation of variations in species diversity patterns between forest fragments and between forests with different management intensities requires knowledge on underlying changes in species composition and relevant environmental parameters. This will be analyzed in the following with ordination techniques.

Summary

- Species richness is clearly highest in Koma for ground layer vegetation, climbers and shrubs.
- Mankira has the highest Shannon indices for tree species and epiphytes. This fragment is also characterized by high species densities and high evenness.
- Kayakela has the lowest Shannon indices of all fragments, because evenness and species richness are generally low.
- Meligawa has an intermediate position regarding species diversity and was not discussed further due to small sample size.
- Sampling effort is highest for tree and epiphyte species (29 plots). In contrast, small trees require few study plots (10 plots). Ground layer vegetation and woody climbers need high sampling effort in Koma only.
- Intensive coffee management increases species richness of the ground layer, climbers and shrubs, but reduces species richness of epiphytes and the upper canopy.

6.3.4 General remarks on species composition and environmental factors

The ordination diagram, based on principal component analysis (PCA) of frequency data of all species, clearly shows differences in species composition between fragments (Figure 6.4). The diagram depicts study plots at Koma, Kayakela and Mankira as distinct clusters, which means that they share similar species compositions. Species that occur in only one study plot are not considered, because it cannot be confirmed if this occurrence is a stochastic event or related to the environmental conditions.

Parameters tested for their influence on species composition are slope, altitude, moss index, exposition, cover index and coppiced plants. The number of coppiced plants is an indicator of coffee management intensity; the cover index is an indirect measure of disturbance based on the percentage cover of the ground and shrub layer (see section 5.3.2). The highest level of disturbance is found in the semi-forest coffee (SFC) systems and thus, the cover index is also an indicator of coffee management intensity. As already mentioned above, SFC systems are referred to as intensively managed forest, while forest coffee (FC) systems and unmanaged forest (disturbed and undisturbed) are considered as natural forest.

The arrows in Figure 6.4 show that the plots at Koma are situated at a higher altitude than the plots at Kayakela and Mankira. Plots at Koma and Mankira generally have steeper slopes and higher moss indices than those at Kayakela, while at Kayakela there are more intensively managed plots with high cover indices and high numbers of coppiced plants.

Plots at Meligawa are scattered across the whole diagram indicating a heterogeneous environment and species composition. Considering the fact that the ordination is based on indirect gradient analysis, the species composition reflects very well the environmental conditions (Table 5.1) and the management intensity (Table 5.9) prevalent in each fragment.

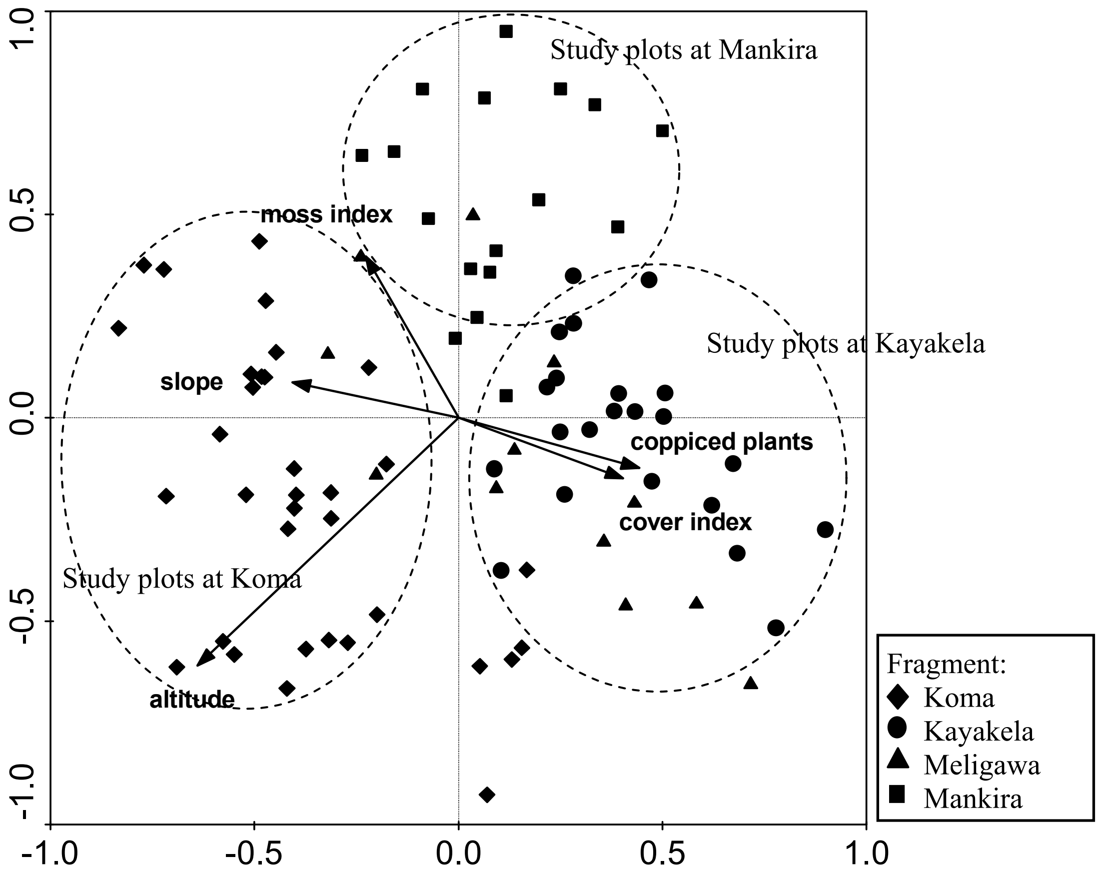


Figure 6.4 Ordination of study plots from four forest fragments according to species frequency data (principal component analysis, PCA); based on 227 species occurring in more than one study plot

Altitude is the most important factor influencing species composition as can be seen by the long arrow in the ordination diagram. The importance of the altitudinal gradient is confirmed by Monte Carlo permutation tests and the automatic forward selection of environmental variables in the redundancy analysis (RDA). Altitude contributes significantly to the model and has the highest value for λ_A (Table 6.12). Cover index, moss index and slope also contribute significantly to the model even though their values for λ_A are considerably lower than for altitude. Data on the exposition of the plots did not contribute significantly to this model or in fact to any of the models generated in this study, and are therefore not used in the subsequent analyses.

Table 6.12 Results for principal component analysis (PCA) and redundancy analysis (RDA) of species frequency data (227 species present in more than one study plot); number of study plots is 85

Axes:	**1**	**2**	**3**	**4**
PCA				
Eigenvalues (λ)	0.084	0.057	0.046	0.046
Species-environment correlations	0.838	0.76	0.381	0.411
Cumulative % variance of species data	8.4	14.1	18.8	23.3
Cumulative % variance of species-environment relation	40	62.2	66.8	72
RDA				
Eigenvalues (λ)	0.067	0.038	0.02	0.014
Species-environment correlations	0.925	0.861	0.739	0.805
Cumulative % variance of species data	6.7	10.5	12.5	13.9
Cumulative % variance of species-environment relation	45.3	71.1	84.4	93.8

Marginal Effects (variance explained singly)		**Conditional effects (order of inclusion in model)**			
	λ_1		λ_A	**P***	**F**
Altitude	0.06	Altitude	0.06	0.002	5.24
Cover index	0.04	Cover index	0.03	0.002	2.91
Coppiced plants	0.03	Moss index	0.03	0.002	2.21
Slope	0.03	Slope	0.02	0.002	1.89
Moss index	0.02	Coppiced plants	0.01	0.222	1.11

** Significance level from the Monte Carlo permutation*

The eigenvalues (λ) and the cumulative percentage of explained variance of species data are very low in both PCA and RDA (Table 6.12). In fact, these values are also low in all other ordination analyses carried out for this study. Such low values, however, are common for ecological field data and do not impede the interpretation of the results (Økland 1999; ter Braak and Šmilauer 2002; Lepš and Šmilauer 2003) (see also section 6.2.2). This is underlined by the good correlation between the results of both constrained and unconstrained ordination methods.

Soil data are not included in the model because soil samples were only taken from 37 study plots. Koma soils have a tendency to be less nutritious than the soils from the other fragments, but the differences are very small (Table 5.2). Further studies need to confirm if statistically significant differences in soil conditions between the fragments also have an ecological significance for plant species distribution.

This global ordination is a first indicator that Koma, Kayakela and Mankira vary in species composition due to underlying differences in environmental parameters. It will be demonstrated that the impact of environmental parameters on species composition depends on the growth forms considered. The clear separation of plots from Mankira and Kayakela, for example, is only observed for the ground layer vegetation.

Summary

- Koma, Mankira and Kayakela have distinct species compositions due to differences in environmental parameters. Meligawa has an intermediate position.

6.3.5 Ground layer composition

The PCA ordination diagram shows that the plots at Mankira share a distinct species composition regarding their ground layer vegetation (Figure 6.5).

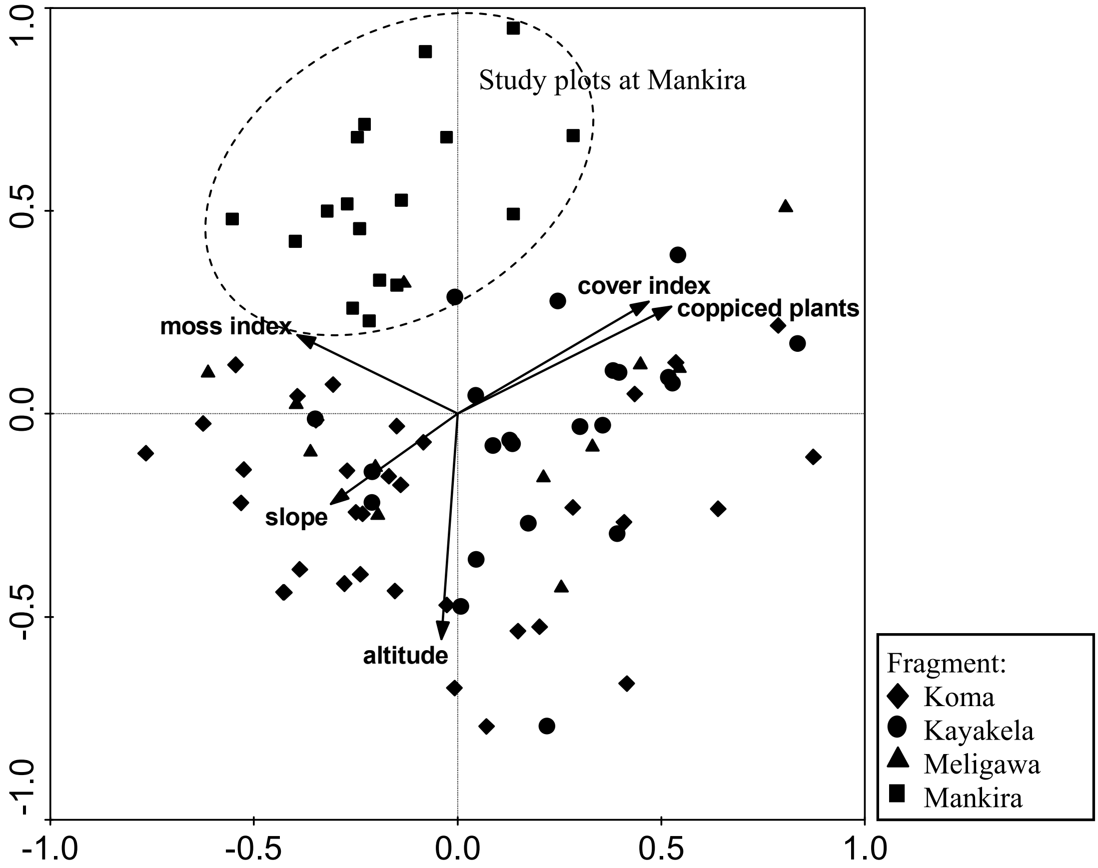


Figure 6.5 Ordination of study plots from four forest fragments according to species frequency data of the ground layer vegetation (principal component analysis, PCA); based on 70 species occurring in more than one study plot

Studies plots at Mankira group together due to some frequent species not found in any of the other fragments, e.g., *Brillantaisia grotanellii*, *Leptaspis zeylanica*, *Selaginella* *kalbreyeri*, and *Euphorbia schimperiana*. In addition, there are some species that are much more common in Mankira than elsewhere, e.g., *Dicliptera laxata*, *Phyllanthus pseudoniruri*, and *Impatiens hochstetteri* (compare Table A 2).

The arrows of all tested environmental parameters are quite long, indicating that all are important for explaining differences in species composition (Figure 6.5). Monte Carlo permutation tests in the RDA confirm that all environmental parameters contribute significantly to the model. Altitude comes second after cover index in the automatic forward selection of environmental variables (Table 6.13). As all plots at Mankira are clustered at the lower end of the altitudinal arrow, their particular species composition is related to the low altitude of the plots (< 1,830 m asl). This is coupled with rather moist plot conditions as indicated by the positioning of the plots in relation to the arrow for the moss index. The Kayakela forest fragment is also situated at low altitude, but is less humid than Mankira. This is underlined by the fact that *Pilea rivularis* and *Elatostema monticolum*, herbs associated with streams (Friis et al. 1982), are frequent in Mankira, but rare or absent in Kayakela. It is assumed that relatively high humidity in Mankira not only causes differences in species composition, but is also the reason for higher species richness, species density, and Shannon index of the ground layer vegetation in Mankira as compared to Kayakela (Table 6.6).

Table 6.13 Results for principal component analysis (PCA) and redundancy analysis (RDA) of ground layer species frequency data (70 species present in more than one study plot); number of study plots is 85

Axes:	**1**	**2**	**3**	**4**
PCA				
Eigenvalues (λ)	0.114	0.079	0.07	0.058
Species-environment correlations	0.724	0.606	0.6	0.16
Cumulative % variance of species data	11.4	19.3	26.3	32.1
Cumulative % variance of species-environment relation	38.7	57.6	74	75
RDA				
Eigenvalues (λ)	0.066	0.042	0.026	0.012
Species-environment correlations	0.787	0.778	0.666	0.596
Cumulative % variance of species data	6.6	10.8	13.4	14.6
Cumulative % variance of species-environment relation	42.8	70.3	87.3	94.8

Marginal Effects (variance explained singly)		**Conditional effects (order of inclusion in model)**			
	λ_1		**λ_A**	**P***	**F**
Cover index	0.05	Cover index	0.05	0.002	4.08
Coppiced plants	0.04	Altitude	0.04	0.002	3.76
Altitude	0.04	Moss index	0.03	0.002	2.62
Moss index	0.03	Slope	0.02	0.002	1.79
Slope	0.02	Coppiced plants	0.01	0.012	1.61

** Significance level from the Monte Carlo permutation*

Due to the particular species composition at Mankira, the PCA is repeated separately for plots at Koma, Kayakela, and Meligawa (Figure 6.6). This ordination depicts most intensively managed SFC plots to the right of the diagram. Cover index and coppiced plants have high values in these plots as shown by the respective arrows.

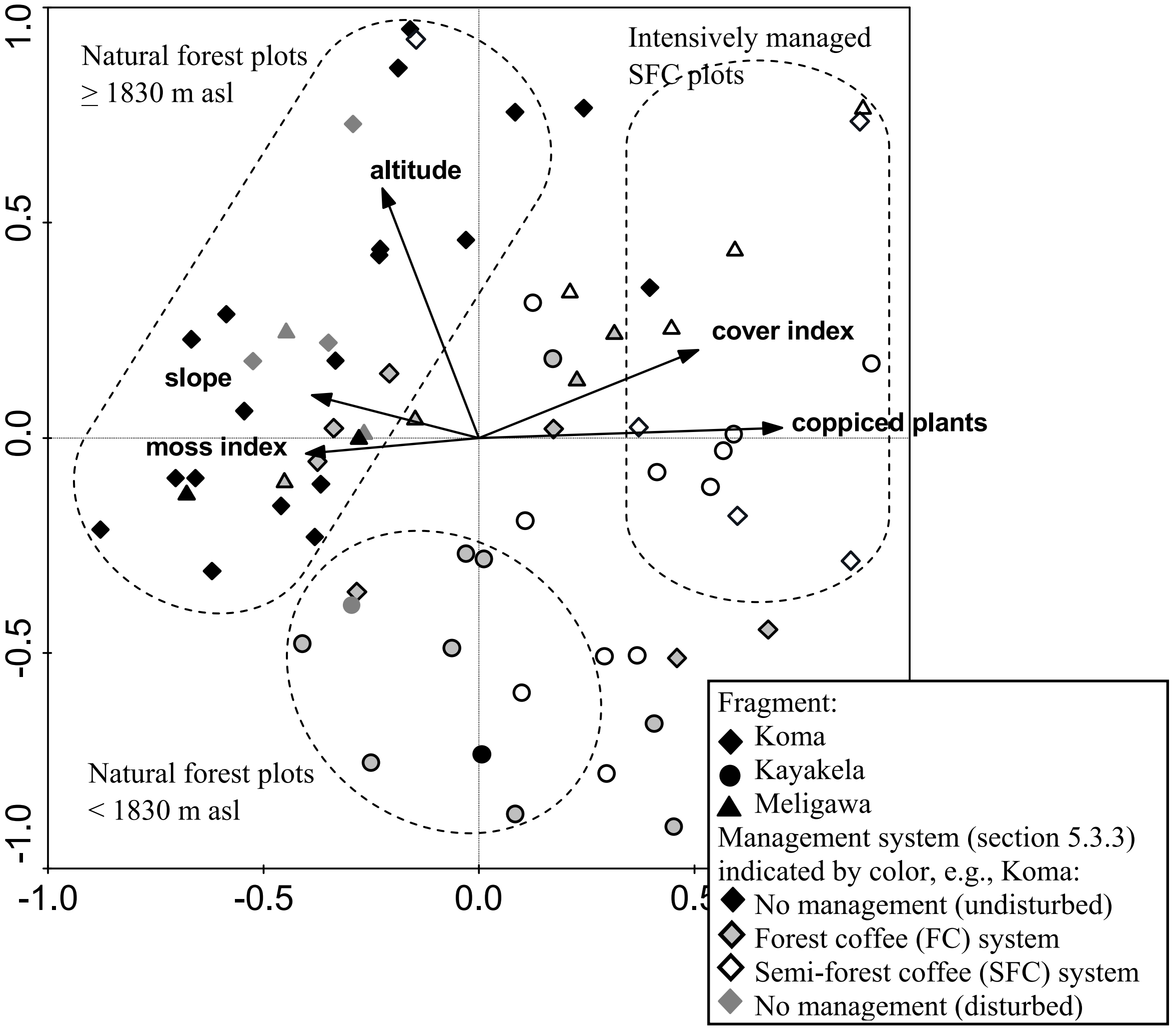


Figure 6.6 Ordination of study plots from three forest fragments according to species frequency data of the ground layer vegetation (principal component analysis, PCA); based on 63 species occurring in more than one study plot

The strong influence of cover index and coppiced plants on the species composition is confirmed by the automatic forward selection in the RDA where coppiced plants has the highest value for λ_A, and both coppiced plants and cover index explain most of the variance singly (Table 6.14). High values for coppiced plants, i.e., the removal of woody vegetation, indicate high management intensity. Increased light penetration in these plots leads to high percentage cover of ground and shrub layer (cover index). Furthermore, humidity is reduced as shown by the arrow for the moss index. The fact that SFC plots at Koma, Kayakela and

Meligawa intermingle underlines the strong impact of coffee management irrespective of the altitudinal gradient.

Table 6.14 Results for principal component analysis (PCA) and redundancy analysis (RDA) of ground layer species frequency data (63 species occurring in more than one study plot); number of study plots is 68 (Koma, Kayakela, and Meligawa)

Axes:	**1**	**2**	**3**	**4**
PCA				
Eigenvalues (λ)	0.13	0.079	0.071	0.06
Species-environment correlations	0.795	0.646	0.384	0.326
Cumulative % variance of species data	13	20.9	28	34.1
Cumulative % variance of species-environment relation	46.6	65.2	71.2	74.9
RDA				
Eigenvalues (λ)	0.087	0.039	0.022	0.016
Species-environment correlations	0.832	0.752	0.675	0.689
Cumulative % variance of species data	8.7	12.6	14.9	16.5
Cumulative % variance of species-environment relation	49.2	71.6	84.3	93.5

Marginal Effects (variance explained singly)		**Conditional effects (order of inclusion in model)**			
	λ_1		**λ_A**	**P***	**F**
Coppiced plants	0.07	Coppiced plants	0.07	0.002	5.08
Cover index	0.05	Altitude	0.04	0.002	2.8
Altitude	0.04	Cover index	0.02	0.006	1.83
Slope	0.03	Slope	0.03	0.004	1.62
Moss index	0.03	Moss index	0.02	0.028	1.51

** Significance level from the Monte Carlo permutation*

The most common forest species, e.g., *Desmodium repandum*, *Oplismenus undulatifolius* and *Achyranthes aspera* (Table 6.3), persist in intensively managed plots. The increase in species richness as compared to the natural forest (Table 6.10) is caused by an increase in ruderal species. They are better adapted to sunny plot conditions than forest species and also tolerate better annual slashing activities and the related trampling. Except the grass *Pseudechinolaena polystachya*, these ruderal species are herbs, e.g., many species from the Asteraceae, Malvaceae and Lamiaceae families (Table A 2). Many of them only occur in one or two of the study plots. They cannot be considered as rare, though, because they are common in ruderal and disturbed habitats outside the forest and are widely distributed in Ethiopia (Edwards et al. 1995). *Desmodium repandum, Achyranthes aspera*, and *Pavonia urens* are also abundant in secondary parts of montane forest in Uganda (Althof et al. 2001).

In contrast to the SFC plots, the plots from the forest coffee (FC) systems and unmanaged forest (disturbed and undisturbed) intermingle in the remainder of the diagram. This validates the initial classification into intensively managed SFC systems, on the one hand, and natural forest on the other. Disturbed plots that are unmanaged have fewer ruderal species than disturbed SFC plots that are intensively managed, because disturbance of vegetation structure is an erratic event in the former, but a systematic and recurring event in the latter plots (compare section 5.3.2).

The position of the natural forest plots is mostly influenced by altitude as indicated by the long arrow in the ordination diagram and by the automatic forward selection in the RDA where altitude comes second in the model after coppiced plants (Figure 6.6, Table 6.14). Plots at Koma and Meligawa on the one hand, and plots at Kayakela on the other, form two separate clusters. The former plots are situated on steeper slopes and at higher altitudes than the latter. Higher altitude is related to higher precipitation and cooler temperatures as illustrated by the respective data for the Bonga region (see Figure 4.2). Most high altitude plots, therefore, have high moss indices, which indicates humidity.

The increase in humidity with altitude is demonstrated by the high number of fern species in Koma forest fragment ≥ 1,830 m asl: 24 pterophytes (including 4 species from outside the study plots). This is more than double the number of pterophyte species in the other fragments. Besides, out of these 24 species, 13 are only found in the Koma fragment. The positive correlation of species richness and frequency of pterophytes with rainfall and the number of wet and shaded habitats is already confirmed for Ghana (Hall and Swaine 1976), Zambia, Rwanda and Mt Kilimanjaro (Hemp 2001).

The fern species richness at Koma is outstanding even in a larger context, because 14 fern species found during this study have not been recorded in other Ethiopian montane forests such as Jaba (own data 2004 unpubl.), Yayu (Tadesse Woldemariam 2003) or Harenna Forest (Feyera Senbeta 2006). The steep species-area curve for Koma (Figure 6.1) suggests that there are still quite a number of unsampled species in this forest fragment. The observation of four additional fern species outside the study plots confirms such a potential.

Species associated with low altitude and humid plot conditions were already mentioned for Mankira. Additionally, there are two species, *Piper umbellatum* and *Aframomum zambesiacum*, that only occur in plots below 1,750 m asl. *Peperomia molleri* is present at all altitudinal levels, but much more common in lower altitude plots.

Piper capense and *Aframomum corrorima* are important spices for the local population, and both are frequent species in the study region (Table 6.3). *Aframomum corrorima* is absent from plots above 2,000 m asl. *Piper capense* has a tendency to be absent from intensively managed plots, because this species needs a certain amount of shade to develop well.

Summary

- Altitude and humidity are the most important factors determining the species composition of the ground layer in the natural forest.
- Plots at Koma at altitudes above 1,830 m asl have high numbers of fern species reflecting the increase in humidity with altitude.
- The low altitude plots can be separated into humid plots at Mankira and drier plots at Kayakela both having a distinct ground layer species composition.
- Intensive coffee management causes an increase in ruderal herbs and a reduction in species that require humidity and shade irrespective of the altitudinal gradient.

6.3.6 Epiphyte composition

Altitude is the most important factor determining epiphytic species composition (Figure 6.7).

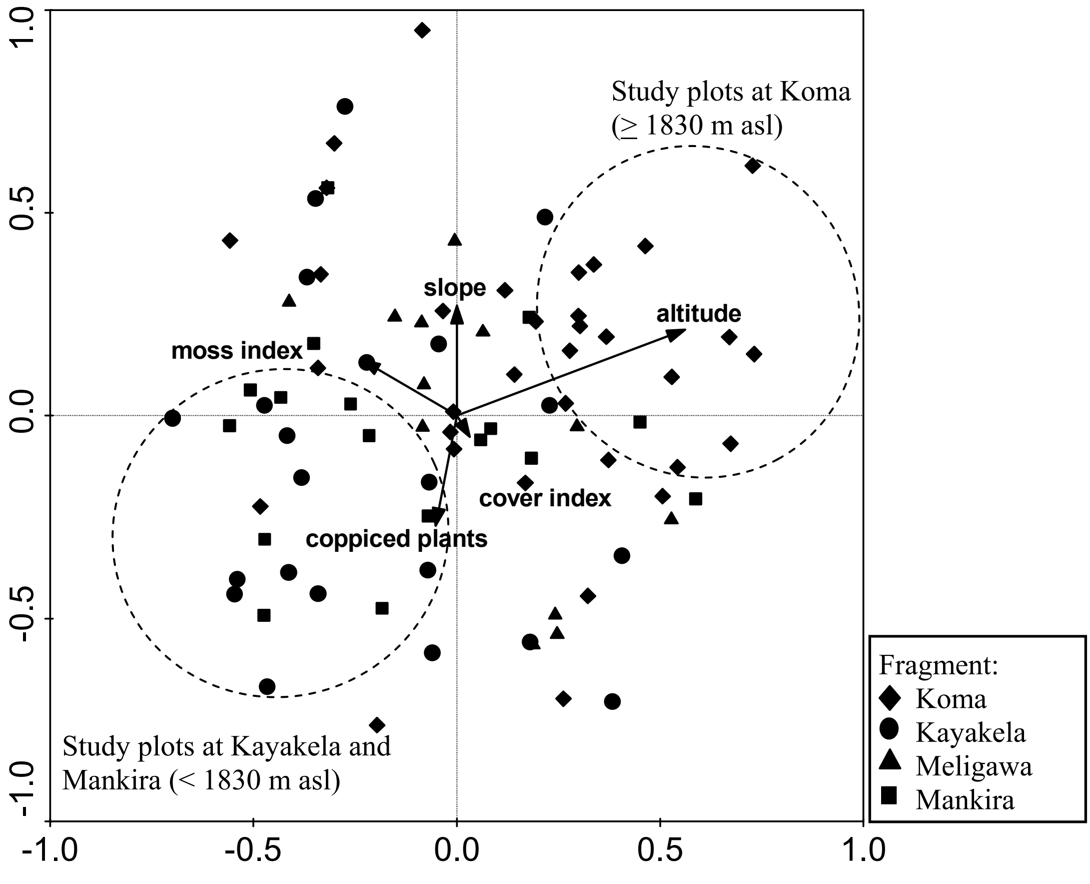


Figure 6.7 Ordination of study plots from four forest fragments according to frequency data of epiphytic species (principal component analysis, PCA); based on 32 species occurring in more than one study plot

The importance of the altitudinal gradient is indicated by the long arrow for altitude in the ordination diagram, and is further confirmed by the high values for λ_1 and λ_A for altitude in the RDA (Table 6.15).

Table 6.15 Results for principal component analysis (PCA) and redundancy analysis (RDA) of epiphytic species frequency data (32 species occurring in more than one study plot); number of study plots is 85

Axes:	**1**	**2**	**3**	**4**
PCA				
Eigenvalues (λ)	0.117	0.093	0.085	0.075
Species-environment correlations	0.601	0.459	0.365	0.384
Cumulative % variance of species data	11.7	21	29.5	36.9
Cumulative % variance of species-environment relation	33.7	49.3	58.3	67.1
RDA				
Eigenvalues (λ)	0.066	0.032	0.012	0.01
Species-environment correlations	0.835	0.609	0.463	0.443
Cumulative % variance of species data	6.6	9.8	11	12
Cumulative % variance of species-environment relation	52.6	78	87.6	95.8

Marginal Effects (variance explained singly)		**Conditional effects (order of inclusion in model)**			
	λ_1		**λ_A**	**P***	**F**
Altitude	0.06	Altitude	0.06	0.002	5.7
Coppiced plants	0.02	Moss index	0.02	0.032	1.62
Moss index	0.02	Slope	0.02	0.024	1.75
Slope	0.02	Coppiced plants	0.01	0.304	1.18
Cover index	0.02	Cover index	0.02	0.514	0.97

** Significance level from the Monte Carlo permutation*

The Koma plots above 1,830 m asl have a different species composition than those at Kayakela and Mankira, which lie below that altitude. The difference in humidity between Kayakela and Mankira that causes large differences in the species composition of the ground layer vegetation, apparently does not affect the epiphytic species composition. It can be assumed, however, that the low epiphyte species richness, species density and Shannon index at Kayakela (Table 6.7) is related to the rather dry conditions in this fragment.

In contrast, the plots at Koma and Mankira have the same species richness, but vary in terms of species composition: *Tridactyle bicaudata*, for example, is more frequent in low altitude plots, while *Asplenium anisophyllum*, *Lepisorus excavatus*, and *Diaphanante adoxa* are significantly positively correlated with high altitude in the t-value biplot. This change in species composition is related to an increase in humidity with altitude, which is also represented by an increase in the number of epiphytic ferns and fern-allies in Koma (20 species including 4 sampled outside the study plots) as compared to Mankira (14 species) and Kayakela (11 species). On Mt. Kilimanjaro, species richness of epiphytic ferns increases with increasing altitude and rainfall, and reaches maximum species richness between 1,800 and 2,000 m asl (Hemp 2001). This is almost the same altitude as for the Koma fragment. Similar to pterophytes of the ground layer, many of the epiphytic ferns and fern-allies found in the Koma fragment (11 species) have not been recorded in other Ethiopian montane forests such as Jaba (own data 2004 unpubl.), Yayu (Tadesse Woldemariam 2003) or Harenna (Feyera Senbeta 2006).

In contrast to the ground layer ordination, the ordination diagram for epiphytes depicts very short arrows for coppiced plants and cover index, which means that these parameters do not explain much of the variation in species data. The results of the PCA are consistent with the RDA because both coppiced plants and cover index are not significant in the Monte Carlo permutation tests (Table 6.15). Cover index and coppiced plants, and thus coffee management, are of little importance for epiphytic species composition, because epiphytes are not as much affected by coffee management activities as the ground layer species. Epiphytes are not prone to slashing or trampling, and microclimatic conditions on tree trunks, and especially in tree crowns, do not change drastically with the removal of vegetation during coffee management. Although coffee management does not lead to changes in species composition, the results for Kayakela indicate that epiphytic species richness can be reduced in SFC systems (Table 6.10).

Generally, epiphytic species do not react as strongly to the environmental gradients examined in this study as the ground layer species, because many of the study plots at all fragments cannot be assigned to a particular group in the ordination diagram. Either parameters not considered in this study are relevant for epiphyte distribution, or the ecological requirements of epiphytes are rather broad, and stochasticity of distribution is thus high. These results are contradictory to other studies postulating that epiphytes normally have very specific environmental requirements (Newmark 2002).

Summary

- The altitudinal gradient has the strongest impact on epiphytes and separates plots at Koma on the one hand, and plots from Kayakela and Mankira on the other.
- Epiphytes are not as much affected by changes in environmental conditions as the ground layer species. This is underlined by the fact that species composition of epiphytes is not influenced by intensive coffee management.

6.3.7 Composition of woody plants and climbers (1): impact of altitude

The ordination diagram based on PCA of woody plants and climbers depicts all plots at Koma as a distinct cluster (Figure 6.8). Thus, the difference in species composition between Koma and the other fragments is more pronounced for woody plants and climbers than for epiphytes or ground layer vegetation.

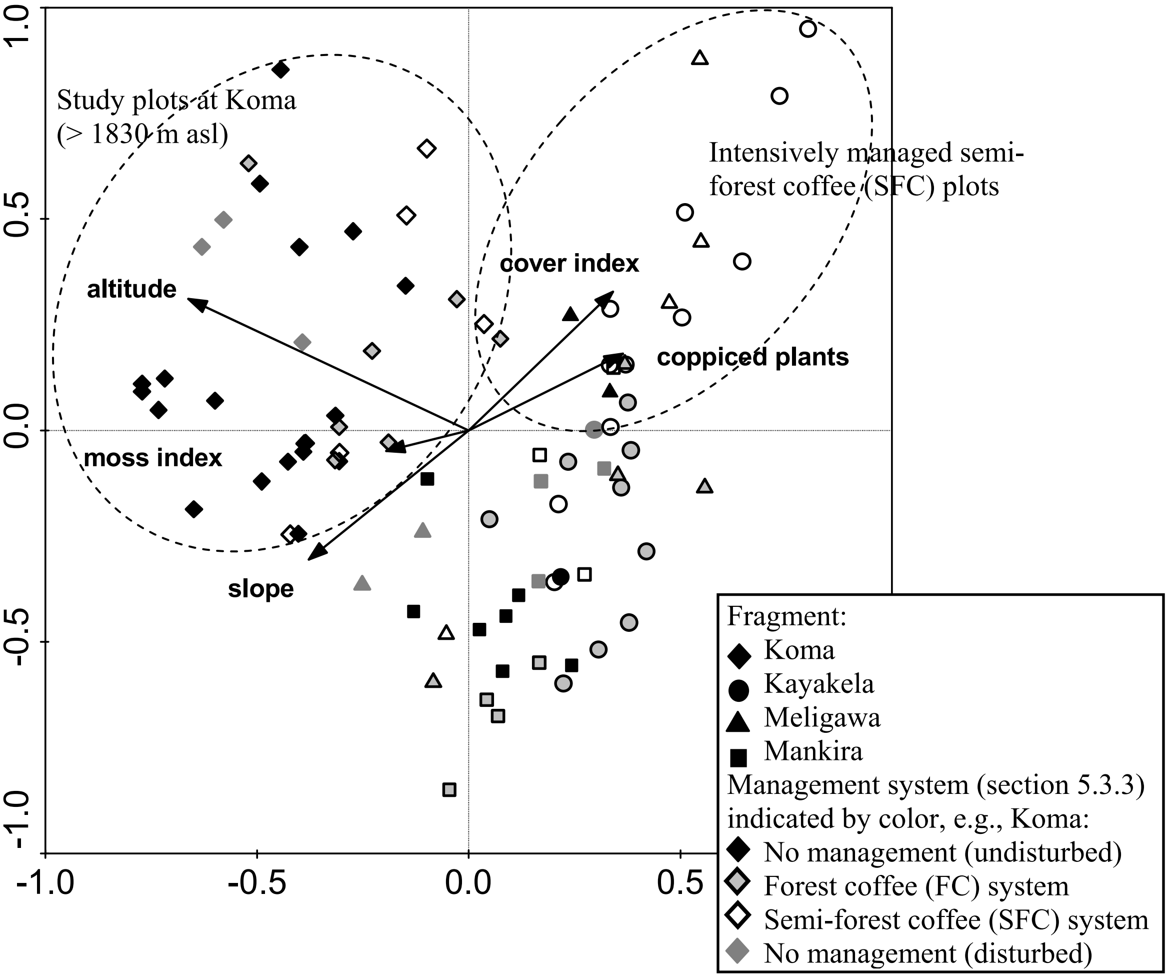


Figure 6.8 Ordination of study plots from four forest fragments according to abundance data of woody species and climbers (principal component analysis, PCA); based on 136 species with more than one individual; data were log transformed

The most important environmental factor for the grouping of the study plots is altitude as indicated by the long arrow in the ordination diagram. The importance of altitude is confirmed by the automatic forward selection of environmental variables in the RDA, where altitude clearly has the highest λ_1 and λ_A of all variables tested (Table 6.16). The altitudinal gradient has a stronger impact on woody plants and climbers than on ground layer species or epiphytes, because the λ-values for altitude are higher in the RDA of the former than in the RDAs of the latter (Table 6.13, Table 6.14, Table 6.15).

Table 6.16 Results for principal component analysis (PCA) and redundancy analysis (RDA) of abundance data of woody species and climbers (136 species with more than one individual); number of study plots is 85

Axes:	**1**	**2**	**3**	**4**
PCA				
Eigenvalues (λ)	0.123	0.076	0.058	0.055
Species-environment correlations	0.81	0.569	0.363	0.46
Cumulative % variance of species data	12.3	19.9	25.6	31.2
Cumulative % variance of species-environment relation	44.9	58.6	62.8	69.3
RDA				
Eigenvalues (λ)	0.089	0.043	0.021	0.017
Species-environment correlations	0.884	0.844	0.715	0.738
Cumulative % variance of species data	8.9	13.2	15.3	17.1
Cumulative % variance of species-environment relation	49.7	73.7	85.4	95.1

Marginal Effects (variance explained singly)		**Conditional effects (order of inclusion in model)**			
	λ1		**λ_A**	**P***	**F**
Altitude	0.08	Altitude	0.08	0.002	6.9
Cover index	0.04	Cover index	0.04	0.002	3.6
Slope	0.04	Moss index	0.02	0.002	2.58
Coppiced plants	0.03	Slope	0.03	0.002	2.54
Moss index	0.02	Coppiced plants	0.01	0.494	0.97

** Significance level from the Monte Carlo permutation*

The importance of the altitudinal gradient is also reflected by the fact that many woody species are significantly positive or negative correlated with altitude as indicated by the t-value biplot (Figure 6.9). All “upper montane species”, i.e., species with a significantly positive response to altitude in this study, have the highest abundance or frequency in the Koma fragment, which is situated above 1,830 m asl. *Triumfetta rhomboidea*, *Sericotachys sandens*, *Clematis longicauda*, and *Urera hypselodendrum* are only found in Koma, while the other upper montane species also occur in the other fragments. Some of the “lower montane species”, i.e., species with a significantly negative response to altitude namely *Marsdenia* spec., *Paullinia pinnata*, *Allophylus macrobotrys*, *Psychotria peduncularis*, *Trilepisium madagascariense* and *Turraea holstii*, are only found in Kayakela, Meligawa and Mankira. All other lower montane species are also present in Koma, but less common there than in the other three fragments. *Coffea* is included in the lower montane group, because study plots at Kayakela situated between 1,610 and 1,750 m asl have very high abundances of coffee individuals.

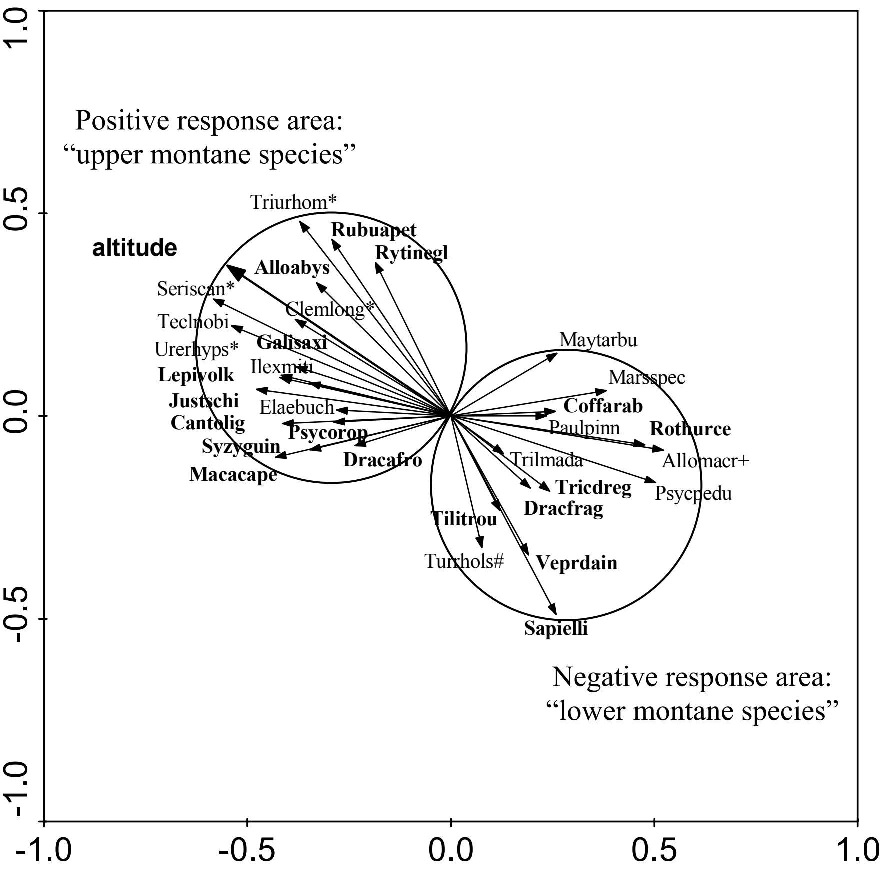


Figure 6.9 T-value biplot for altitude based on the principal component analysis (PCA) of woody species and climbers (Figure 6.8); species with significant response to altitude are depicted (the first four letters of the generic name followed by the first four letters of the species name; full names in Table A 1 and Table A 3); species distribution in fragments: bold = present in all fragments, * in Koma only, + in Kayakela only, # in Mankira only

For some upper and lower montane species, an affinity with altitudes above 1,700 m asl (*Canthium oligocarpum*, *Dracaena afromontana*, *Urera hypselodendrum*) or below 1,750 m asl (*Trilepisium madagascariense*, *Dracaena fragrans*, *Psychotria peduncularis*, *Trichilia dregeana*) is already known (Hedberg and Edwards 1989; Edwards et al. 1997; Hedberg et al. 2003). For the other species, the altitudinal ranges given in the literature are very wide. This information is usually based on collections only. Most species, however, occur over a wide altitudinal gradient, but are most frequent and abundant within a certain altitudinal range representing their ecological optimum (Mueller-Dombois and Ellenberg 1974; Austin 2005). This is supported by vegetation surveys from Harenna (southeastern Ethiopia) and Boginda (southwestern Ethiopia), where changes in the abundance of species with altitude coincide with the results of the present study (Zerihun Woldu et al. 1989; Getachew Berhan 2001; Getachew Tesfaye et al. 2002).

Higher altitude is related to cooler temperatures and higher precipitation (Figure 4.2). Apparently, these two factors reach a threshold level at around 1,830 m asl in the Bonga region causing a shift in species composition. The high diversity of pterophyte species in Koma fragment supports the notion that this fragment is more humid than the others.

Generally, 1,800 m asl is a critical altitude in tropical forests. According to the World Conservation Monitoring Centre (WCMC) and the Centre for International Forestry Research (CIFOR), tropical forest at 1,200 – 1,800 m asl is considered as lower montane forest while forest above 1,800 m asl is upper montane forest (CBD 2005). In Tanzania, these two montane forest types are floristically different (Lovett 1993).

In Ethiopia, forests between 1,525 and 1,830 m asl are known to harbor more phytogeographical elements and to be richer in tree species than forests between 1,830 and 2,135 m asl (Friis 1992). This is also the case in the present study: The species richness of trees, particularly in the canopy, is relatively low in Koma (> 1,830 m asl) taking into account the large sample size in this fragment (Table 6.9). All upper montane species are Afromontane endemics or near endemics whereas lower montane species also belong to other phytogeographical elements: *Rothmannia urcelliformis*, *Trilepisium madagascariense*, *Dracaena fragrans* and *Sapium ellipticum* are Guineo-Congolian-East African forest belt linking species (Friis 1992). *Ficus ovata*, which is absent from Koma, but has few individuals in the other fragments, is also such a linking species.

In Ethiopia, a separation of humid forest into lower and upper montane forest has not been postulated as yet. While some authors define distinct vegetation types, which seem too exclusive and often lack a profound analysis of the underlying environmental factors (von Breitenbach 1963; Zerihun Woldu et al. 1989; Zerihun Woldu 1999; Yeshitela and Bekele 2002), other authors define wide vegetation zones that are apparently too general (Friis et al. 1982; Friis and Mesfin Tadesse 1990; Friis and Sebsebe Demissew 2001). Summarising the altitudinal ranges as indicated by the latter authors, there are two main humid forest types in Ethiopia, the lowland rainforest between 450 and 1,000 m asl and the upland rainforest between 1,300 and 2,600 m asl. Between 500 and 1,500 m asl, there is a transition area, which is most similar in physiognomy and composition to the upland rain forest in the addition of species from the lowland forest and some species only known from humid forests of other countries. Species reported to be restricted to this transitional forest are *Dracaena fragrans*, *Elaeodendron buchananii*, *Eugenia bukobensis*, *Phoenix reclinata*, *Trichilia* *dregeana*, *Trilepisium madagascariense*, and *Vepris dainellii* (Friis 1992). All of these species, however, occur in Bona region up to 1,830 m asl, and *Phoenix reclinata* and *Elaeodendron buchananii* even above that altitude. The present study, therefore, suggests that the existing concept of the transitional forest zone has to be revised.

The shift in species composition at around 1,830 m asl observed in this study does not justify the definition of a floristic critical altitude in the strict sense, i.e., "altitudes or narrow altitudinal bands within which a substantially greater number of species reach either the upper or lower limits of their ranges than in the intervening intervals" (Hamilton 1975), because most species do not reach the limit of their range at this point. Further vegetation surveys have to confirm if the observed shift in species composition is consistent throughout other Afromontane forest regions in Ethiopia, and if the classification of two new forest types on the basis of the upper and lower montane species identified in this study is feasible.

Studies in Ethiopia and Uganda show that changes in tree species distribution may be influenced not only by positive correlation of altitude with rainfall, but also by negative correlation of altitude with pH and calcium (Zerihun Woldu et al. 1989; Eilu et al. 2004). The Koma soils tend to have lower pH and to be less nutritious than the soils from the other fragments (Table 5.2). These differences are small for each soil parameter taken on its own, but in a synergetic way they may have an impact on the distribution of sensitive species.

Besides altitude, slope and moss index have a significant influence on species variation even though they have shorter arrows than altitude in Figure 6.8 and much lower values for λ_1 and λ_A in the automatic forward selection of environmental variables (Table 6.16). Many Koma plots are situated on steep slopes and have high moss indices, but they are clearly separated from the plots at Mankira that are also situated on steep slopes and have high moss indices, which underlines the prevalence of the altitudinal gradient.

For the ground layer, differences in humidity cause large differences in species composition between the lower montane forest fragments Kayakela and Mankira. This is not the case regarding woody plants and climbers. The low species density for woody plants and climbers (Table 6.8) and the dominance of *Trilepisium madagascariense* in Kayakela may, however, be linked to the drier plot conditions as compared to Mankira. It can be assumed that ground layer species react to small scale changes in environmental conditions, while woody plant and climber composition is rather governed by changes on a larger scale, i.e., mainly altitude. The same observation was made in Harenna (southeastern Ethiopia) (Zerihun Woldu et al. 1989).

Summary

- Altitude is the most important environmental factor influencing species composition of woody plants and climbers.
- Upper montane forest (1,830 – 2,280 m asl) is characterized by high abundance of Afromontane endemics or near endemics, while lower montane forest (1,560 – 1,830 m asl) has greater diversity of tree species and pytogeographical elements (Table 6.17).
- Kayakela and Mankira are representative of lower montane forest and Koma of upper montane forest.
- Further studies have to evaluate if the division in lower and upper montane forest can be applied to other Afromontane regions, and in which way the transitional forest zone in Ethiopia should be revised

Table 6.17 Species characteristic of lower and upper montane forest in the Bonga region (summary of sections 6.3.5, 6.3.6, and 6.3.7); species distribution: bold = species present in all four fragments; * in Koma only; $^{+}$ in Kayakela only; $^{\#}$ in Mankira only

Growth form	**Lower montane forest (1,560 – 1,830 m asl)**	**Upper montane forest (1,830 – 2,280 m asl)**
Ground layer	e.g., *Piper umbellatum*, *Aframomum zambesiacum*; additional species in moist forest: e.g., *Brillantaisia grotanellii* $^{\#}$, *Leptaspis zeylanica* $^{\#}$	many fern species
Epiphytes	*Tridactyle bicaudata*	many fern species
Herbaceous climbers	-	-
Shrubs	*Maytenus arbutifolia*, *Allophylus macrobotrys* $^{+}$, *Psychotria peduncularis*, *Turraea holstii* $^{\#}$	*Triumfetta rhomboidea**, ***Rubus apetalus***, ***Rytigynia neglecta***, ***Justicia schimperiana***
Woody climbers	*Marsdenia* spec, *Paullinia pinnata*, ***Tiliacora troupinii***	*Sericostachys scandens**, *Urera hypselodendron**, *Clematis longicauda**
Small trees	***Rothmannia urcelliformis***, ***Dracaena fragrans***, ***Vepris dainellii***, ***Coffea arabica***	*Teclea nobilis*, ***Galineria saxifraga***, ***Lepidotrichilia volkensii, Psychotria orophila***, ***Dracaena afromontana***
Trees	*Trilepisium madagascariense,* ***Sapium ellipticum***, ***Trichilia dregeana***	***Allophylus abyssinicus***, *Ilex mitis*, *Elaeodendron buchananii*, ***Syzygium guineense***, ***Macaranga capensis***, ***Canthium oligocarpum***

6.3.8 Composition of woody plants and climbers (2): management impact

Next to altitude, coffee management has a strong impact on the floristic composition of woody plants and climbers. The cover index, the indicator of management intensity, comes second after altitude in the automatic forward selection of variables (Table 6.16). In the ordination diagram, intensively managed semi-forest coffee (SFC) plots at Kayakela, Mankira and Meligawa form a cluster in the upper right corner (Figure 6.8). The SFC plots at Koma are plotted at the margin of this group because they contain not only some upper montane species, but also some species typical for intensively managed plots.

The SFC plots have a disturbed forest structure as indicated by the arrows for cover index and coppiced plants (Figure 6.8). Increased light penetration reduces humidity in these plots as reflected by the arrow for the moss index, which points in the opposite direction. Furthermore, SFC plots are mostly located on flat slopes because farmers prefer to manage coffee there (see section 5.3.6).

The plots at Meligawa, Kayakela and Mankira situated in natural forest, i.e., in unmanaged forest (disturbed and undisturbed) and in forest coffee (FC) systems, intermingle in the lower right corner of the ordination diagram (Figure 6.8). This indicates that moderate coffee management in FC systems that does not disturb the vegetation structure of the forest (see section 5.3.3) does not change species composition. It also shows that disturbed plots without coffee management have a similar species composition as unmanaged and undisturbed forest plots. In these plots, disturbance is only a singular event, e.g., felling or fall of a large tree, while in intensively managed SFC plots, disturbance (i.e., coffee management) recurs on an annual basis.

The evaluation of the plots at Kayakela indicates that the impact of coffee management on species richness varies in the case of different woody growth forms (Table 6.11). Therefore, the ordination results are discussed separately for each growth form. In the following, all ordination diagrams are based on the initial PCA of woody species and climbers (Figure 6.8), but depict species arrows instead of plots. Species names in the diagrams are abbreviated with the first four letters of the generic name followed by the first four letters of the species name. The full names can be looked up in Table A 1 and Table A 3.

Herbaceous climbers and shrubs

Coffee management has a positive impact on species richness of herbaceous climbers and shrubs (Table 6.11). This is also obvious in the ordination diagram for herbaceous climbers, where most species arrows are positively correlated with cover index and coppiced plants and point towards the direction of SFC plots (Figure 6.10).

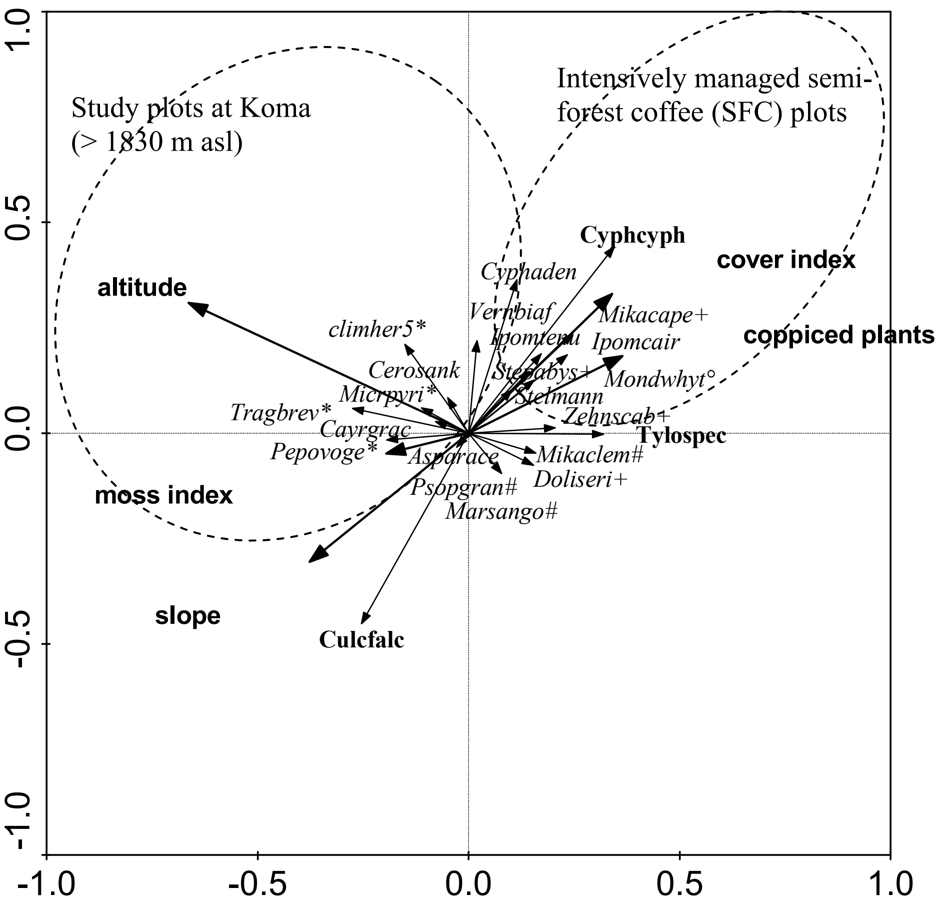


Figure 6.10 Scores for herbaceous climbers in the ordination of woody species and climbers (see Figure 6.8); species distribution in fragments: bold = present in all fragments, * in Koma only, + in Kayakela only, # in Mankira only, ° in Meligawa only

This species distribution is explained by the fact that most shrubs and herbaceous climbers are ruderal species, which establish better in more open and sunny sites as created by coffee management than in dense and shaded undisturbed forest. They are common outside the forest, e.g., in thickets, live fences or shrubland, but rather rare in the present study: 69 % of the shrubs and herbaceous climbers have less than 20 individuals in total and 58 % are only present in one of the fragments. In Panama, herbaceous climbers are also associated with openings in the forest (Brokaw 1985). High species richness of herbaceous climbers and shrubs in the natural forest of Koma (Table 6.9) is caused by encroachment of ruderal species in slightly disturbed plots, e.g., those located at forest edges.

Culcasia falcifolia is the only herbaceous climber that occurs in natural forest throughout all fragments (Figure 6.10). For shrubs, several species are common in natural forest throughout all fragments, i.e., *Maytenus gracilipes*, *Erythrococca trichogyne*, *Pavetta abyssinica* and *Rytigynia neglecta*. As they compete with coffee in the undergrowth they are coppiced in SFC plots and their overall individual number is reduced. Compared with trees, shrubs have persistent, reproductively active shoots close to the ground, greater ability to reproduce vegetatively, and the capacity to return to the reproductive mode more quickly following crown damage (Ewel and Bigelow 1996). Shrubs therefore regenerate quickly from coppiced stems in SFC systems and do not need any special attention in terms of conservation.

Small trees

In contrast to herbaceous climbers and shrubs, most small trees are typical forest species that are highly abundant and frequent in all forest fragments (Table 6.3). High abundance is reflected by long species arrows in the ordination diagram (Figure 6.11). Species occurrence in all fragments is indicated by bold type script.

Some species typical of disturbed and secondary forests (Hedberg and Edwards 1989; Edwards et al. 1997) are associated with the SFC plots in this study, namely *Dracaena steudneri*, *Clausena anisata*, *Maesa lanceolata* and *Ehretia cymosa*. *Maesa lanceolata* and *Clausena anisata* are characterized as early successional species (Chapman and Chapman 1999; Chapman et al. 2002; Mwima and McNeilage 2003). *Clausena anisata* has very high abundance of saplings in the SFC plots whereas *Maesa lanceolata* and *Ehretia cymosa* are also present with larger individuals. The latter two species are often used as small shade trees for coffee.

In natural forest, small trees occupy exactly the same habitat as *Coffea arabica*. They are coppiced in SFC plots to reduce competition with coffee plants. As a result, most small tree species are less abundant in the SFC plots and have their arrows pointing away from the upper right corner in the ordination diagram (Figure 6.11). The main difference between natural forest and SFC systems is, however, that in natural forest, small tree species often have thick stems and reach heights of 8 - 12 m, while in the SFC systems they are mostly present as saplings (height < 5 m, dbh < 2 cm) or coppiced individuals (Figure 6.12).

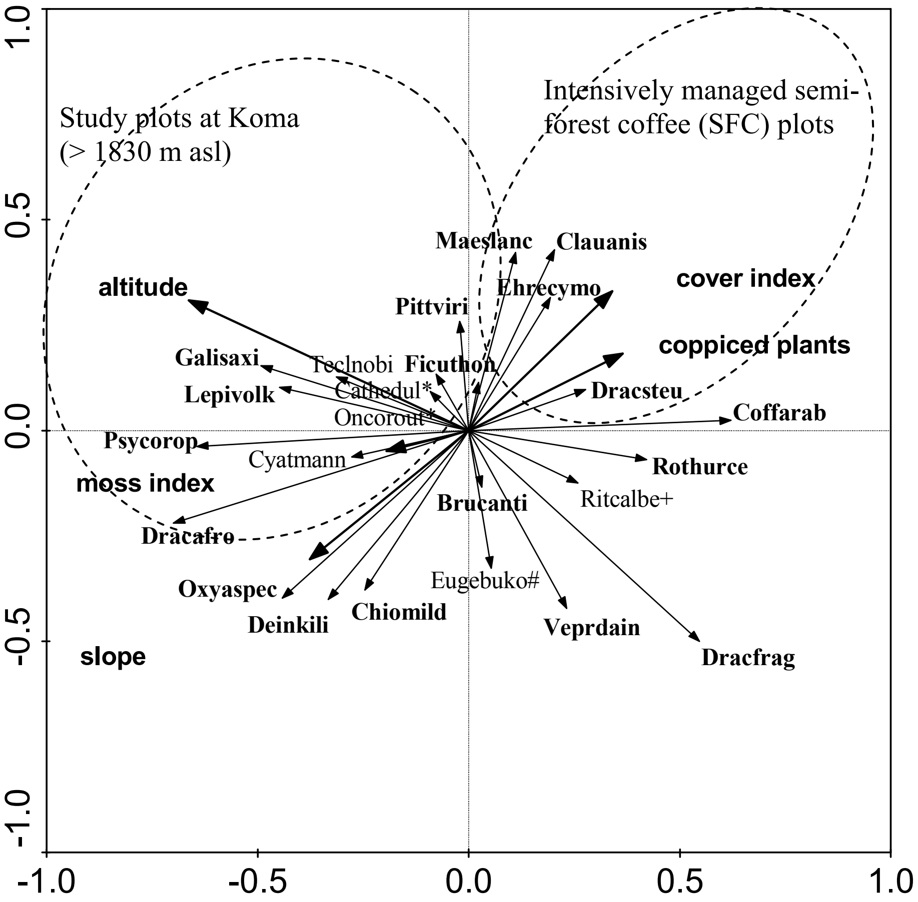


Figure 6.11 Scores for small trees in the ordination of woody species and climbers (see Figure 6.8); species distribution in fragments: bold = present in all fragments, * in Koma only, + in Kayakela only, # in Mankira only

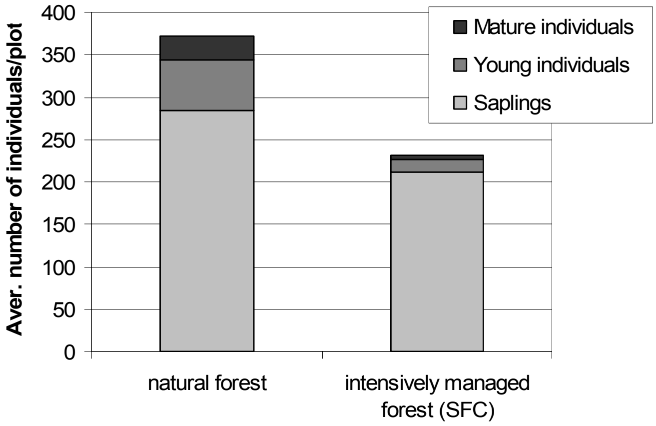


Figure 6.12 Population structure of small trees in natural forest and semi-forest coffee (SFC) systems, respectively; based on data of all small tree species except four species associated with SFC systems (see text); saplings: height < 5 m; dbh < 2 cm, young individuals: height < 5 m; dbh ≥ 2 cm; mature individuals: height ≥ 5 m; dbh ≥ 2 cm

Most small tree species persist in SFC systems because they resprout from coppiced stems. They were also observed to regenerate well under quite open canopy conditions in the SFC plots. It is unknown, though, if their regeneration is mainly from the soil seed bank or if it depends on fresh propagules from mature individuals in adjacent natural forest. Tree ferns are exceptional because they are only known from few locations in Ethiopia, require well-shaded and moist conditions to grow and quickly disappear completely in SFC systems (BirdLife International 2005).

Woody climbers

Similar to the small tree species, most of the woody climbers occur in all fragments as indicated by the bold typescript in the ordination diagram (Figure 6.13).

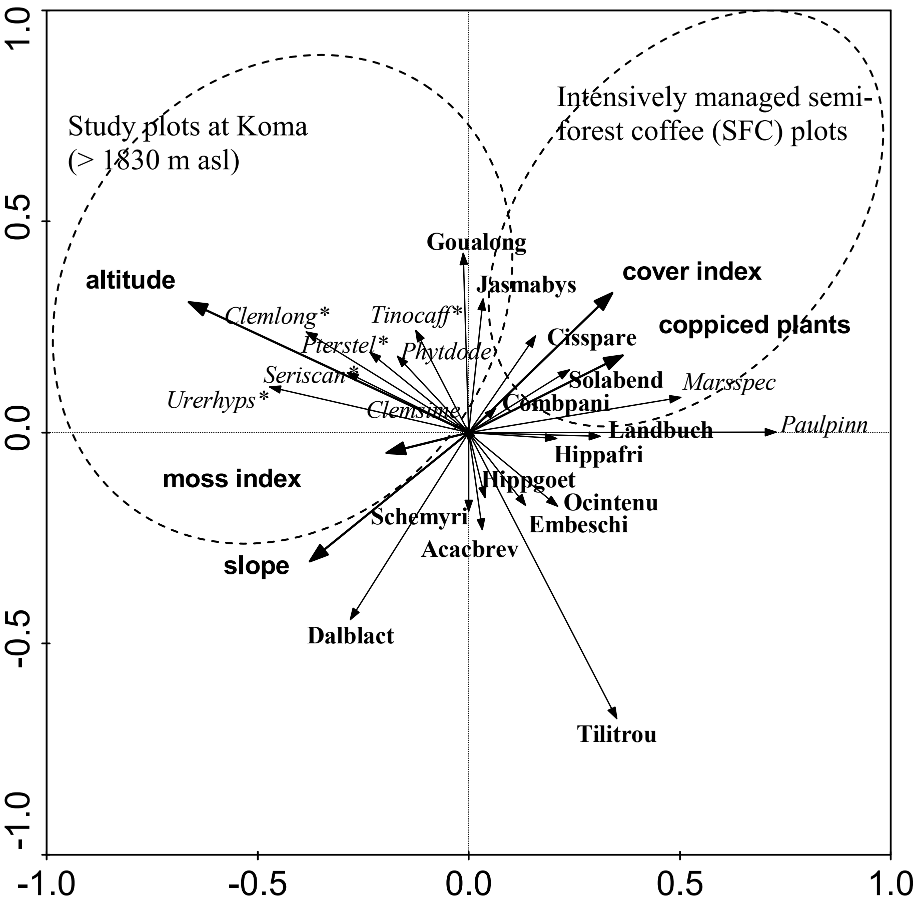


Figure 6.13 Scores for woody climbers in the ordination of woody species and climbers (see Figure 6.8); species distribution in fragments: bold = present in all fragments, * in Koma only

Tiliacora troupinii, *Hippocratea goetzii*, *Jasminum abyssinicum*, and *Landolphia buchananii* are highly abundant species with more than 900 individuals each, all plots taken together (Table A 3). In contrast, *Gouania longispicata*, *Cissampelos pareira*, *Solanum benderianum* and *Schefflera myriantha* are quite rare naturally, because they occur throughout all forest fragments, but with less than 100 individuals each all plots taken together. High species richness of woody climbers in the Koma fragment (Table 6.9) is reflected by species with arrows pointing to the upper left corner in the ordination diagram. All of these species have less than 25 individuals, however.

No climber species are particularly associated with SFC plots. The fact that many species arrows point to the upper right corner of the ordination diagram is simply due to higher abundances in SFC plots than in natural forest (Figure 6.13). Even though there is no change in species composition, the plots at Kayakela indicate an increase in species richness of woody climbers in the SFC systems (Table 6.11) as compared to natural forest.

Similar to the small trees, woody climbers are mostly present as saplings in the SFC plots, whereas they are present as mature individuals in the natural forest plots (Figure 6.14). High regeneration in SFC plots indicates that woody climbers are adapted to regeneration in open habitats. In fact, the first significant growth of lianas occurs in gaps (Putz 1984), and most woody climber species found in the Bonga region are known to be associated with disturbed forest and forest margins (Hedberg and Edwards 1989; Edwards et al. 1995; Edwards et al. 2000; Hedberg et al. 2003)

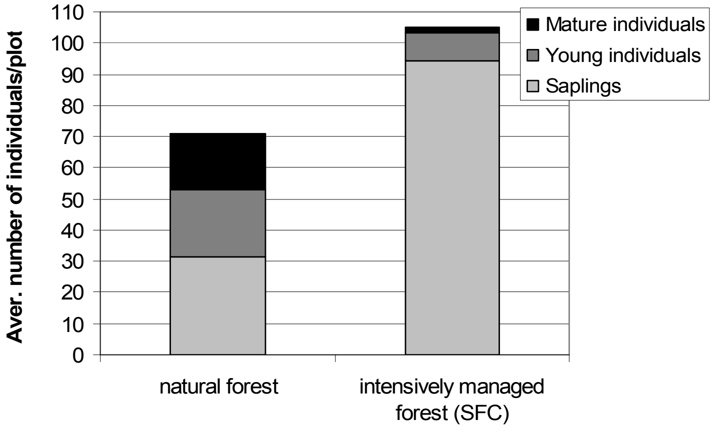


Figure 6.14 Population structure of woody climbers in natural forest and semi-forest coffee (SFC) systems, respectively; saplings: length < 5 m, young individuals: length 5 – 15 m, mature individuals: length > 15 m

On the one hand, the high species richness and abundance of large climbers in the natural forest plots, e.g., in Koma, could indicate that these plots were subject to natural or anthropogenic disturbance in the past. On the other hand, climbers can be an integral part of the natural forest vegetation as was observed in Ghana, where there is little change in climber diversity during the later stages of forest succession after disturbance and where, even in apparently undisturbed forest, large climbers, climber seedlings and saplings are always abundant (Hall and Swaine 1976).

Many woody climbers have an almost irrepressible ability to resprout from a long-lived base (Ewel and Bigelow 1996). Their regeneration is, therefore, not impeded by coppicing in SFC systems. If regeneration of a species relies on seed production from mature individuals, however, it depends on natural forest parts where it can fully develop.

Trees

The farmers cut the trees in the lower and upper canopy of SFC systems in order to reduce shading of coffee. The cutting of trees is also motivated by the fact that many tree species have a high commercial timber value, and almost all tree species are used for local construction activities and as fire wood (Ibrahim 1986; Ensermu Kelbessa and Teshome Soromessa 2004). Selective cutting and increased light penetration lead to a shift in tree species composition of SFC systems as compared to the natural forest (Figure 6.15).

Tree species with arrows pointing to the upper right corner of the ordination diagram are associated with SFC systems, namely *Milletia ferruginea*, *Croton macrostachys*, *Bersama abyssinica*, *Celtis africana*, *Cordia africana*, *Albizia grandibracteata*, *Ficus ovata*, and *Prunus africana* (“SFC species”). All other tree species are considered as “forest species”. The change in tree species composition with coffee management is illustrated by the fact that the 8 SFC species make up only 18 % of all individuals in the natural forest plots, but constitute 34 % of the total individual number in the SFC plots.

Milletia ferruginea is the most abundant species in the SFC plots, but is also an integral part of the natural forest vegetation. Farmers like to retain it as a shade tree for coffee due to its suitable leaf and crown structure. Besides, it regenerates well and grows fast in open sites (Mersha Gebrehiwot 2003). As a result, the canopy of SFC systems is often dominated by *Milletia* trees and the total number of tree species is reduced (Table 6.11). This is also obvious in the vegetation profiles through SFC system type 1 (Figure 5.4) and semi-forest coffee plantation (Figure 5.6).

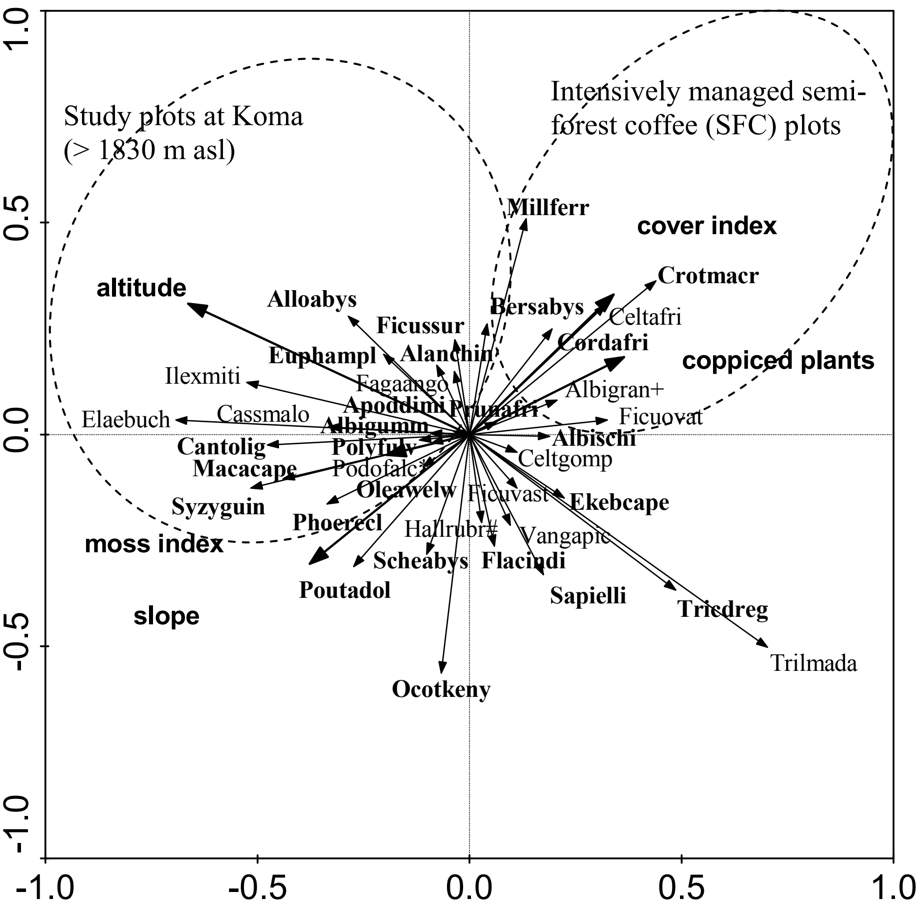


Figure 6.15 Scores for trees in the ordination of woody species and climbers (see Figure 6.8); species distribution in fragments: bold = present in all fragments, * in Koma only, + in Kayakela only, # in Mankira only

SFC species are pioneer or secondary forest species. They are typical for forest edges, secondary vegetation or disturbed sites, and have the ability to grow quickly into mature trees in forest gaps such as those created by coffee management (Hedberg and Edwards 1989; Friis 1992; Edwards et al. 1995; Abayneh Derero 1998; Chapman and Chapman 1999; West et al. 2000; Chapman et al. 2002; Mersha Gebrehiwot 2003).

The number of saplings of forest species is almost equal in the natural forest and SFC plots (Figure 6.16) because many forest species regenerate equally well in both forest types (see Chapter 7). They are, however, not as competitive as SFC species in open sites, grow more slowly, and are likely to be coppiced during annual management activities. As a result, the number of medium-sized and mature individuals is reduced in the SFC plots. In contrast, SFC species have higher abundances of saplings and mature individuals in the SFC than in natural forest plots.

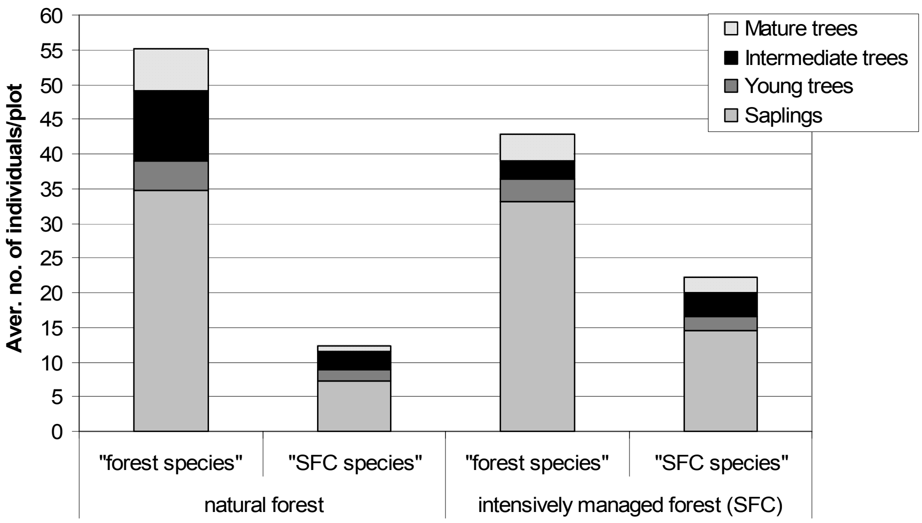


Figure 6.16 Population structure of trees in natural forest and semi-forest coffee (SFC) systems; for explanation of forest species and SFC species see text; saplings: height < 5 m; dbh < 2 cm, young trees: height < 5 m; dbh $\geq$ 2 cm; intermediate trees: height 5 - 15 m; dbh $\geq$ 2 cm; mature trees: height > 15 m; dbh $\geq$ 2 cm

Tree species composition is more affected by coffee management than species composition of small trees and woody climbers, because trees have specialized regeneration niches and need much longer to reach maturity. This is aggravated by the fact that the individual numbers of most tree species are very low. If large parts of natural forest are turned into SFC systems, many forest species of trees are likely to disappear completely in the long run.

Summary

- Selective cutting of woody plants and climbers as well as increased light penetration leads to changes in species composition and species population structures in intensively management semi-forest coffee (SFC) systems as compared to natural forest (Table 6.19).
- Species richness of herbaceous climbers and shrubs increases in SFC plots because they include many species adapted to regeneration in disturbed forest and open sites.
- Species composition of woody climbers and small trees is only slightly modified in the SFC systems. Species of these growth forms persist in SFC systems due to their ability to regenerate vegetatively and under open site conditions.
- The shift in species composition from forest species to SFC species is strongest for tree species. This is related to selective cutting of trees and to the fact that trees have more

specialized regeneration niches, are less abundant, and need longer time to reach maturity than other growth forms.

Table 6.18 Impact of intensive semi-forest coffee (SFC) management on species composition, species richness and species population structure of natural forest (summary of sections 6.3.3, 6.3.5, 6.3.6, and 6.3.8); species distribution: bold = species present in all four fragments; $^+$ in Kayakela only

Growth form	**Species typical for SFC systems**	**Impact of SFC management on:**	
		Species richness	**Species population structure**
Ground layer	many ruderal species	increase	
Epiphytes	-	decrease	
Herbaceous climbers	many ruderal species	increase	
Shrubs	many ruderal species	increase	decrease in saplings and mature individuals
Woody climbers	all species	increase	increase in saplings, decrease in mature individuals
Small trees	***Maesa lanceolata***, ***Clausena anisata***, ***Ehretia cymosa***, ***Dracaena steudneri***, ***Coffea arabica***	no impact	decrease in saplings and mature individuals (except *Coffea arabica*)
Trees	***Milletia ferruginea***, ***Cordia africana***, ***Croton macrostachys***, ***Bersama abyssinica***, ***Prunus africana***, *Celtis africana*, *Ficus ovata*, *Albizia grandibracteata*$^+$	decrease in upper canopy (trees with height > 15 m)	decrease in mature individuals

6.4 Implications for conservation

The studied forest fragments differ considerably in species diversity patterns and species composition. The question which fragment has the highest conservation value can only be answered on the basis of clearly defined conservation objectives (see section 3.3). In the case of the Bonga region, these objectives are *in situ* conservation of wild *Coffea arabica*, and conservation of the representative vegetation structure, species composition and functions of the Afromontane forest ecosystem. Crucial issues are location, number and size of protected fragments needed to meet these objectives.

Location and number of protected forest fragments

The Afromontane forest in the Bonga region can be separated into upper montane forest above 1,830 m asl and lower montane forest below that altitude (Table 6.17). The Koma fragment is representative for upper montane forest whereas Kayakela and Mankira comprise lower montane vegetation. Meligawa is at intermediate altitude and contains both forest types. The size of this forest fragment is very small, however (Table 6.19).

As a consequence, at least two complementary forest fragments are required to conserve the representative species composition of Afromontane rainforest in the Bonga region. The Koma fragment is crucial in this regard due to its upper montane vegetation, which also includes many fern species that were not recorded in other Afromontane forests in Ethiopia (Tadesse Woldemariam 2003, own data 2004 unpubl.; Feyera Senbeta 2006). The forests in Kayakela and Mankira are both representative for lower montane vegetation, because species of woody plants, climbers and epiphytes are rather similar in these two fragments.

Table 6.19 Important parameters for appraisal of the conservation value of the forest fragments

	Koma	**Kayakela**	**Mankira**	**Meligawa**
Altitude (m asl)	1,830 – 2,280	1,610 – 1,750	1,560 – 1,810	1,710 – 1,920
Size of natural forest (ha)	1,300	300	700	200
Presence of endangered or vulnerable species (Vivero et al. 2005)	all fragments: *Scadoxus nutans*, *Vernonia tewoldii*, *Tiliacora troupinii*, *Aframomum corrorima*; in Kaykakela: *Phyllanthus limmuensis*; in Mankira: *Brillantaisia grotanellii*, *Dorstenia soerensii*			
Presence of wild coffee	yes	yes	yes	yes
Soil protection	yes	yes	yes	yes
Shannon index rank (natural forest)[1]				
Ground layer	1	4	2	3
Epiphytes	2	4	1	3
Woody plants/ climbers	1	4	2	3
Canopy (trees > 15 m)	3	4	1	2
Number of sampling plots needed for:				
Epiphytes, trees	29	29	29	not evaluated due to small sample size
Ground layer	40	11	14	
Small trees	10	10	10	
Woody climbers	29	10	10	

[1] *fragments are numbered according to the order of their Shannon indices for the different vegetation parts: 1 = highest Shannon index, 4 = lowest Shannon index (see section 6.3.3)*

Despite similarities in species composition, species diversity as indicated by the Shannon index is much higher in Mankira than in Kayakela, which is probably related to relatively high humidity in this fragment (Table 6.19). Mankira has high Shannon indices for all growth forms due to high species densities and high species evenness. It can thus be assumed that most species occur in viable populations to maintain the representative species composition of this fragment in the long run. In addition, species richness of the ground layer and of epiphytes is much higher in the natural forest in Mankira than in that in Kayakela.

Shannon indices are low in Kayakela because there are few highly abundant species. In the canopy layer, for example, *Trilepisium madagascariense* is dominant. Canopy individuals of other species have very low abundance in Kayakela, and it is doubtful if they will form viable populations in the long run.

Considering species composition and species diversity, Koma and Mankira are the most important fragments for conserving a representative part of the Afromontane forest in the Bonga region. Kayakela and Mankira also become important, however, when taking into account further conservation objectives such as soil protection and *in situ* conservation of *Coffea arabica*. All forest fragments are partly situated on very steep slopes, and the forests function as soil protection against erosion (Table 6.19). Furthermore, all forest fragments play a role in conserving the genetic diversity of wild *Coffea arabica*. Variations in microclimatic conditions and species composition between the fragments presumably lead to different natural selection processes and thus to genetically different coffee populations.

Conservation of the complete species richness of the Afromontane forest in the Bonga region is a far too ambitious goal. It should be kept in mind, however, that each forest fragment contains some endangered or vulnerable species. Presumably, there are more endangered or vulnerable species in the Bonga region, e.g., ferns species such as tree ferns (*Cyathea manniana*), but information is very limited because a red list only exists for endemic species of Ethiopia (Vivero et al. 2005).

Size of protected areas

In general terms, the larger the size of a protected area the better (Cowling et al. 2003). Large areas usually include more species than small ones and have more potential for natural forest processes such as natural disturbance regimes (Hubbell and Foster 1986). For the Bonga region, it is not known whether there are any keystone species regarding forest ecosystem functioning. There is also no information on the area requirements of forest animals. The forest ecosystem is virtually a “black box”, and the larger the protected area is, the higher the chance that all essential species and processes are included.

The minimum reserve size for tropical forest in Panama is estimated to be 10 km^2 in order to include a representative species number of 303 woody plant species (Hubbell and Foster 1986). In the Bonga region, 29 study plots are likely to contain most woody plant species of a forest fragment (Table 6.19). In Koma, these 29 study plots are located within an area of ca. 8 km^2. The minimum reserve size in the Bonga region is, therefore, probably slightly smaller than in Panama because the forest is less species rich. Taking into account the considerations on population viability made above, it is assumed that the natural forests in Koma and Mankira are large enough to sustain the typical species composition of the Afromontane forest in the Bonga region. In contrast, the remaining natural forest areas in Kayakela and Meligawa might be too small to maintain viable populations of representative tree species. It is a common observation that few species become dominant in small fragments (Turner and Corlett 1996). In addition to rather dry conditions, small forest size can therefore be another reason for the dominance of *Trilepisium madagascariense* in the upper canopy of the Kayakela forest.

Conservation, however, should not only focus on tree species that require large areas for protection (Gentry 1992). Ground layer vegetation, small trees, and climbers also constitute an important part of the species diversity of Afromontane forest. Species of these growth forms require few study plots for comprehensive sampling because most of them are abundant throughout the forest. Natural forest of ca. 2 km^2, which is still present in Kayakela and Meligawa, is estimated large enough to conserve viable populations and a representative species composition of ground layer, small tree and climber species.

Conservation needs to restrict intensive coffee management

Intensive coffee management in semi-forest coffee (SFC) systems is not harmful to the abundance and distribution of wild coffee populations, but transforms the species composition and structure of the natural forest to a great extent (Table 6.18). There is a strong increase in ruderal species, while species typical of undisturbed and humid forest disappear. Besides, most woody plants are regularly coppiced and lack mature individuals. This suppresses species that depend on fresh propagules for regeneration. Conservation of the typical species composition and structure of the Afromontane rainforest in the Bonga region and management of SFC systems are, therefore, not compatible within the same forest area.

As was already pointed out in section 5.4, the picking of coffee cherries and moderate management activities in forest coffee (FC) systems do not alter the vegetation structure of the natural forest. The present study confirms that these management types also do not change the species composition of the natural forest.

The livelihoods of the local communities strongly depend, however, on the management of SFC systems. Conservation concepts that integrate forest protection and coffee production are discussed in Chapter 8.

7 ABUNDANCE AND DISTRIBUTION OF CANOPY TREE SPECIES

7.1 Introduction

Tropical forests are very species rich, but many individual species have extremely low abundance, i.e., they are rare (sensu Gaston 1994). The fraction of rare woody species in samples from tropical forests usually varies between 30 % and 50 % (Hubbell and Foster 1986; Valencia et al. 1994; Plotkin et al. 2000; Cadotte et al. 2002; Terborgh et al. 2002).

The causes for rarity are manifold and have to be examined for each particular species (Gaston 1994). One possible reason is limited colonization ability due to low population-level seed availability (source limitation), low disperser activity (dissemination limitation), or lack of suitable regeneration sites (establishment limitation) (Schupp et al. 2002). Some rare species have special habitat requirements, are immigrants from population centers outside the study area, or naturally occur as very scattered individuals (Hubbell and Foster 1986; Barrett and Kohn 1991; Bawa and Ashton 1991). Besides, past and present human activities, e.g., selective logging, are often root causes for low abundance of species.

Rare species are more vulnerable to genetic pauperization, stochastic threats, habitat degradation and fragmentation than common species (Menges 1991; Gaston 1994; Newmark 2002). Species that occur naturally in sparsely distributed, small populations may possess genetic systems adjusted to close inbreeding, as well as adaptations that offset the disadvantages of rarity, e.g., special seed dispersal mechanisms. In contrast, species that have experienced severe reductions in population size owing to habitat destruction may be more susceptible to genetic stress imposed by small population size (Barrett and Kohn 1991; Bawa and Ashton 1991; Huenneke 1991).

In the natural forest of the Bonga region, many tree species have low abundance, but no attempts have been made so far to analyze the reasons for their rarity. There is also little information on population dynamics and colonization strategies of Afromontane tree species. This knowledge is important for conservation planning, however, because it helps to identify species that are naturally rare as opposed to species where low abundance implies threat of local extinction.

This chapter, therefore, has the objective

- to identify the colonization strategies of tree species, and to use this information
- to interpret species abundances, and
- to estimate the impact of increasing human disturbance on their populations.

7.2 Material and methods

7.2.1 Data set

Vegetation surveys were carried out in 20 m x 20 m study plots in four forest fragments in the Bonga region (for details see section 4.2). In this chapter, 63 study plots at Koma, Kayakela, and Mankira are considered. The plots at Meligawa are omitted, because the sample size in this forest fragment was very small.

Of the study plots, 54 were located in natural forest (N) (Koma: 29; Kayakela: 11; Mankira: 17) and 19 in semi-forest coffee (SFC) systems (Koma: 5; Kayakela: 11; Mankira: 3). Natural forest is defined as unmanaged forest (disturbed and undisturbed) and forest coffee (FC) systems (see section 5.3.3). In Chapters 5 and 6 it is shown that species composition and forest structure of natural forest are strongly modified by intensive coffee management in SFC systems.

7.2.2 Survey of tree species

A tree is defined as a woody plant with one main trunk and a rather distinct and elevated head, observed to grow larger than 15 m in the study region or reported to grow larger than 15 m in the Flora of Ethiopia and Eritrea (Hedberg and Edwards 1989; Edwards et al. 1995; Edwards et al. 2000; Hedberg et al. 2003). Additionally, the palm *Phoenix reclinata* is considered as a tree. In each study plot, height was measured for tree individuals with height $\geq$ 0.5 m and diameter at breast height (dbh) was recorded if dbh $\geq$ 2 cm.

7.2.3 Data analysis

Data analysis was done in a qualitative way by description of species population structure and spatial distribution. As no information exists on the gene flow between individuals of the studied tree species in the Bonga region, population is defined as the individuals of a species present in one forest fragment.

7.3 Results and discussion

7.3.1 Definition of rarity for tree species in the Bonga region

Rarity is defined on the basis of the abundance and frequency data from 54 study plots located in natural forest at Koma, Kayakela and Mankira. The abundance of tree species varies between one individual (*Mimusops kummel*) and 460 individuals (*Albizia gummifera)* all study plots taken together. Frequency is highest for *Bersama abyssinica* with 96%.

Abundance and frequency are equally important for describing the distribution pattern of trees, because locally abundant species may only be present with infrequent patches. In the Bonga region, the relative frequency of trees increases with increasing relative abundance (Figure 7.1). This means that most species with more than 150 individuals also occur in more than 60 % of the study plots (Table 7.1).

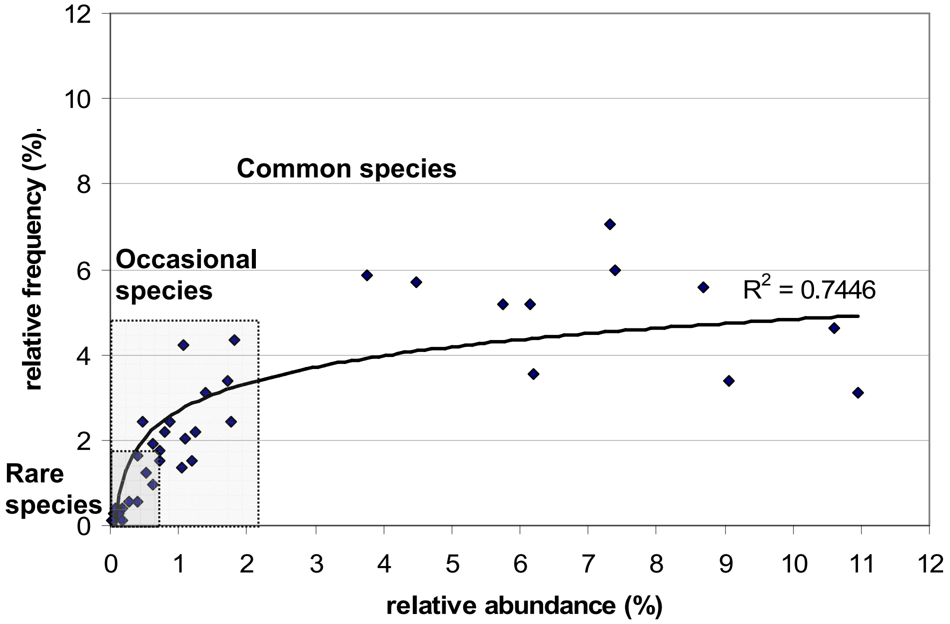


Figure 7.1 Relationship between relative abundance and relative frequency of tree species in natural forest at Koma, Kayakela and Mankira; based on individuals with height ≥ 0.5 m in 54 study plots

The distribution index (DI) based on relative abundance and relative frequency of each tree species was developed as a means to define rarity in the study region:

$$DI_{\text{species x}} = (\text{relative frequency}_{\text{species x}}) + (\text{relative abundance}_{\text{species x}}).$$

Tree species with DI > 9 are considered as abundant or common, species with DI > 2 are considered as occasional and species with DI ≤ 2 are referred to as rare (Table 7.1).

Table 7.1 Distribution characteristics of selected tree species at Koma, Mankira, and Kayakela; for explanation see text

	Natural forest				DI_{SFC} versus DI_N	Sapling aggregation		Succ. class
	Abundance	Frequency (%)	DI	Canopy		Forest type	Max no.	
Common species								
Elaeodendron buchananii	445	63.0	15.2	Ko	SFC	N+SFC	51	S
Bersama abyssinica	307	96.3	14.4		SFC	N+SFC	17	S
Milletia ferruginea	365	75.9	14.3	Ko	SFC	SFC	30	S
Albizia gummifera	460	42.6	14.1		N	N+SFC	94	S
Phoenix reclinata	311	81.5	13.4	Ma, Ka	N	N	28	S/C
Trilepisium madagascariense	381	46.3	12.5	Ma, Ka	N	N+SFC	23	S/C
Canthium oligocarpum	258	70.4	11.3	n	=			S/C
Allophylus abyssinicus	242	70.4	10.9	n	=	N+SFC	53	S
Syzygium guineense	188	77.8	10.2	Ko	N	SFC	16	S/C
Ocotea kenyensis	260	48.1	9.7		N	N+SFC	29	S/C
Olea welwitschii	158	79.6	9.6	Ko, Ma, Ka	N			S/C
Occasional species								
Pouteria adolfi-friederici	76	59.3	6.2		N			C
Schefflera abyssinica	45	57.4	5.3	Ko, Ma, Ka	N			S/C
Apodytes dimidiata	72	46.3	5.1		SFC			S
Flacourtia indica	59	42.6	4.5		N			S
Macaranga capensis	74	33.3	4.2	n	SFC	SFC	12	P
Trichilia dregeana	52	29.6	3.4		SFC			S
Sapium ellipticum	37	33.3	3.3	Ma, Ka	=			S
Albizia schimperiana	46	27.8	3.1	n	N			S
Ekebergia capensis	33	29.6	3.0		SFC			S
Polyscias fulva	20	33.3	2.9		=			S
Ilex mitis	50	20.4	2.7					S/C
Ficus sur	26	25.9	2.5		SFC			S
Prunus africana	30	24.1	2.5		SFC			S
Euphorbia ampliphylla	44	18.5	2.4	n				P
Fagaropsis angolensis	30	20.4	2.2	n	N			S
Rare species								
Alangium chinense	17	22.2	2.0		SFC	SFC	13	P
Cassipourea malosana	22	16.7	1.7					S/C
Celtis africana	26	13.0	1.6	n	SFC			P
Croton macrostachys	17	7.4	0.9		SFC			P
Cordia africana	11	7.4	0.8		SFC			P
Ficus ovata	7	5.6	0.6		=			S
Hallea rubrostipulata	4	5.6	0.5	n				P
Albizia grandibracteata	4	3.7	0.4	n	=			P
Ficus vasta	2	3.7	0.3					S
Vangueria apiculata	2	3.7	0.3					P

The cut-off points used for the definition of rare, occasional and common species should be regarded as points of reference only. In fact, it makes more sense to regard rarity as a continuous variable, because plant species assemblages typically comprise a range of different abundances and frequencies, and it is unusual that species separate into discrete groups with abundances or frequencies of distinctly different magnitudes (Gaston 1994).

The definition of rarity varies enormously between vegetation studies (Gaston 1994). In tropical forests, rare woody species are considered as species (dbh $\geq$ 10 cm) being present in only one out of 21 1- or 2-ha plots (Terborgh et al. 2002), as species (dbh $\geq$ 1 cm) with less than 50 individuals in 50 ha (Hubbell and Foster 1986), and species with only one individual in 1 ha (dbh > 1 cm or 5 cm) (Valencia et al. 1994; Plotkin et al. 2000). Despite different definitions of rarity, the percentage of rare species is high in all of these tropical studies and lies between 30 and 50 %. The percentage of rare tree species in the Bonga region (40 %) also falls within this range.

The abundance of tree species in natural forest is closely linked to their respective colonization strategies, i.e., their dispersal and establishment abilities. Important parameters to describing the colonization ability of tree species in the Bonga region are (Table 7.1):

- "**Canopy**" states whether trees belong to the five most important species regarding abundance and frequency of individuals in the canopy layer (> 15 m) of natural forest at Koma, Mankira and Kayakela.

  Ko: important canopy species in natural forest in Koma
  Ka: important canopy species in natural forest in Kayakela
  Ma: important canopy species in natural forests in Mankira
  n: no canopy individual in natural forest in any of the fragments

- "**DI_{SFC} versus DI_N**" indicates whether species have a higher DI in shaded natural forest plots or in disturbed SFC plots with high light penetration. The comparison is based on study plots at Kayakela where 11 plots were studied in both forest types.

  =: species cannot be assigned to a forest type, because difference in DI between natural forest and SFC systems < 1
  N: species is associated with natural forest because $DI_N > DI_{SFC}$ by a least 1
  SFC: species is associated with SFC plots because $DI_{SFC} > DI_N$ by at least 1
  no value: species has less than 2 individuals in Kayakela

- "**Sapling aggregation**" refers to the fact that some species form clumps of saplings (height 0.5 – 5 m; dbh < 2 cm). Average sapling density (average number of saplings per study plot) was calculated for each species in natural forest and SFC plots considering Koma, Kayakela and Mankira.

  N: average sapling density > 5 in natural forest

SFC: average sapling density > 5 in SFC systems

Max no.: maximum sapling density observed for species with sapling aggregation

- "**Succ. class**" shows the assignment of species into successional classes according to their respective distribution in shaded natural forest and disturbed SFC systems, and by drawing on information from other studies (Table 7.2).

  P: pioneer species

  S: secondary forest species

  C: climax species

In the following, the relation between species abundance, distribution and colonization strategy will be discussed in detail for rare, occasional, and common species.

Summary

- The distribution index (DI) was developed to define rare, common and abundant tree species: $DI_{species\ x}$ = (relative $frequency_{species\ x}$) + (relative $abundance_{species\ x}$)
- 40 % of the tree species in natural forest in the Bonga region are rare.

7.3.2 Rare species

Podocarpus falcatus, *Celtis gomphophylla*, and *Mimusops kummel* are rare because they are at their geographic margin of distribution in the Bonga region (Friis 1992; Thirakul no year). Most other rare tree species in this study are classified as pioneer species. Pioneer species depend on relatively large forest gaps for regeneration (see section 3.2.2). The DI of many rare species is higher in SFC systems than in natural forest, underlining their affinity with disturbed sites (Table 7.1). Five of these species are also shown to be associated with SFC systems by ordination techniques (Table 6.18).

The majority of forest gaps in natural forest in the Bonga region is very small (< 0.05 ha) because they are created by the fall of just one or two trees (Abayneh Derero 1998). Pioneer species thus do not encounter adequate conditions for regeneration in natural forest. Rarity caused by lack of suitable sites for recruitment (establishment limitation) is a common observation in tropical forests (Schupp et al. 2002). In Panama, at least 50 % of the rare species in mature forest are common species in second-growth forest elsewhere on the island (Hubbell and Foster 1986).

Table 7.2 Seed size, dormancy, dispersal agent, and wood density for selected trees

Species	Seed size (mm)[1]	Seed dormancy[2]	Dispersal agent[3]	Wood density (kg/m^3)[4]	Succ. class[5]
Common species					
Elaeodendron buchananii			B-S	720-959	S
Bersama abyssinica	8 x 11	high		720-839	S
Milletia ferruginea			B-S		S
Albizia gummifera	8-10 x 8-12		B-S	360-839	S
Phoenix reclinata			B-SU, M		S/C
Trilepisium madagascariense	8 x 10				S/C
Canthium oligocarpum	7-8 x 12-14		B-S		S/C
Allophylus abyssinicus	5-5.5 x 5.5-6		B-U, M	480-839	S
Syzygium guineense	diam.: 13-14	present		600-839	S/C
Ocotea kenyensis	6 x 14		B-S		S/C
Olea welwitschii	length: 10		B-S, M	720-839	S/C
Occasional species					
Pouteria adolfi-friederici	length: 30	low		360-719	C
Schefflera abyssinica	< 4				S/C
Apodytes dimidiata			B-U		S
Flacourtia indica	4-7 x 8-10		B-SU	850-880	S
Macaranga capensis	diam.: 2.5-4		B-S	360-599	P
Trichilia dregeana			B-SU		S
Sapium ellipticum	diam.: 5-6		B	480-719	S
Albizia schimperiana	6.5-8 x 9-11	present	B-S		S
Ekebergia capensis	5 x 10	medium	B-SU, M	592	S
Polyscias fulva	< 5		M		S
Ilex mitis	< 5		B-SU, M	480-719	S/C
Ficus sur	tiny	high	B-SU, Ba, M		S
Prunus africana	6 x 8		B, M	721	S
Euphorbia ampliphylla	diam.: 4.5		B-S		P
Fagaropsis angolensis	6 x 8			520	S
Rare species					
Alangium chinense	5 x 10			360-479	P
Cassipourea malosana	< 8			600-839	S/C
Celtis africana	< 8		B-S, M	600-839	P
Croton macrostachys	4 x 7	high	M	360-719	P
Cordia africana		present	B	360-719	P
Ficus ovata	tiny		B-SU, Ba, M		S
Hallea rubrostipulata	length: 2-3			360-719	P
Albizia grandibracteata	6.5-8 x 8-11		B-S		P
Ficus vasta	tiny		B-SU, Ba, M		S
Vangueria apiculata	4-6 x 9-17		M		P

[1] *(Edwards et al. 2000; RBG 2004; Farwig et al. 2005; ICRAF 2006)*

[2] *(Shehaghilo 1989; Demel Teketay 1993; Hedberg et al. 2003)*

[3] *B (birds): S (specialized)/ U (unspecialized); Ba (bats); M (monkeys) (Snow 1981; Foster et al. 1986; Lambert 1998; Kaplin and Lambert 2001; Turner 2001; Githiru et al. 2002; Farwig et al. 2005; ICRAF 2006)*

[4] *(ICRAF 2006)*

[5] *Successional class: P (pioneer species), S (secondary forest species), C (climax species); for explanation see text*

Pioneer tree species presumably grow fast but are short-lived, and thus do not persist in more mature forest as indicated by the lack of canopy individuals in the natural forest (Table 7.1). Furthermore, they have typical pioneer traits such as relatively small seeds and low wood densities (Table 7.2). Pioneers usually have seeds with dormancy mechanisms, but information on this issue is not available for most of the studied species.

All trees classified as pioneer species in this study are reported to be common in disturbed areas, secondary forests, forest margins, or forest gaps: *Alangium chinenese* (Hedberg and Edwards 1989; Chapman et al. 2002), *Albizia grandibracteata* (Abayneh Derero 1998; Chapman and Chapman 1999; Chapman et al. 2002), *Celtis africana* (West et al. 2000; Chapman et al. 2002; Mersha Gebrehiwot 2003), *Cordia africana* (Friis 1992; Abayneh Derero 1998; Chapman and Chapman 1999), *Croton macrostachys* (Edwards et al. 1995; Abayneh Derero 1998; Getachew Tesfaye et al. 2002), *Euphorbia ampliphylla* (Friis et al. 1982; Friis 1992), and *Hallea rubrostipula* (Hedberg et al. 2003).

The whole genus *Macaranga* is typical for large gaps in Africa and Asia and comprises typical traits of pioneer species, i.e., bird dispersed, strongly light demanding and fast-growing with pale wood of low density (Corlett 2001; DFSC and IPGRI 2001a; Turner 2001). *Macaranga capensis* recorded in this study also establishes well in smaller gaps as indicated by a relatively high DI in natural forest (Table 7.1).

Summary

- Most rare trees are pioneer species. They are rare in natural forest because they are adapted to regeneration in disturbed forest parts.

7.3.3 Occasional species

Most occasional tree species have large canopy individuals in the natural forest, which indicates that they are representative for later stages of succession (see section 3.2.2). Occasional tree species with higher DI in SFC systems than in natural forest are considered to be relatively light demanding and are therefore classified as secondary forest species (Table 7.1). In contrast, occasional species with DI larger in natural forest than in SFC systems are presumably more shade tolerant. They are thus considered as secondary forest to climax species.

Seed sizes and wood densities are highly variable amongst occasional species (Table 7.2). The assumed correspondence between small seed size and early successional status and large seed size and late successional status has only been observed in few cases (Snow 1981; Brokaw 1985; Vázquez-Yanes and Orozco-Segovia 1990; Turner 2001).

As it is difficult to draw general conclusion on the species' ecology, in the following, the relation between abundance, distribution and colonization strategy is analyzed in more detail for selected occasional species.

- *Ficus sur*:

  The genus *Ficus* has some typical pioneer traits such as tiny seeds and high dormancy in the case of *F. sur* (Demel Teketay 1993). Many *Ficus* species are known from secondary shrub and forest margins (Hedberg and Edwards 1989), but also persist as large trees in natural forest, and are therefore classified as secondary forest species (Table 7.1).

- *Sapium ellipticum*, *Polyscias fulva*:

  Sapium ellipticum and *P. fulva* are typical secondary forest species, because they are light demanding and thus need forest gaps for regeneration, but persist in the canopy of mature forest (Friis et al. 1982; Friis 1992; Althof et al. 2001; Getachew Tesfaye et al. 2002; ICRAF 2006). Both species have many mature individuals in the natural forest, but few regenerating ones (Figure 7.2).

  Such a senescent population structure of secondary forest species in mature forest is also observed in West Africa and Panama (Hubbell and Foster 1986; Turner 2001). Presumably, these species are relics of intense disturbance in the past, or their regeneration is tied to very sporadic disturbance events after which new recruits grow rapidly and soon reach large size. *Sapium ellipticum* probably requires large gaps for regeneration because it is abundant in plots with forest recovery after complete clearing in Uganda (Chapman and Chapman 1999). In the Bonga region, some forest parts used to be village areas that were abandoned two or three generations ago. The presence of large individuals of secondary forest species could be an indicator of such sites. It is also suggested that selective cutting of *P. fulva* for beehive-making has caused a lack of medium-sized individuals of this species (Ensermu Kelbessa and Teshome Soromessa 2004).

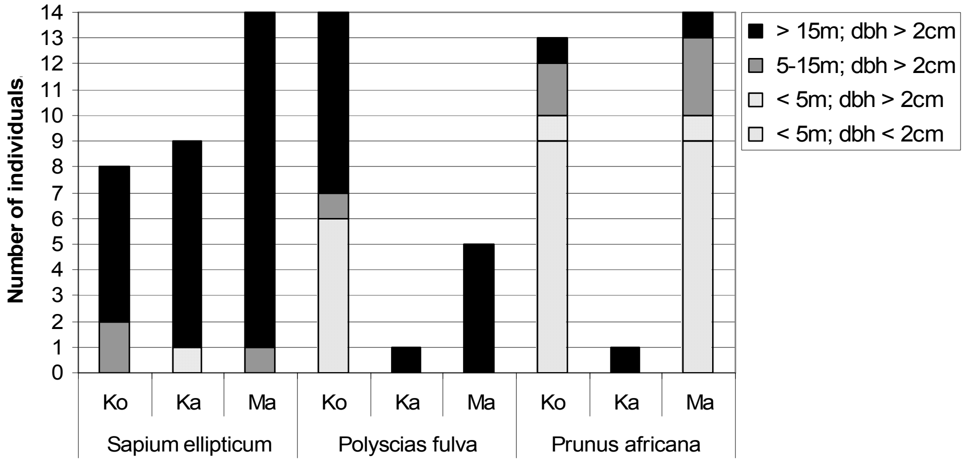


Figure 7.2 Abundance (four size classes) of *Sapium ellipticum*, *Polyscias fulva* and *Prunus africana* in natural forest at Koma (Ko), Kayakela (Ka) and Mankira (Ma); data from 29 (Ko), 12 (Ka), and 14 (Ma) study plots

- *Prunus africana*:

Prunus africana is recognized as a non-pioneer light demander (Kiama and Kiyiapi 2001; Opiyo Odhiambo et al. 2004) and a common species in forest regrowth following clearing (Chapman and Chapman 1999). The species is less light demanding than *S. ellipticum* and *P. fulva* (Chapman et al. 2002), because it can germinate under shady conditions (Farwig et al. 2005). Saplings of *P. africana*, though, require light gaps for further growth. This is also indicated in the present study: Even though *P. africana* is more abundant in SFC plots than in natural forest plots in Kayakela (Table 7.1), the species has many saplings in the natural forest in Koma and Mankira (Figure 7.2). These saplings probably persist in the shaded understory until a gap develops and allows for further growth. The small number of mature *Prunus* trees in the natural forest could thus be related to the fact that saplings require some disturbance to grow into mature trees.

In many African forests, *P. africana* is threatened by unsustainable bark harvesting methods (Fashing 2004). In the Bonga region, the bark of *P. africana* is not harvested, but the tree is a valued timber species (Table A 4). Hence, the small number of mature *Prunus* trees in the Bonga region could also be related to over-exploitation by the local population.

- *Schefflera abyssinica*:

  Schefflera abyssinica belongs to the five most frequent and abundant canopy species in Koma, Kayakela, and Mankira (Table 7.1). The species starts its life cycle as an epiphyte (Cannon 1978). Due to absence of young individuals on the ground, it has relatively low abundance. Canopy individuals, though, are frequent in natural forest.

- *Apodytes dimidiata*:

  Apodytes dimidiata often occurs in forest clearings and at forest edges (Friis 1992). It has tiny fruits in superabundance to attract birds, a character typical for early successional species (Snow 1981; Howe 1986). The tree is classified as secondary forest species, because large individuals persist in the canopy of natural forest even though their number is quite small in the present study. This could be due to the fact that the species reaches 25 m, but often only develops into shrubs or small trees of 5 – 15 m (Mendes 1963; Friis 1992). Another study suggests that older individuals are removed by the local population for various uses such as for fuel and construction wood (Ensermu Kelbessa and Teshome Soromessa 2004).

- *Fagaropsis angolensis*, *Ekebergia capensis*:

  Fagaropsis angolensis and *E. capensis* are classified as secondary forest species because they are known from secondary forest formations and forest edges (Friis 1992). Both species probably tolerate a wide range of light conditions, because in this study, saplings of *F. angolensis* are more abundant in shaded natural forest plots, and saplings of *E. capensis* in open SFC plots, while the opposite is the case in another study (Abayneh Derero 1998). In South Africa, *E. capensis* shows successful sub-canopy regeneration (West et al. 2000).

- *Pouteria adolfi-friederici*:

  Pouteria adolfi-friederici is exceptional because it is the only species in the Bonga region with typical climax traits. It has large seeds with very short viability, and seedlings require shade for successful growth (Hedberg et al. 2003). Though the wood has quite low density (Table 7.2), it is classified as hard and heavy (Thirakul no year). The population structure of *P. adolfi-friederici* is characteristic for shade-tolerant climax species, since the percentage of regenerating individuals is high (Figure 7.3). Climax species have slow growth rates among small size classes and typically accumulate large numbers of individuals in the lower intervals (Clark and Clark 2001; Turner 2001; Antos et al. 2005).

In the Bonga region, *P. adolfi-friederici* is uncommon in relation to other emergent canopy species such as *Olea welwitschii* and *Trilepisium madagascariense*. In contrast, in forests around Gore, 120 km northwest of Bonga, it often is the only emergent tree species (Friis et al. 1982). A FAO study suggests that this was also the case in the Bonga forest, but selective logging removed the best trees from the stand (Kidane Mengistu 2003). Selective logging in southwestern Ethiopia apparently started as early as in the mid 1950s and was encouraged by the proximity of the main Jimma-Mizan road (Mateos Ersado 2001). The intensive commercial exploitation of the Bonga forest, however, could not be confirmed with local authorities during this study. It is therefore more likely that *P. adolfi-friederici* has a natural low abundance in the study region.

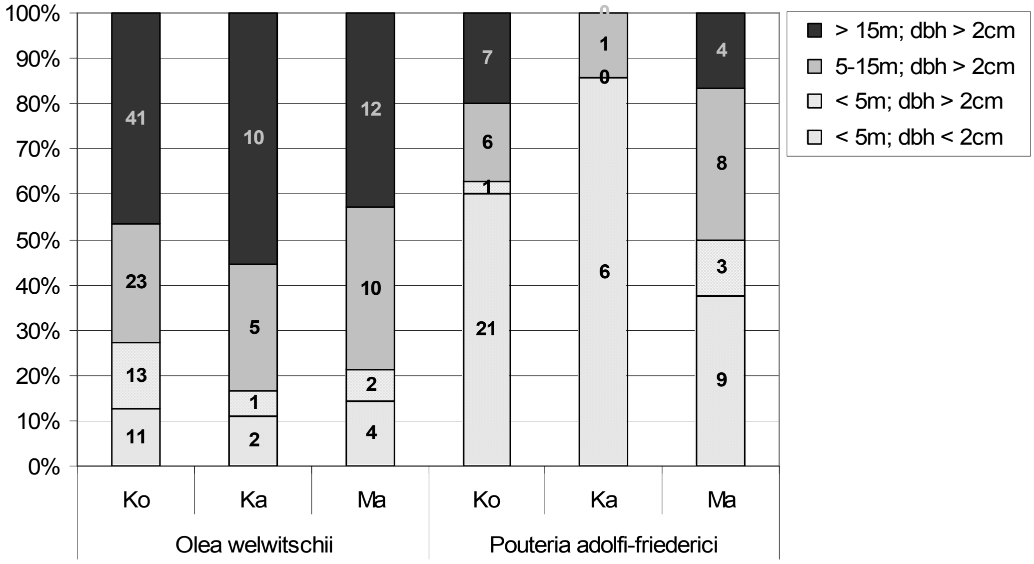


Figure 7.3 Relative abundance (%) of individuals of *Olea welwitschii* and *Pouteria adolfi-friederici* (four size classes) in natural forest at Koma (Ko), Kayakela (Ka) and Mankira (Ma); data from 29 (Ko), 12 (Ka), and 14 (Ma) study plots; figures indicate absolute individual numbers

Except one pioneer species, none of the occasional species shows aggregation of saplings in natural forest or SFC plots (Table 7.1). Individuals of *P. fulva*, *P. africana* and *P. adolfi-friederici*, for example, are scattered throughout the natural forest in Koma. In a few study plots only, several conspecific individuals of these species were observed (Table 7.3).

Clumped seedlings often face greater mortality due to competition for resources, higher level of density-dependent seed or seedling predation and higher frequency of pathogen infection. Many tropical species, therefore, have a scattered distribution (Howe 1986; Howe 1990; Poulsen et al. 2002; Terborgh et al. 2002, Lambert, pers. comm., 2006). High mortality of individuals in dense stands might also be responsible for the scattered distribution of occasional species. The seeds of most occasional species are transported away from mother trees by birds or monkeys (Table 7.2). It is likely that these animals also disperse seeds of *P. adolfi-friederici*.

Table 7.3 Distribution of *Polyscias fulva*, *Prunus africana* and *Pouteria adolfi-friederici* in natural forest plots (20 m x 20 m) at Koma forest fragment; distance between study plots (P) at least 300 m; size classes: I (< 5 m; dbh < 2 cm), II (< 5 m; dbh ≥ 2 cm), III (5 - 15 m), IV (> 15 m)

P	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Polyscias fulva (number of individuals)																													
I														**2**		**1**		**1**		**1**	**1**								
II																													
III																		**1**											
IV						**1**				**1**			**1**		**1**								**1**		**1**				**1**
Prunus africana (number of individuals)																													
I	**2**									**4**							**1**	**2**											
II																											**1**		
III																											**2**		
IV																			**1**								**1**		
Pouteria adolfi-friederici (number of individuals)																													
I	**1**	**2**			**1**		**1**	**1**	**1**		**2**			**5**	**2**			**1**						**2**		**1**		**1**	
II		**1**																											
III		**1**		**1**	**1**							**1**												**2**					
IV		**1**																				**2**	**1**	**3**					

Summary

- Except *Pouteria adolfi-friederici*, a typical climax species, most occasional trees are secondary forest species. Large canopy individuals of secondary forest species are scattered throughout the natural forest, but their regeneration depends on forest gaps.

7.3.4 Common species

Most common species are abundant because they have many saplings and many canopy individuals. They are classified as secondary forest species if they are more abundant in SFC systems than in natural forest, and as secondary forest to climax species if the opposite is the case (Table 7.1). Seed size and wood density are highly variable for common species, and it is difficult to make the supposed link between climax species, large seed size and high wood density (Table 7.2).

Except *Olea welwitschii* and *Canthium oligocarpum*, common species form sapling aggregates in natural forest, in SFC systems, or in both of these forest types (Table 7.1). Sapling aggregation is the reason for high abundance but relatively low frequency of *Ocotea kenyensis*, *Trilepisium madagascariense*, and *Albizia gummifera*. Saplings of *Elaeodendron buchananii* are also abundant in plots with adult trees (Table 7.4). The high abundance of common species as compared to occasional species in this study could thus be related to their adaptation to regeneration near conspecific individuals (Howe 1986; Terborgh et al. 2002).

In the following, the relation between abundance, distribution and colonization strategy is analyzed in more detail for selected common species.

- *Olea welwitschii*:

  Olea welwitschii is a common canopy species in Koma, Mankira and Kayakela (Table 7.1). Due to relatively low recruitment it is, however, the least abundant of the common species. It is described as early secondary forest species characteristic of extensive gaps (0.5 - 3 ha) (DFSC and IPGRI 2001a) or as early to mid-successional species (Chapman et al. 2002). The low abundance of young individuals in the natural forest is therefore probably related to the fact that light conditions are too shady for successful germination and regeneration of this species.

  Another study claims that the low number of young *Olea* individuals is caused by over-exploitation, since it is a highly valued fuel wood species (Table A 4). The population structure of *O. welwitschii* is, however, consistent throughout the study plots at Koma (Table 7.4), and rather similar in all forest fragments (Figure 7.3).

Table 7.4 Distribution of *Olea welwitschii* and *Elaeodendron buchananii* in natural forest plots (20 m x 20 m) at Koma forest fragment; distance between plots (P) at least 300 m; size classes: I (< 5 m; dbh < 2 cm), II (< 5 m; dbh ≥ 2 cm), III (5 -15 m), IV (> 15 m)

P	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Olea welwitschii (number of individuals)																													
I				**3**						**4**				**1**			**1**						**1**	**1**					
II												**1**					**1**			**6**					**2**			**1**	**2**
III						**1**			**2**	**4**	**1**		**1**	**2**	**1**		**1**	**1**	**1**	**3**	**1**	**1**		**1**			**2**		
IV							**1**			**3**	**1**		**4**	**4**	**1**	**3**	**4**	**2**	**1**	**1**		**3**	**3**			**4**	**2**	**2**	**2**
Elaeodendron buchananii (number of individuals)																													
I	**2**	**2**		**2**	**4**		**3**	**5**	**4**	**3**			**51**	**5**	**4**	**17**	**28**	**5**			**1**	**10**	**2**	**2**		**2**			**14**
II	**8**			**1**			**3**	**2**		**5**	**4**	**1**	**7**	**1**		**6**	**12**	**5**	**1**	**2**		**1**	**4**			**2**			
III	**6**	**2**	**2**	**2**	**2**		**3**	**1**	**2**	**16**	**6**	**2**	**15**	**2**	**7**	**6**	**29**	**5**		**5**		**2**	**6**	**1**		**5**			**1**
IV		**3**								**2**	**2**	**1**	**8**		**7**		**1**	**6**				**1**	**1**						

It is rather unlikely that farmers removed most young individuals of *O. welwitschii* in all forest fragments. In the case of *Elaeodendron buchananii*, another species in high demand by farmers due to its straight poles, medium-sized individuals are in high abundance throughout the forest. It is thus hypothesized that the two species have different regeneration strategies, which result in different population structures.

- *Syzygium guineense, Elaeodendron buchananii*, *Trilepisium madagascariense*:
  Syzygium guineense, E. buchananii and *T. madagascariense* belong to the most common canopy species (Table 7.1). They show sapling aggregation in disturbed SFC systems as well as in shaded natural forest. Apparently, they are generalists that germinate under a wide range of light conditions. Likewise in Panama, the most common forest species are generalists in terms of habitat and regeneration requirements (Hubbell and Foster 1986).

  The population structures of *S. guineense*, *E. buchananii* and *T. madagascariense* are quite similar in all forest fragments despite different abundances (Figure 7.4). The high percentage of individuals in the small size classes indicates that the species are able to germinate under shady conditions in natural forest. Hence, they accumulate large numbers of saplings persisting in the understory until growth conditions improve. Common species also usually have less than 20 % adults in Panama (Hubbell and Foster 1986).

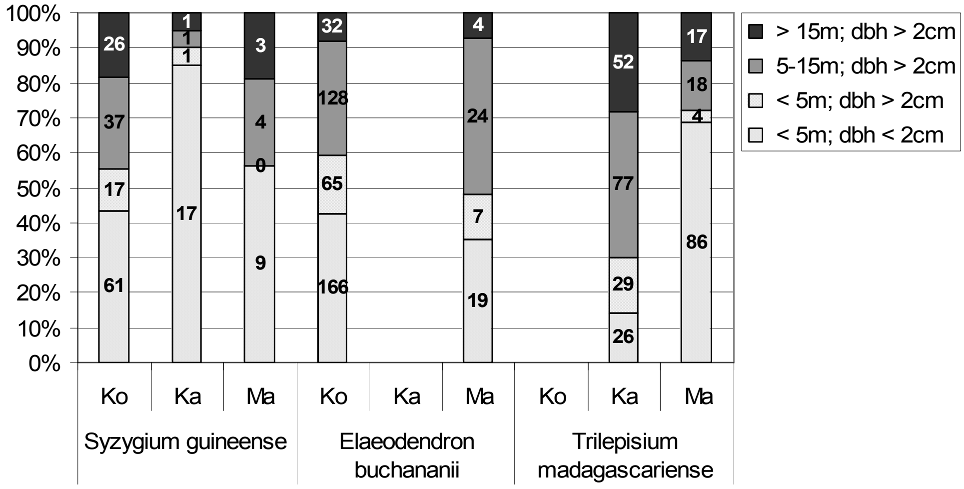


Figure 7.4 Relative abundance (%) of individuals of *Syzygium guineense*, *Elaeodendron buchananii* and *Trilepisium madagascariense* (four size classes) in natural forest at Koma (Ko), Kayakela (Ka) and Mankira (Ma); data from 29 (Ko), 12 (Ka), and 14 (Ma) study plots; figures indicate absolute individual numbers

The population structure of *T. madagascariense* in Kayakela is different due to a high fraction of medium-sized and tall trees. This species is the dominant canopy tree species in this fragment. It is probably highly competitive and young individuals quickly grow into large trees.

- *Bersama abyssinica*, *Allophylus abyssinicus*, *Canthium oligocarpum*, *Ocotea kenyensis*:
  Bersama abyssinica, *A. abyssinicus*, and *C. oligocarpum* usually do not reach heights larger 15 m and therefore have few individuals in the canopy of the studied forest fragments (Hedberg and Edwards 1989; Friis 1992; Hedberg et al. 2003; Thirakul no year). The same holds true for *O. kenyensis*, which can grow up to 40 m tall, but is mostly much shorter (Stannard 1997), and reaches only 20 m in Uganda (Friis 1992). Though *O. kenyensis* is a highly valued timber species (Edwards et al. 2000; Ensermu Kelbessa and Teshome Soromessa 2004), its low number of large individuals is probably characteristic for southwestern Ethiopia and not a sign of human interference.

  Bersama abyssinica and *A. abyssinicus* are secondary forest species associated with forest edges and secondary forests (Hedberg and Edwards 1989; Friis 1992). *Canthium oligocarpum* and *O. kenyensis* are probably secondary forest to climax species. *Ocotea kenyensis*, for example, belongs to the Lauraceae plant family, which has coevolved with specialized frugivorous birds. Lauraceous fruits have a single large seed, a typical feature of climax forest species (Snow 1981).

- *Milletia ferruginea*:
  Milletia ferruginea is a secondary forest species that regenerates well and grows fast in open sites, but persists in mature forest (Mersha Gebrehiwot 2003). In the Bonga region, it is abundant in natural forest, but even more so in SFC plots, because the species is selected by farmers as a shade tree for coffee.

Summary

- Common tree species in this study tolerate regeneration close to conspecifics. They are generalists in terms of light requirement and recruit well in shaded natural forest as well as in disturbed SFC systems.
- *Olea welwitschii* is exceptional because this species is abundant in the canopy of natural forest, but regeneration seems to require forest gaps.

7.4 Implications for conservation

7.4.1 Impact of human disturbance

For centuries, the natural forest in the Bonga region has been subject to human activities such as the removal of tree poles and trunks for timber, construction, farm implements, firewood, charcoal, and beehive-making (Table A 4). Man-made forest gaps and abandoned villages could be responsible for the presence of secondary forest species in mature forest parts. The impact of human activities on tree species distribution and population structure is, however, difficult to estimate, because pristine reference sites are not available for direct comparison.

The results of this study show that most of the common tree species in the Bonga region are habitat generalists and have high rates of recruitment in shaded natural forest as well as in open semi-forest coffee systems. They are probably able to maintain viable populations even if anthropogenic forest disturbance increases. The rare species in natural forest are mostly pioneer species. These species are abundant in forest margins and ruderal sites. They are adapted to long-distance seed dispersal, have seeds in the soil seed bank, and their abundance will naturally increase with increasing forest disturbance.

Regarding the occasional species, e.g., *Pouteria adolfi-friederici*, *Sapium ellipticum*, *Polyscias fulva*, and *Prunus africana*, skewed population structures and relatively low abundances could be related to human impact or to natural gap dynamics. As population structures of these species are similar throughout all forest fragments, it is hypothesized that their light requirement for regeneration, and thus gap dynamics, is the most crucial factor in determining their abundance. This means that population size and structure of secondary forest species, e.g., *Sapium ellipticum* and *Polyscias fulva*, are probably subject to natural fluctuations.

Increasing human disturbance, i.e., the creation of forest gaps, presumably has negative impacts on the species identified as climax species, e.g., *Pouteria adolfi-friederici*, but positive impacts on others, e.g., pioneer species, depending on intensity, frequency and spatial distribution of disturbance. The creation of small gaps by felling of one or two trees can enhance regeneration of species that require moderate light conditions, e.g., *Prunus africana* and *Olea welwitschii*. If the created gaps are large, light demanding species such as *Sapium ellipticum* and *Polyscias fulva* and pioneer species will be more competitive. As long as these man-made gaps are infrequent throughout the forest, and the vegetation is given time to develop back into mature forest, human disturbance mimics natural gap dynamics and will not modify the natural species composition in the long run. If anthropogenic disturbance recurs, however, on an annual basis like in semi-forest coffee systems, there will be a change in species composition.

High levels of human disturbance finally lead to forest degradation and fragmentation, which has particularly negative impacts on species with small population sizes (see section 3.2.3). To estimate the minimum viable population size of species, it is necessary to know whether fragmented populations are part of a metapopulation (for an in-depth review of the metapopulation theory see Gilpin and Hanski 1991; Hanski and Gaggiotti 2004). Regarding animal-dispersed tree species, one critical question in this context is whether seed dispersers are able to move between forest fragments and thus facilitate the gene flow between geographically separated populations of the same species.

In the Bonga region, the silvery-cheeked hornbill (*Ceratogymna brevis)* and white-cheeked turaco (*Tauraco leucotis*) are the main large frugivorous birds (Snow 1981, Tadesse Woldemariam, pers. comm., 2006). Fruit bats are probably also among the main pollinators and seed dispersers (Newmark 2002). Out of three primate species, vervet monkeys *(Cercopithecus aethiops)* defecate seeds in viable conditions, but black-and-white colobus monkeys (*Colobus guereza*) and olive baboons (*Papio anubis*) eat and kill seeds rather than disperse them (Howe 1986; Kaplin and Lambert 2001, Forget pers. comm. 2006, Lambert pers. comm. 2006). Most of the studied tree species are bird-dispersed, many are also dispersed by monkeys, and there is no evidence for specialized tree-seed disperser relationships (Foster et al. 1986; Lambert 1998; Kaplin and Lambert 2001; Turner 2001; Farwig et al. 2005; ICRAF 2006). In general, there is little specialization in frugivorous birds regarding fruits of particular tree species in Africa (Snow 1981; Githiru et al. 2002).

Hornbills and turacos are much more effective seed dispersers than primates, and hornbills in particular are known for large-scale movements (Turner 2001; Githiru et al. 2002; Holbrook et al. 2002; Poulsen et al. 2002; Cordeiro et al. 2004). They presumably disperse seeds of most species between forest fragments in the Bonga region, which is supported by the fact that some trees, e.g., *Celtis gomphophylla*, *Ficus vasta*, *Cassipourea malosana*, and *Mimusops kummel* were only found with one regenerating individual in a forest fragment. Even small forest fragments can, therefore, be considered as important stepping stones (sensu Murphy and Lovett-Doust 2004) for seed dispersers and as islands of propagules for other fragments.

It is concluded that species abundances and population structures in natural forest of the Bonga region are mainly governed by natural processes. Human disturbance and forest fragmentation are currently at a level that has not led yet to major changes in the natural species composition of the remaining forest fragments. Hence, rare species are not threatened by local extinction.

7.4.2 Preventive measures

The occasional cutting of mature trees by local farmers does not jeopardize the original species composition of natural forest. The population in the Bonga region is increasing, however, and the demand for timber and fuel wood is thus growing. Wood extraction will have to be controlled in the future to prevent the over-exploitation of particular tree species. Vulnerable species are secondary forest and climax species with relatively few individuals such as occasional tree species that are in high demand by local communities, e.g., *Polyscias fulva*, *Pouteria adolfi-friederici*, and *Prunus africana* (Table A 4).

Wood extraction can only be restricted if farmers are able to meet their demands for timber and fuel wood from alternative sources. One possibility is the propagation of pioneer and secondary forest species in semi-forest coffee (SFC) systems, field margins and home gardens, because these species regenerate well in open sites, grow quite fast, and produce wood that can be used for many purposes. Some of these species are also traded at the national level and can constitute an alternative income for farmers, e.g., *Cordia africana* and *Croton macrostachys* (timber) as well as *Albizia gummifera* and *Apodytes dimidiata* (charcoal production) (Million Bekele 2001).

Local communities in the Bonga region do not have any traditional management systems for tree propagation. From their point of view, the forest is an everlasting resource, and as trees grow naturally, there is no need for planting them. In other parts of Ethiopia, however, *Cordia africana* and other species are propagated by local farmers by means of natural regeneration, direct seeding, wildings, and cuttings. Of the source of planting material, 50 % is from farmers themselves, indicating that nurseries are not always needed (Abebe Seifu 2000).

Germination is often a problem with tropical trees (Demel Teketay 1993), but many indigenous tree species can be regenerated from cuttings or wildlings and are already successfully cultivated in other African countries (Table 7.5). Training and support of farmers in the propagation of trees within the framework of a regional development program can, therefore, be a viable method for mitigating wood extraction from natural forest. This will only be successful, however, if farmers are integrated in the planning process of such a program and can select tree species for propagation according to their own needs.

Table 7.5 Propagation method and growth rate for selected pioneer and secondary forest species

Species	Dormancy/ Pre-sowing treatment	Propagation method	Growth rate	Remarks
Albizia gummifera [10]		seeds		regeneration easy, germination in 7-14 days, seedlings reach plantable size in 4-5 months
Apodytes dimidiata [9]		seeds	0.7 m yr^{-1}	germination very slow; grown in home gardens in South Africa
Bersama abyssinica [1]	dorm.: very high			
Celtis africana [5, 8]			2 m yr^{-1}	research needed on extraction, drying, germination, pretreatment, storage; grown in home gardens in South Africa
Cordia africana [2, 3, 5, 6, 10, 12]	dorm.: physical	seeds	fast; 7-8 m in 7 yrs	germination rate in field low; germination from seed erratic, but after it starts, tree grows well; research needed on extraction, drying, germination, pretreatment, storage; germination in 21 days, seedlings reach plantable size in 5-7 months; cultivated in Kenya
Croton macrostachys [1, 3, 4, 5]	dorm.: very high/ poses problems; pre-sowing treatm.: yes[1, 4]; no[3]	coppicing, wildlings, seeds	fairly fast if not too dry	sun-dried fruits can be stored for some months if kept cool and dry, germination rate ca. 40-70%; grown in Kenya, but seed storage and germination difficult; research needed on drying, storage
Ekebergia capensis [1, 3, 7, 10]	dorm.: medium	seeds, wildlings, cutting	1 m yr^{-1}	grown in home gardens in South Africa; slow germination, seedlings reach plantable size in 9-10 months
Fagaropsis angolensis [5]				research needed on extraction, storage
Macaranga capensis [3]		seeds, wildlings	fast	little management needs once established
Polyscias fulva [3]		seeds, wildlings		
Prunus africana [3, 5, 10, 11, 12]		seeds, wildlings	moderate	responds well to cultivation; sensitive to loss of moisture content, needs coldstore; slow germination, seedlings reach plantable size in 9-12 months
Sapium ellipticum [3]	pre-sowing treatm.: no	seeds, wildlings		

[1]*(Demel Teketay 1993)*, [2]*(Chapman and Chapman 1999)*, [3]*(ICRAF 2006)*, [4]*(Kamra 1989)*, [5]*(Schaefer 1989)*, [6]*(Shehaghilo 1989)*, [7]*(Dlamini 2004)*, [8]*(Mbambezeli and Notten 2003)*, [9]*(Mbambezeli 2003)*, [10]*(Ibrahim 1986)*, [11]*(DFSC and IPGRI 2001b)*, [12]*(Bernard 2001)*

8 CONSERVATION PLANNING FOR THE BONGA REGION

8.1 Introduction

The main conservation objectives for the Bonga region are *in situ* preservation of wild *Coffea arabica* in its natural habitat, and maintenance of typical species composition and vegetation structure of the remaining natural forest areas. The preceding chapters point out important prerequisites for the achievement of these objectives:

- It is crucial to protect natural forest in at least two forest fragments, namely Koma and Mankira, because they represent different vegetation types and have high species diversity (Chapter 6). The size of natural forest in these fragments is also large enough to sustain viable populations and a representative number of infrequent species such as many epiphyte and tree species.
- Eventually, all natural forest areas with wild coffee have high conservation value. Due to small-scale environmental variations, they constitute different habitats for maintenance of high genetic diversity of wild coffee (Chapter 5). Besides, the forest is often located on steep slopes and serves as protection against soil erosion. Small forest fragments help to protect species with little area requirements (Chapter 6). In addition, they function as important stepping stones for seed dispersers and as a source of propagules for neighboring forest fragments (Chapter 7).
- Coffee management is not a danger to wild populations of *Coffea arabica*, but rather promotes wild coffee growth (Chapter 5). Semi-forest coffee (SFC) systems have relatively high yields, but strongly modify the original vegetation structure and species composition of natural forest (Chapter 5 and 6). Consequently, coffee production in SFC systems and forest conservation are not compatible within the same forest area.
- As intensification of coffee production is a danger to currently unmanaged or little managed forest parts, coffee management activities need to be monitored and production ceilings have to be put in place (Chapter 5). Over-exploitation is a particular threat to certain secondary forest and climax tree species, and wood extraction from natural forest should therefore be controlled (Chapter 7).
- Conservation concepts should not only designate protected areas, but also need to consider the landscape matrix. SFC systems, for example, constitute important buffer zones for natural forest and serve as corridors for seed dispersers in the fragmented forest landscape of the Bonga region. Adequate management of buffer zones and

agricultural areas, e.g., the propagation of fast-growing pioneer and secondary forest species, can take human pressure off natural forest (Chapter 7).

The results of this study point out that forest conservation and the use of wild coffee populations are best combined within a zoning system, i.e., a network of strictly protected core areas for *in situ* conservation of wild *Coffea arabica* in natural, unmodified forest, and less strictly protected buffer zones where intensive coffee management and wood extraction are allowed. Such conservation schemes will only work successfully if they consider the demands of rural communities whose livelihoods depend on forest resources, and who are in fact the custodians of the forest. Since conservation has a long-term perspective, it is crucial to put in place measures and activities that ensure the overall sustainable development of the Bonga region. They should best be integrated in an international framework to gain maximum support at local, national, and international levels (see section 3.3).

The biosphere reserve scheme is well suited to implement the requirements for successful forest conservation in the Bonga region. It offers the opportunity to create a network of protected areas including zones with different protection status and according management plans. Furthermore, it recognizes the claims of the local communities inside the reserve and has long-term conservation, development, and logistic support as main principles. Biosphere reserves also have the advantage that they integrate a wide variety of conservation measures and management approaches. They are not a panacea, however. All suggestions for management activities, incentives, and development processes made within the biosphere reserve framework can also be modified for implementation with other conservation schemes.

8.2 Proposal for a biosphere reserve in the Bonga region

8.2.1 Objectives

The proposed biosphere reserve in the Bonga region fulfills the three main functions of biosphere reserves as required by the Man and the Biosphere (MAB) Program, namely conservation, development, and logistic support (see section 3.4). It contributes towards conservation of genetic diversity of the world-wide unique wild *Coffea arabica* and towards conservation of the last Afromontane forest ecosystems in Ethiopia (function 1). It supports regional economic and human development by promoting sustainable use of forest and agricultural resources (function 2). The Bonga region is representative for environmental, social and economic conditions of Afromontane forest areas in Ethiopia. It is thus an appropriate site for initiating further research projects on wild coffee and the Afromontane forest ecosystem as well as for creating training and education opportunities for the local population, and other national and international interest groups (function 3).

The proposed biosphere reserve in the Bonga region entirely meets the criteria for designation of biosphere reserves as outlined in section 3.4. In this region, there is a great diversity of natural habitats and land-cover types ranging from managed and unmanaged forest, traditional agriculture, home gardens, and grasslands to small rivers and marsh areas (criteria a). Therefore, it has the potential to serve as a demonstration area regarding research on and implementation of sustainable forest and land-use practices (criteria c). The Bonga region also has high significance for biological diversity conservation because the Afromontane ecosystem is classified as a biodiversity hotspot. Besides, *in situ* conservation of genetic diversity of wild *Coffea arabica* is of global economic importance, and wild coffee management systems constitute a worldwide unique land-use practice (criteria b). The Bonga region is also large enough to encompass the recommended zoning system for biosphere reserves (criteria d and e).

There are already a number of non-governmental organizations (NGOs) and governmental organizations in the Bonga region that work closely with local communities in the area of rural development. This existing network can be used to ensure involvement and participation of all stakeholders in designing and implementing the biosphere reserve (criteria f). At the national level, the proposed biosphere reserve fits well into the protected area system of Ethiopia, which is already in place (UNDP-GEF 2004). The national committee of the MAB Programme in Addis Ababa could facilitate the planning and implementation process for the Bonga biosphere reserve (UNESCO 2006).

In terms of the IUCN classification of protected area management categories, the biosphere reserve in the Bonga region falls into category VI (managed resource protected area) (IUCN-WCPA and WCMC 1994). There are currently no biosphere reserves in Ethiopia; the Kiunga Marine National reserve in Kenya is an example for a biosphere reserve defined as category VI of the IUCN.

8.2.2 Benefits and incentives

The designation of a biosphere reserve in the Bonga region provides substantial benefits to Ethiopia on national as well as regional levels in terms of international recognition, capacity building and funding opportunities (UNESCO 2006). For example, it can serve as a tool to meet obligations under international conventions, such as the Convention on Biological Diversity (CBD), which was signed by Ethiopia in June 1992 and ratified in April 1994 (CBD 2005).

The effort to establish a biosphere reserve is internationally recognized and may be rewarded with increased development co-operation. Through the process of establishing a biosphere reserve, government decision-makers and agencies obtain valuable information on natural resources. They further receive technical and institutional assistance in managing natural resources in a sustainable manner. Capacity building in managing and marketing the highly valuable genetic resources of *Coffea arabica* would be a particular benefit for Ethiopia.

Biosphere reserves encourage interdisciplinary research on ecological and socio-economic processes, include monitoring schemes, facilitate information exchange, and attract allocation of international research funds (CBD 2005). Many international governmental and non-governmental organizations are associated with the functioning of the World Network of Biosphere Reserves and the implementation of the concept at field level. Conservation and appropriate development in biosphere reserves are, for example, financially supported by the World Bank, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the Food and Agriculture Organisation of the United Nations (FAO), the World Conservation Union (IUCN), Conservation International and the World Wide Fund for Nature (WWF). Furthermore, biosphere reserves attract tourists who may enhance the development of the tourism sector in Ethiopia.

If the proposed biosphere reserve is established, local communities will face restrictions regarding their current forest and land-use systems, on the one hand. On the other, they will profit from the biosphere reserve due to various potential benefits such as protection of basic land and water resources, continued opportunities to maintain existing traditions and lifestyles, and healthier environment (CBD 2005). Biosphere reserves also provide access to training and demonstration projects on alternative land-uses and management strategies, which maintain natural values such as soil fertility and water quality. These are not, however, true incentives for communities in the Bonga region to support the biosphere reserve concept, because they perceive these benefits as an intrinsic part of their environment. In the Bonga region, soil erosion, water and air pollution are problems unknown to the local population. Incentives that will be recognized as compensation for real or perceived restrictions of traditional management systems, therefore, have to offer something that was not available before and should be collectible over a longer period of time.

An important incentive would be, for example, enhanced tenure security for local farmers through legal recognition of the zoning system within the biosphere reserve by the Ethiopian government. In addition, technical support and capacity building in the marketing of wild coffee, honey, spices and sustainably produced timber can provide a more stable and diverse economic base to local farmers. It should be combined with improvement of the public transport system to allow for better access to regional as well as national markets. The development of regional infrastructure within the framework of a biosphere reserve, e.g., schools and hospitals, is a further incentive. Biosphere reserves also create additional employment opportunities for guards and extension workers. Besides, carefully planned eco-tourism can provide direct benefits to individuals and to local communities as a whole, and can help to link conservation with economic development (Newmark 2002; Krüger 2005).

8.2.3 Management guidelines

The Bonga region is a mosaic of relatively undisturbed forest fragments, disturbed forest parts, agricultural fields, and grasslands. These land-use types fulfill different functions within the biosphere reserve. Accordingly, they are assigned to core, buffer and transition areas and are subject to varying management approaches (Figure 8.1). The borders of the biosphere reserve follow landmarks like roads and rivers, and are demarcated in a way as to include only two *woredas*, namely Gimbo and Decha, for simplification of regional planning processes (compare Figure 4.1).

During the concrete development phase of the biosphere reserve, detailed management plans will have to be prepared for local administrative units (*kebeles*) as has already been done for Kayakela (Tästensen 2006). These detailed plans need to take into account small-scale variations in population density, forest degradation, traditional land-use types, and ethnic composition.

Each village has traditional allocations of forest and land-use rights to private individuals or to the community as a whole (Stellmacher in prep.). Semi-forest coffee (SFC) system areas, for example, are usually perceived as owned by individual farmers, while wood collected from natural forest is a common good. Thus, the restriction of forest access in core areas is a greater problem for poor community members without ‘private’ forest than for farmers who are able to meet their demand for wood from their own SFC systems. As a consequence, the detailed management plans have to put measures in place that mitigate negative impacts on the poor.

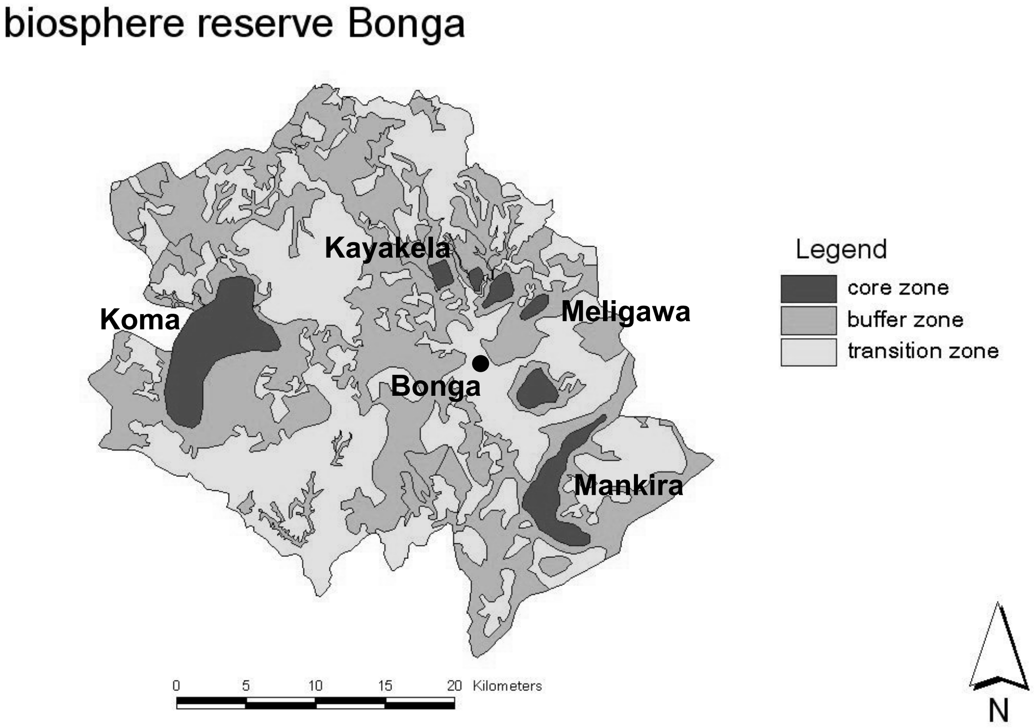


Figure 8.1 Zoning of the proposed biosphere reserve in the Bonga region (modified Tästensen 2006); demarcation according to vegetation surveys and field observations during this study, land cover map of Kafa Zone (SUPAKS 2003) and potential forest coffee map (Georg Lieth, unpubl. 2005)

The planning, implementing, and monitoring of management activities could be assisted by organizations already active in the Bonga region. Farm Africa, for example, has been working closely together with local communities in the framework of a participatory forest management (PFM) program since 1996. The aim of PFM is to ensure environmental sustainability through community-based natural resource management systems. The goals of the PFM program are complementary, and in some areas identical with those of biosphere reserves (PFMP 2006). Farm Africa has already collected valuable baseline information on ecological and social issues in the Bonga region and started a process of capacity building and education concerning sustainable management at the local level.

8.2.4 Core area

> "The ***core area*** needs to be legally established and give long-term protection to the landscapes, ecosystems and species it contains. It should be sufficiently large to meet these conservation objectives. As nature is rarely uniform and as historical land-use constraints exist in many parts of the world, there may be several core areas in a single biosphere reserve to ensure a representative coverage of the mosaic of ecological systems. Normally, the core area is not subject to human activity, except research and monitoring and, as the case may be, to traditional extractive uses by local communities." (UNESCO 2006)

The conservation objectives for the core area in the Bonga region are:

(1) *in situ* conservation of wild *Coffea arabica* in its natural, undisturbed habitat, and

(2) conservation of the typical vegetation structure and species composition of natural forest.

The core area includes all forest fragments in the Bonga region with relatively undisturbed, natural forest and wild populations of *Coffea arabica*. It comprises 72 km^2 (6.9 %) of the biosphere reserve (Tästensen 2006). The forest fragments Koma, Kayakela, Meligawa, and Mankira constitute most of the core area (Figure 8.1). The detailed vegetation studies carried out in these fragments during this study can serve as basis for monitoring and further research.

The guidelines for biosphere reserves require that core areas need to be legally established, sufficiently large, and have very limited human activity. Most core areas in the Bonga region fall within the regional National Forest Priority Area (NFPA) (Figure 4.1) and are thus already under legal protection. The extension of the NFPA to the Kayakela forest fragment, which is currently not included, is probably feasible.

The core areas in Koma and Mankira are large enough for conservation of the typical species composition of the Afromontane forest in the Bonga region (Chapter 6). Smaller core areas such as Kayakela and Meligawa are also important for *in situ* conservation of the genetic diversity of *Coffea arabica* (Chapter 5), as stepping stones for seed dispersers and as source of propagules for other forest areas (Chapter 7). Furthermore, forests on steep slopes are a protection against soil erosion.

The forest in the core areas has presumably been used by local communities for centuries, but low frequencies and intensities of use have so far allowed for natural forest recovery (Chapter 7). Conservation objectives for the core area can only be met if there is no intensification of the present forest-use. Hence, traditional non-destructive forest-uses will be allowed in core areas within the current level of intensity, but destructive forest-uses will be restricted (Table 8.1).

Wild coffee management should be kept at very low intensity in core areas in order to avoid modification of the vegetation structure and species composition of the natural forest. The simple collection of coffee fruits and the management of coffee in FC systems do not pose a threat to the plant diversity of natural forest (Chapter 5 and 6). The demand for Ethiopian wild coffee on the international market has recently been increasing, however, which is an incentive for farmers to manage coffee more intensively. It is, therefore, necessary to control coffee management interventions in natural forest. Establishment of new FC system areas should be restricted because they can quickly be turned into intensively managed SFC systems. Farmers could be motivated to comply with these management rules by compensating them for low yields from less intensively managed wild coffee with higher prices and by supporting intensive coffee management in buffer zones. A compensation system has to include the definition of production ceilings, e.g., 15 kg cc ha^{-1} a^{-1} for FC systems, to avoid fraud (Chapter 5).

Table 8.1 Management restrictions and supportive measures for core areas of the proposed biosphere reserve in the Bonga region

General guideline: no intensification of the present forest usage		
Use type	**Legal status**	**Comments**
Non-destructive forest-uses		
Collection of wild coffee, spices, medicinal plants, edible plants and mushrooms; traditional hunting by Manja people	allowed	activities should be monitored to avoid intensification of current use level
Traditional honey production	allowed	timber for beehive construction should be harvested from buffer zone
Destructive forest-uses		
Forest coffee (FC) systems	limited	existing FC systems can be managed (at low intensity), but no creation of additional ones
Extraction of fire wood, lianas, poles, and timber for traditional uses	limited	will be reduced or faded out according to specific management plans for each core area
Wood pasture	forbidden	
Supportive measures (examples) ▪ Compensation of farmers for low yields from coffee collection and FC systems by higher prices ▪ Activities undertaken in buffer and transition areas are intended to take off human pressure from core areas		

Collection of spices and medicinal plants from core areas are allowed as long as there is no intensification of exploitation, because currently their harvest has little impact on forest vegetation and structure. Besides, the commercially important wild pepper (*Piper* *capense*) is difficult to cultivate outside the forest, as it requires sufficient shade (Chapter 6). Honey production *per se* has little impact on the forest ecosystem, but timber for beehive construction should be harvested from buffer zones.

At present, core areas are a vital source of fire wood, lianas, timber and poles for the local population. Anticipating growing population pressure, however, communities will be encouraged to meet their demands for wood from buffer and transition areas. Wood extraction from core areas will be leveled out or restricted to a very low level as other sources of wood gain importance. Specific management plans will be put in place that take into account the particular environmental and socio-economic settings of each core area (section 8.2.3). Development, implementation, and monitoring of such management plans can, for example, be assisted by the participatory forest management program of Farm Africa in the Bonga region.

The Manja people need special consideration regarding core area management, because they are under great social pressure from other ethnic groups and are highly dependent on forest resources. They are the only group carrying out traditional hunting activities in the Bonga region. As other ethnic groups do not eat any bush meat, these hunting activities are at very low level and are allowed within the core area as long as they are not intensified.

8.2.5 Buffer zone

> “The ***buffer zone*** (or zones) is clearly delineated and surrounds or is contiguous to the core area. Activities are organized here so that they do not hinder the conservation objectives of the core area but rather help to protect it, hence the idea of "buffering". It can be an area for experimental research, for example to discover ways to manage natural vegetation, croplands, forests, fisheries, to enhance high quality production while conserving natural processes and biodiversity, including soil resources, to the maximum extent possible. In a similar manner, experiments can be carried out in the buffer zone to explore how to rehabilitate degraded areas. It may accommodate education, training, tourism and recreation facilities.” (UNESCO 2006)

The conservation objectives for the buffer zone in the Bonga region are:

(1) conserving the original genetic diversity of wild *Coffea arabica*,

(2) conserving the forest cover in its present extent, and

(3) guaranteeing long-term environmental, social and economic benefits of the forest resource to the local population.

Buffer zones consist mainly of relatively undisturbed forest above 2,100 m asl where coffee does not grow naturally, and of disturbed forest parts with wild coffee below 2,100 m asl (Figure 8.1). Additionally, buffer zones include perennial and seasonal swamps that do not have a natural forest cover and are often used for grazing. Hamlets and small villages are considered as part of the buffer zones if the deforested area is smaller than 10 ha. In total, the buffer zone constitutes 488.4 km^2 (46.9 %) of the biosphere reserve (Tästensen 2006).

Buffer zones help to protect core areas because they ameliorate possible edge effects and act as corridors for seed dispersers. Swamps are considered as a buffer because they make access to core areas difficult and are not suited for agricultural activities. Besides, they help to protect river catchment areas and are important for the water household of the Bonga region.

Management restrictions and supportive measures for buffer zones have the objective to enhance buffer effects (Table 8.2). They ensure that buffer forests are not clear cut to gain land for agricultural activities and regulate the extraction of wood to impede over-exploitation. The ultimate aim is to develop sustainable wood production in buffer zones that will replace wood extraction from core areas in the long run. Buffer zones are, therefore, particularly suited for research on sustainable forest management and as demonstration and training sites for local communities. They could also serve as demonstration sites or work camps in ecotourism projects.

Large parts of the forests without wild coffee above 2,100 m asl are currently quite undisturbed, and wood extraction should be kept at low level there. Most of the disturbed forest parts below 2,100 m asl are managed as SFC systems. Sustainable wood production by propagation of fast-growing, indigenous trees can be part of SFC management activities (Chapter 7). Additionally, farmers could receive training to improve coffee yields in SFC systems, e.g., by pruning of trees (Chapter 5). The notion is that increased coffee production in SFC systems discourages farmers from collecting low-yielding coffee in remote core areas. The planting of improved coffee cultivars has to be prohibited, though, to safeguard the original genetic diversity of wild coffee.

Increased income from support in the marketing of coffee, honey, spices and sustainably produced timber from buffer zones is a further incentive for farmers to comply with conservation measures in core areas. The Bonga Coffee Union could be assisted, for example, in applying for organic certification of wild coffee from SFC systems, in order to gain higher prices on the international market (Mallet and Karmann 2001; SIPPO et al. 2002).

Further income generating activities can be introduction of modern beehive technologies (Willis 1997) and employment in the eco-tourism sector. It has to be kept in mind, however, that the introduction of new technologies like tree propagation, modern beehives and modern coffee management techniques will only be successful in the long run if local farmers get the opportunity to actively participate in the development process of the biosphere reserve and define their own needs.

Table 8.2 Management restrictions and supportive measures for buffer zones of the proposed biosphere reserve in the Bonga region

General guideline: forest cover has to stay at the present level

Use types	**Legal status**	**Comments**
Establishment of semi-forest coffee (SFC) systems; honey production	allowed	
Wood pasture	limited	allowed where the forest is already disturbed
Extraction of fire wood, lianas, poles, and timber	limited	sustainable production according to specific management plans for each buffer zone
Planting of improved coffee cultivars	forbidden	

Supportive measures (examples)

- Training and support in planting of fast-growing, indigenous trees for sustainable wood production
- Introduction of modern bee-keeping technologies
- Capacity building and training in coffee production, e.g., pruning and processing techniques, and in fulfilling requirements for organic certification of coffee
- Strengthening local institutions, e.g., peasant associations and the Bonga Coffee Union through capacity building
- Support in marketing of wild and certified organic coffee and other forest products
- Employment opportunities in eco-tourism projects

8.2.6 Transition area

> "An outer ***transition area*** or area of co-operation extends outwards, which may contain a variety of agricultural activities, human settlements and other uses. It is here that the local communities, conservation agencies, scientists, civil associations, cultural groups, private enterprises and other stakeholders must agree to work together to manage and sustainably develop the area's resources for the benefit of the people who live there. Given the role that biosphere reserves should play in promoting the sustainable management of the natural resources of the region in which they lie, the transition area is of great economic and social significance for regional development." (UNESCO 2006)

The conservation objectives for the transition area in the Bonga region are:

(1) conserving the original genetic diversity of wild *Coffea arabica*,

(2) conserving the diverse landscape pattern, and

(3) conserving the traditional agro-biodiversity, e.g., land races of coffee, teff and other crops.

The transition area comprises Eucalyptus and tea plantations, coffee investment areas, agricultural fields, grasslands, and villages with more than 10 ha of deforested area (Figure 8.1). In total, the transition area constitutes 481.1 km^2 (46.2 %) of the biosphere reserve (Tästensen 2006).

The mosaic of agricultural fields, grazing areas, and home gardens in the Bonga region is representative of many regions in southwestern Ethiopia. The transition areas of the biosphere reserve are therefore suitable model areas for research on and implementation of sustainable land-use options. Research on the genetic resources of local landraces of coffee, teff and other crops is likely to attract international attention.

Sustainable development of the Bonga region is enhanced by training and capacity building for farmers concerning ecologically sound agriculture and diversification of home gardens, e.g., by honey, fruit, spice, coffee and timber production (Table 8.3). Sustainable timber production with indigenous trees could also be extended to field margins and degraded or vulnerable land, e.g., steep slopes. The planting of improved coffee cultivars in home gardens is prohibited within a distance of 6.5 km from the buffer zones in order to avoid cross-pollination by bees between wild coffee and newly bred coffee cultivars (Chapter 5). Support in the marketing of agricultural and home garden products is a possibility for compensating farmers for real or perceived losses through restrictions imposed in the core areas and buffer zones. Environmental education in schools is another important activity in the transition area.

Bonga town has the appropriate infrastructure to set up an information and training center concerned with sustainable management and conservation of forest ecosystems, agro-biodiversity and coffee genetic resources for local, national as well as international interest groups. It could also be a starting point for eco-tourism activities such as hiking, horseback riding, and visits to traditional villages.

Table 8.3 Management restrictions and supportive measures for transition areas of the proposed biosphere reserve in the Bonga region

General guideline: intensification of agriculture only within ecologically sound limits

Use type	**Legal status**	**Comments**
Planting of improved coffee cultivars	limited	forbidden within a distance < 6.5 km from the margins of buffer and core areas
Agricultural production	limited	sustainable production according to specific management plans for each transition area
Livestock husbandry	limited	sustainable grazing schemes according to specific management plans for each transition area

Supportive measures (examples)

- Training and support in planting of fast-growing, indigenous trees for sustainable wood production
- Introduction of modern bee-keeping technologies
- Capacity building and training in diversification of home gardens, e.g., fruit trees and spices, and in garden coffee production, e.g., coffee pruning and processing techniques
- Research and training programs in sustainable land-use including soil improvement measures
- Strengthening local organizations, e.g., peasant associations and youth clubs, and governmental bodies, e.g., environmental offices, through capacity building and training
- Support in marketing of agricultural and home garden products
- Environmental education in schools
- Employment opportunities in eco-tourism projects

9 CONCLUSIONS

Plant diversity

- Vegetation surveys in the Bonga region show that the current classification of “transitional forest zone” and “upland rainforest” in Ethiopia needs revision. In the Bonga region, it could be replaced by two alternative forest types, “lower montane forest” and “upper montane forest”.
- Conservation of the original plant diversity of Afromontane forest in the Bonga region requires protection of both forest types with a minimum reserve size of 800 ha. Species-based conservation approaches are not needed if human utilization of currently undisturbed forest stays at the present level.

Wild coffee management

- Wild coffee populations in the Bonga region are not threatened by over-exploitation, but planting of improved coffee cultivars inside the forest or close to forest margins endangers wild coffee genetic diversity.
- Semi-forest coffee systems are the most productive type of wild coffee management and constitute an important source of income for local farmers. The original plant diversity of Afromontane forest is, however, jeopardized by this management type due to severe disturbance of the forest structure and suppression of characteristic forest species.

Conservation planning

- Conservation concepts for the Afromontane rainforests in Ethiopia have to accommodate protection of plant diversity and interests of local forest users. This is best achieved by comprehensive land-use planning that includes a zoning system with strictly protected core areas, buffer forests and farmland utilized according to specific management plans. Biosphere reserves as designated by the UNESCO Man and the Biosphere (MAB) Programme provide a suitable framework for implementing such conservation concepts.
- Protection of both forest types in the Bonga region requires the designation of at least two core areas (Koma fragment and Mankira fragment), but the number of core areas should ideally be maximized.

- Improving wild coffee management techniques in buffer forests within ecologically sound limits and introduction of sustainable timber production can reduce human use pressure in core areas.
- The interference of conservation measures with traditional forest utilization practices should be mitigated by appropriate incentives and participative approaches.

Further research

- Further studies have to evaluate if the division in “lower montane” and “upper montane” forest can be applied to other Afromontane regions.
- Evaluation of the extent of past and present human impact on wild coffee distribution inside the forest requires further knowledge on its natural growth and regeneration patterns. This includes the definition of wild coffee population size based on pollination and seed dispersal mechanisms.
- This thesis identifies tree species that are likely to be threatened by over-exploitation. The definition of sustainable use levels for these species necessitates information on their regeneration requirements and viable population sizes. Considering the progressing forest fragmentation in the Bonga region, studies on seed dispersal between forest fragments are particularly important for tree species with low abundance.
- Pollinators and seed dispersers are essential for the Afromontane forest ecosystem, but little is known on animal-plant interaction in the Bonga region. Above all, it is necessary to evaluate whether number and size of core areas recommended for conservation of plant diversity are also sufficient for protection of faunal diversity. If the presence of forest lions in the Bonga region can be confirmed, they would constitute a unique flagship species for forest conservation.

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11 APPENDICES

Table A 1 List of species recorded in the Bonga region. H: herbs; F: ferns and fern-allies; G: grasses and sedges; hC: herbaceous climbers; wC: woody climbers; sT: small trees; T: trees; epi: epiphytic; N: naturalized (Newmark 2002); O: observed outside the study plots; E: endemic; EN: endangered; VU: vulnerable; R: rare; LC: least concern (Hedberg and Edwards 1989; Ensermu Kelbessa et al. 1992; Edwards et al. 1997; Edwards et al. 2000; Ensermu Kelbessa and Teshome Soromessa 2004; Ensermu Kelbessa 2005; Vivero et al. 2005)

Acanthaceae
Acanthus eminens C.B. Cl [S]
Brillantaisia grotanellii Pich.-Serm. [H]; E-VU
Dicliptera laxata C.B. Cl [H]
Isoglossa punctata (Vahl) Brummitt & J.R.I. Wood [H]; O
Justicia schimperiana (Nees) T. Anderson [S]
Phaulopsis imbricate (Forssk.) Sweet [H]
Agavaceae
Dracaena afromontana Mildbr. [sT]
Dracaena fragrans (L.) Ker Gawl. [sT]
Dracaena steudneri Engl. [sT]
Alangiaceae
Alangium chinense (Lour.) Harms [T]
Amaranthaceae
Achyranthes aspera Lam. [H]
Cyathula uncinulata (Schrad.) Schinz [H]
Sericostachys scandens Gilg & Lopr. [wC]
Amaryllidaceae
Scadoxus multiflorus (Martyn) Raf. [H]
Scadoxus nutans (Friis & Bjørnstad) Friis & Nordal [H-epi]; E-EN
Antheracaceae
Chlorophytum comosum (Thunb.) Jacques [H]; O
Chlorophytum macrophyllum (A. Rich.) Asch. [H]
Apiaceae
Hydrocotyle mannii Hook. f. [H]
Sanicula elata Ham. ex D. Don. [H]
Apocynaceae
Landolphia buchananii (Hall. f.) Stapf [wC]
Oncinotis tenuiloba Stapf [wC]
Aquifoliaceae
Ilex mitis (L.) Radlk. [T]
Araceae
Amorphophallus gallaensis (Engl.) N.E.Br. [H]; E
Culcasia falcifolia Engl. [hC]
Sauromatum venosum (Ait.) Kunth [H]
Araliaceae
Polyscias fulva (Hiern) Harms [T]
Schefflera abyssinica (Hochst. ex A. Rich.) Harms [T]
Schefflera myriantha (Bak.) Drake [wC]
Arecaceae
Phoenix reclinata Jacq. [T]
Asclepiadaceae
4 species [hC]
Ceropegia af sankurensis Schltr. [hC]
Marsdenia angolensis N. E. Br. [hC]
Marsdenia spec [wC]
Mondia whytei af (Hook. f.) Skeels [hC]
Tylophora spec [hC]
Asparagaceae
Asparagus racemosus Willd. [hC]
Aspidiaceae
Didymochlaena truncatula (Swartz) J. Sm. [F]
Polystichum transvaalense N. C. Anthony [F]
Tectaria gemmifera (Fee) Alston [F]
Aspleniaceae
Asplenium aethiopicum (Burm. f.) Becherer [F-epi]
Asplenium anisophyllum Kze. [F-epi]
Asplenium bugoiense Hieron [F]
Asplenium ceii Pich.-Serm. [F-epi]
Asplenium elliotti C.H. Wright [F]; O
Asplenium friesiorum C. Chr [F]
Asplenium hypomelas Kuhn [F]
Asplenium linckii Kuhn [F]
Asplenium lunulatum sl Sw. [F]
Asplenium mannii Hook. [F-epi]
Asplenium sandersonii Hook. [F-epi]
Asplenium theciferum (Kunth.) Mett. [F-epi]
Asteraceae
Adenostemma perrottetii DC. [H]
Bothriocline schimperi Oliv. & Hiern [H]
Crassocephalum montuosum (S. Moore) Milne-Redhead [H]
Dichrocephala integrifolia (L. f.) Kuntze [H]
Emilia abyssinica (S. Moore) C. Jeffrey [H]
Galinsoga parviflora Cav. [H]; N
Laggera pterondonta (DC) Sch. Bip ex. Oliv. [H]
Microglossa pyrifolia (Lam.) O. Ktze [hC]
Mictactis bojeri DC. [H]
Mikania capensis DC. [hC]

Mikaniopsis clematoides (A. Rich.) Milne-Redh. [hC]; E-LC
Solanecio gigas (Vetke) C. Jeffrey [S]; E-LC
Vernonia amygdalina Del. [S]
Vernonia auriculifera Hiern [S]
Vernonia biafrae Oliv. & Hiern [hC]
Vernonia glabra (Steetz) Vatke [H]
Vernonia hochstetteri Sch. Bip. ex Walp. A. Rich. [H]
Vernonia tewoldei Mesfin [H]; E-EN
Vernonia wollastonii S. Moore [H]
Athyriaceae
Athyrium schimperi Fee [F]
Balsaminaceae
Impatiens hochstetteri Warb. [H]
Boraginiaceae
Cordia africana Lam. [T]
Cynoglossum amplifolium Hochst. ex DC. [H]
Cynoglossum coeruleum A. DC. [H]
Ehretia cymosa Thonn. [sT]
Brassicaceae
Cardamine africana L. [H]
Capparidaceae
Ritchiea albersii Gilg [sT]
Caryophyllaceae
Drymaria cordata (L.) Schultes in Roem. & Schultes [H]; N
Stellaria mannii Hook. f. [hC]
Celastraceae
Catha edulis (Vahl) Forssk. ex Endl. [sT]
Elaeodendron buchananii (Loes.) Loes [T]
Hippocratea africana (Willd.) Loes. [wC]
Hippocratea goetzii Loes. [wC]
Maytenus arbutifolia (A. Rich.) Wilczek [S]
Maytenus gracilipes ssp.arguta (Loes.) Sebsebe [S]
Colchicaceae
Gloriosa superba L. [H]
Combretaceae
Combretum paniculatum Vent. [wC]
Commelinaceae
Commelina diffusa Burm. f. [H]
Pollia condensata C. B. Clarke [H]
Convolvulaceae
Dichondra repens J.R. & G. Forst. [H]
Ipomoea cairica (L.) Sweet. [hC]
Ipomoea tenuirostris Choisy [hC]
Crassulaceae
Kalanchoe spec [H]
Cucurbitaceae
Oreosyce africana Hook. f. [hC]
Peponium vogelii (Hook. f.) Engl. [hC]
Zehneria scabra (L. f.) Sond. [hC]
Cyathaceae
Cyathea manniana Hook. f. [sT]
Cyperaceae
Carex chlorosaccus C.B. Clarke [G]
Cyperus rotundus L. [G]
Cyperus spec [G]
Dennstaediaceae
Blotiella glabra (Bory) Tryon. [F]
Microlepia speluncae (L.) Moore [F]
Dryopteridaceae
Dryopteris inaequalis (Schlechtend.) Kuntze [F]
Dryopteris kilemensis (Kuhn) Kuntze [F]
Ebenaceae
Diospyros abyssinica (Hiern) F. White [T]; O
Euphorbiaceae
Acalypha psilostachya A. Rich. [H]; O
Bridelia micrantha (Hochst.) Baill. [T]; O
Croton macrostachys Del. [T]
Erythrococca trichogyne (Muell. Arg.) Prain [S]
Euphorbia ampliphylla Pax [T]
Euphorbia schimperiana Scheele [H]
Macaranga capensis (Baill.) Sim [T]
Phyllanthus limmuensis Cufod. [S]; E-VU
Phyllanthus ovalifolius Forssk. [S]
Phyllanthus pseudoniruri Pax [H]
Ricinus communis L. [S]; N, O
Sapium ellipticum (Krauss) Pax [T]
Tragia brevipes Pax [hC]
Fabaceae
Acacia brevispica Harms [wC]
Albizia grandibracteata Taub. [T]
Albizia gummifera (J. F. Gmel.) C.A. Sm. [T]
Albizia schimperiana Oliv. [T]
Calpurnia aurea (Ait.) Benth. [S]
Dalbergia lactea Vatke [wC]
Desmodium adscendens (Sw.) DC. [H]
Desmodium repandum (Vahl) DC. [H]
Desmodium salicifolium (Poir) DC. [H]
Dolichos sericeus E. Mey. [hC]
Erythrina brucei Schweinf em Gillett [T]; E-LC
Milletia ferruginea (Cuf.) Gillett [T]; E-LC
Psophocarpus grandiflorus Wilczek [hC]
Pterolobium stellatum (Forssk.) Brenan [wC]
Flacourtiaceae
Flacourtia indica (Burm. f.) Merr. [T]
Oncoba routledgei Sprague [sT]
Hemionitidaceae
Coniogramme africana Hieron [F]; O
Icacinaceae
Apodytes dimidiata E. Mey ex Arn. [T]
Lamiaceae
Achyrospermum schimperi (DC) Oliv. [H]
Ajuga alba (Guerke) Robyns [H]
Clerodendrum myricoides (Hochst.) R. Br. ex Vatke [S]
Lantana trifolia L. [H]; N

Lippia adoensis Hochst. ex Walp. [S]; O, E-LC
Plectranthus sylvestris Guerke [H]
Premna schimperi Engl. [S]
Satureja paradoxa (Vatke) Engler [H]; E
Lauraceae
Ocotea kenyensis (Chiov.) Robyns & Wilczek [T]
Lomariopsidaceae
Elaphoglossum deckenii (Kuhn) C. Chr. [F-epi]
Elaphoglossum lastii (Bak.) C. Chr. [F-epi]
Lycopodiaceae
Lycopodium dacrydioides Baker [F-epi]
Lycopodium verticillatum L. f. [F-epi]; O
Malvaceae
Kosteletzkya begoniifolia (Ulbr.) Ulbr. [H]
Pavonia burchellii (DC) Dyer [H]
Pavonia urens Cav. [H]
Sida rhombifolia L. [H]
Marattiaceae
Marattia fraxinea J. E. Smith [F]; O
Melastomataceae
Tristemma mauritianum J. F. Gmel. [H]
Meliaceae
Ekebergia capensis Sparrm. [T]
Lepidotrichilia volkensii (Gürke) Leroy [sT]
Trichilia dregeana Sond. [T]
Turraea holstii Gürke [S]
Melianthaceae
Bersama abyssinica Fresen. [T]
Menispermaceae
Cissampelos pareira L. [wC]
Stephania abyssinica (Dillon & A. Rich.) Walp. [hC]
Tiliacora troupinii Cufod. [wC]; E-VU
Tinospora caffra (Miers) Troupin [wC]
Moraceae
Dorstenia brownii Rendle [H]
Dorstenia soerensenii Friis [H]; E-VU
Ficus exasperata Vahl [T]; O
Ficus ovata Vahl [T]
Ficus palmata Forssk. [T]; O
Ficus sur Forssk. [T]
Ficus thonningii Blume [sT]
Ficus vasta Forssk. [T]
Trilepisium madagascariense DC. [T]
Myrsinaceae
Embelia schimperi Vatke [wC]
Maesa lanceolata Forssk. [sT]
Myrtaceae
Eugenia bukobensis Engl. [sT]
Syzygium guineense ssp. afromontanum F. White [T]
Oleaceae
Chionanthus mildbraedii (Gilg & Schellenb.) Stearn [sT]
Jasminum abyssinicum Hochst. ex DC. [wC]
Olea welwitschii (Knobl.) Gilg & Schellenb. [T]
Schrebera alata (Hochst.) Welw. [sT]
Oleandraceae
Arthropteris monocarpa (Cordem.) C. Chr. [F-epi]
Arthropteris orientalis (J. F. Gmel.) Posth. [F-epi]
Oleandra distenta Kunze [F-epi]; O
Orchidaceae
Aerangis brachycarpa (A. Rich.) Th. Dur. & Schinz [H-epi]
Aerangis luteoalba var. rhodosticta (Kraenzl.) J. Stewart [H-epi]
Angraecopsis trifurca (Rchb. f.) Schltr. [H-epi]
Bulbophyllum josephii (Kuntze) Summerh. [H-epi]
Cyrtorchis ehrythraeae (Rolfe) Schltr [H-epi]; E, O
Diaphananthe adoxa Rasm. [H-epi]
Diaphananthe fragrantissima (Rchb. f.) Schltr. [H-epi]
Diaphananthe tenuicalcar Summerh. [H-epi]
Habenaria malacophylla Rchb. f. [H]
Habenaria petitiana (A. Rich.) Th. Dur. & Schinz [H]
Liparis deistelii Schltr. [H-epi]
Liparis nervosa (Thunb.) Lindl. [H]; O
Malaxis weberbaueriana (Kraenzl.) Summerh. [H]
Microcoelia globulosa (Hochst.) L. Jonsson [H-epi]
Nervilia bicarinata (Bl.) Schltr. [H]
Oberonia disticha (Lam.) Schltr. [H-epi]
Polystachya bennettiana Rchb. f. [H-epi]
Polystachya cultriformis (Thouars) Spreng. [H-epi]
Polystachya fusiformis (Thou.) Lindl. [H-epi]
Polystachya lindblomii Schltr. [H-epi]
Stolzia repens (Rolfe) Summerh. [H-epi]
Tridactyle bicaudata (Lindl.) Schltr. [H-epi]
Passifloraceae
Passiflora edulis Sims [hC]; N
Phytolaccaceae
Phytolacca dodecandra L'Hérit. [wC]
Piperaceae
Peperomia abyssinica Miq. [H-epi]
Peperomia molleri C. DC. [H]
Peperomia retusa (L. f.) A. Dietr. [H-epi]
Peperomia tetraphyll a(Forster) Hook. & Arn. [H-epi]
Piper capense L. f. [H]
Piper umbellatum L. [H]
Pittosporaceae
Pittosporum viridiflorum Sims [sT]
Poac.
1 species [G]
Digitaria abyssinica (Hochst. ex A. Rich.) Stapf. [G]
Leptaspis zeylanica Nees ex Steud. [G]
Oplismenus hirtellus (L.) P. Beauv. [G]

Oplismenus undulatifolius (Ard.) Roemer & Schultes [G]
Panicum calvum Stapf. [G]
Poecilostachys oplismenoides (Hack.) W.D. Clayton [G]
Pseudechinolaena polystachya (Kunth.) Stapf [G]
Setaria megaphylla (Steud.) Th. Dur. & Schinz [G]
Podocarpaceae
Podocarpus falcatus (Thunb.) Mirb. [T]
Polypodiaceae
Drynaria volkensii J. Sm [F-epi]
Lepisorus excavatus (Willd.) Sledge [F-epi]
Lepisorus schraderi (Mett.) Ching [F-epi]
Loxogramme lanceolata (Sw.) Presl. [F-epi]
Pleopeltis macrocarpa (Willd.) Kaulf. [F-epi]
Primulaceae
Ardisiandra sibthorpioides Hook. f. [H]
Pteridaceae
Pteris catoptera Kze. [F]
Pteris cretica L. [F]
Pteris dentata Forsk. [F]; O
Pteris pteridioides (Hook. f.) Ballard. [F]
Ranunculaceae
Clematis hirsuta Perr. & Guill. [wC]
Clematis longicauda Steud. ex A. Rich. [wC]; E
Clematis simensis Fresen. [wC]
Thalictrum rhynchocarpum Dill. & A. Rich. [H]
Rhamnaceae
Gouania longispicata Engl. [wC]
Rhamnus prinoides L'Hérit. [S]
Rhizophoraceae
Cassipourea malosana (Bak.) Alston [T]
Rosaceae
Prunus africana (Hook. f.) Kalkm. [T]
Rubus apetalus Poir. [S]
Rubus rosifolius Sm. [S]; N
Rubus steudneri Schweinf. [S]
Rubiaceae
Canthium oligocarpum Hiern [T]
Coffea arabica L. [sT]
Galiniera saxifrage (Hochst.) Bridson [sT]
Hallea rubrostipulata (K. Schum.) J.-F. Leroy [T]
Oxyanthus speciosus DC. [sT]
Pavetta abyssinica Fresen. [S]
Pentas lanceolata (Forssk.) Deflers [H]
Pentas tenuis Verdc. [S]; O, E-R
Psychotria orophila Petit [sT]
Psychotria peduncularis Verdc. [S]
Rothmannia urcelliformis (Hiern) Robyns [sT]
Rytigynia neglecta (Hiern) Robyns [S]
Vangueria apiculata K. Schum. [T]
Rutaceae
Clausena anisata (Willd.) Benth. [sT]
Fagaropsis angolensis (Engl.) Dale [T]
Teclea nobilis Del. [sT]
Vepris dainellii (Pichi-Serm.) Kokwaro [sT]; E-LC
Sapindaceae
Allophylus abyssinicus (Hochst.) Radlkofer [T]
Allophylus macrobotrys Gilg [S]
Deinbollia kilimandscharica Taub. [sT]
Paullinia pinnata L. [wC]
Sapotaceae
Mimusops kummel A. DC. [T]
Pouteria adolfi-friederici (Engl.) Baehni [T]
Selaginellaceae
Selaginella kalbreyeri Bak. [H]
Selaginella kraussiana (Kze.) A. Br. [H]
Simaroubaceae
Brucea antidysenterica J.F. Mill. [sT]
Solanaceae
Cyphomandra betacea (Cav.) Sendtn. [S]
Solanum benderianum af Schimp. ex Engl. [wC]
Solanum capsicoides Guatteri [H]
Solanum giganteum L. [S]
Sterculiaceae
Dombeya torrida (J. F. Gmel.) P. Bamps [S]
Thelypteridaceae
Cyclosorus dentatus (Forssk.) Ching [F]
Tiliaceae
Grewia ferruginea A. Rich. [S]
Triumfetta rhomboidea Jacq. [S]
Ulmaceae
Celtis africana Burm. f. [T]
Celtis gomphophylla Bak. [T]
Urticaceae
Didymodoxa caffra (Thunb.) Friis & Wilmot-Dear [H]
Elatostema monticola Hook. f. [H]
Pilea bambuseti ssp aethiopica Friis [H]; E
Pilea johnstonii Oliv. [H]
Pilea rivularis Wedd. [H]
Pouzolzia parasitica Oliv. [H]
Urera hypselodendrum (A. Rich.) Wedd. [wC]
Vitaceae
Cayratia gracilis (Guill. & Perr.) Suesseng. [hC]
Cissus petiolata Hook. f. [wC]
Cyphostemma adenocaule (Steud. ex A. Rich.) Descoings ex Wild & Drummond [hC]
Cyphostemma cyphopetalum (Fresen.) Descoings ex Wild & Drummond [hC]
Vittariaceae
Antrophyum mannianum Hooker [F-epi]
Vittaria guineensis Desv. [F-epi]
Vittaria volkensii Hieron. [F-epi]
Zingiberaceae
Aframomum corrorima (Braun) Jansen [H]; E-VU
Aframomum zambesiacum (Bak.) K. Schum. [H]
Unidentified: 10 [H]; 2 [F]; 7 [hC]; 1 [wC]; 5 [T]

Table A 2 Frequency of ground layer species and epiphytes; GF: growth form; H: herbs; F: ferns and fern-allies; G: grasses and sedges; x: found outside study plot; Koma (34 study plots), Kaya: Kayakela (22 study plots), Meli: Meligawa (12 study plots), Mank: Mankira (17 study plots); Total (all 85 study plots)

No	**Species**	**Family**	**GF**	**Frequency (%) (number of plots)**				
				Total	**Koma**	**Kaya**	**Meli**	**Mank**
Ground layer species								
1	*Desmodium repandum*	Fabac.	H	**97.6**	97.1	100.0	91.7	100.0
2	*Oplismenus undulatifolius*	Poac.	G	**94.1**	94.1	86.4	100.0	100.0
3	*Piper capense*	Piperac.	H	**83.5**	82.4	81.8	66.7	100.0
4	*Sanicula elata*	Apiac.	H	**80.0**	76.5	77.3	75.0	94.1
5	*Poecilostachys oplismenoides*	Poac.	G	**75.3**	79.4	40.9	100.0	94.1
6	*Aframomum corrorima*	Zingiberac.	H	**75.3**	73.5	90.9	41.7	82.4
7	*Achyranthes aspera*	Amaranthac.	H	**75.3**	61.8	90.9	83.3	76.5
8	*Pteris catoptera*	Pteridac.	F	**75.3**	58.8	81.8	83.3	94.1
9	*Tectaria gemmifera*	Aspidiac.	F	**71.8**	76.5	45.5	66.7	100.0
10	*Asplenium lunulatum sl*	Aspleniac.	F	**68.2**	82.4	59.1	66.7	52.9
11	*Pteris pteridioides*	Pteridac.	F	**58.8**	55.9	63.6	50.0	64.7
12	*Peperomia molleri*	Piperac.	H	**51.8**	29.4	59.1	58.3	82.4
13	*Asplenium bugoiense*	Aspleniac.	F	**44.7**	47.1	22.7	41.7	70.6
14	*Phaulopsis imbricata*	Acanthac.	H	**43.5**	41.2	54.5	25.0	47.1
15	*Pilea rivularis*	Urticac.	H	**38.8**	44.1	9.1	41.7	64.7
16	*Setaria megaphylla*	Poac.	G	**35.3**	38.2	31.8	50.0	23.5
17	*Elatostema monticola*	Urticac.	H	**28.2**	35.3	0.0	25.0	52.9
18	*Carex chlorosaccus*	Cyperac.	G	**27.1**	50.0	18.2	16.7	0.0
19	*Impatiens hochstetteri*	Balsaminac.	H	**25.9**	17.6	0.0	33.3	70.6
20	*Thalictrum rhynchocarpum*	Ranunculac.	H	**23.5**	23.5	18.2	33.3	23.5
21	*Brillantaisia grotanellii*	Acanthac.	H	**20.0**	0.0	0.0	0.0	100.0
22	*Cyclosorus dentatus*	Thelypteridac.	F	**18.8**	23.5	27.3	8.3	5.9
23	*Pseudechinolaena polystachya*	Poac.	G	**17.6**	11.8	27.3	16.7	17.6
24	*Amorphophallus gallaensis*	Arac.	H	**17.6**	26.5	9.1	33.3	0.0
25	*Didymochlaena truncatula*	Aspidiac.	F	**16.5**	23.5	13.6	8.3	11.8
26	*Ardisiandra sibthorpioides*	Primulac.	H	**14.1**	8.8	13.6	0.0	35.3
27	*Dicliptera laxata*	Acanthac.	H	**14.1**	2.9	9.1	0.0	52.9
28	*Vernonia tewoldei*	Asterac.	H	**11.8**	2.9	4.5	41.7	17.6
29	*Pavonia urens*	Malvac.	H	**10.6**	2.9	18.2	16.7	11.8
30	*Panicum calvum*	Poac.	G	**10.6**	14.7	0.0	0.0	23.5
31	*Achyrospermum schimperi*	Lamiac.	H	**9.4**	2.9	18.2	8.3	11.8
32	*Piper umbellatum*	Piperac.	H	**9.4**	0.0	31.8	8.3	0.0
33	*Phyllanthus pseudoniruri*	Euphorbiac.	H	**9.4**	0.0	0.0	8.3	41.2
34	*Plectranthus silvestris*	Lamiac.	H	**9.4**	20.6	0.0	8.3	0.0
35	*Sida rhombifolia*	Malvac.	H	**8.2**	8.8	13.6	8.3	0.0
36	*Polystichum transvaalense*	Aspidiac.	F	**8.2**	20.6	0.0	0.0	0.0
37	*Leptaspis zeylanica*	Poac.	G	**8.2**	0.0	0.0	0.0	41.2
38	*Commelina diffusa*	Commelinac.	H	**7.1**	0.0	9.1	0.0	23.5
39	*Sauromatum venosum*	Arac.	H	**5.9**	2.9	4.5	8.3	11.8
40	*Chlorophytum macrophyllum*	Antheracac.	H	**5.9**	2.9	9.1	0.0	11.8
41	*Vernonia wollastonii*	Asterac.	H	**5.9**	2.9	4.5	0.0	17.6
42	*Aframomum zambesiacum*	Zingiberac.	H	**5.9**	0.0	4.5	8.3	17.6
43	*Athyrium schimperi*	Athyriac.	F	**5.9**	14.7	0.0	0.0	0.0
44	*Cardamine africana*	Brassicac.	H	**4.7**	2.9	0.0	25.0	0.0

45	*Selaginella kalbreyeri*	Selaginellac.	F	**4.7**	0.0	0.0	0.0	23.5
46	*Drymaria cordata*	Caryophyllac.	H	**3.5**	2.9	4.5	8.3	0.0
47	*Kalanchoe spec*	Crassulac.	H	**3.5**	0.0	9.1	0.0	5.9
48	*Cyathula uncinulata*	Amaranthac.	H	**3.5**	2.9	0.0	8.3	5.9
49	*Dryopteris inaequalis*	Dryopteridac.	F	**3.5**	2.9	0.0	16.7	0.0
50	*Asplenium friesiorum*	Aspleniac.	F	**3.5**	5.9	0.0	8.3	0.0
51	*Tristemma mauritianum*	Melastomatac.	H	**3.5**	8.8	0.0	0.0	0.0
52	*Hydrocotyle mannii*	Apiac.	H	**2.4**	2.9	4.5	0.0	0.0
53	*Nervilia bicarinata*	Orchidac.	H	**2.4**	2.9	4.5	0.0	0.0
54	*Emilia abyssinica*	Asterac.	H	**2.4**	2.9	0.0	0.0	5.9
55	*Habenaria petitiana*	Orchidac.	H	**2.4**	2.9	0.0	8.3	0.0
56	*Pavonia burchellii*	Malvac.	H	**2.4**	0.0	4.5	8.3	0.0
57	*Solanum capsicoides*	Solanac.	H	**2.4**	0.0	4.5	8.3	0.0
58	*Dryopteris kilemensis*	Dryopteridac.	F	**2.4**	5.9	0.0	0.0	0.0
59	*Gloriosa superba*	Colchicac.	H	**2.4**	5.9	0.0	0.0	0.0
60	*Malaxis weberbaueriana*	Orchidac.	H	**2.4**	5.9	0.0	0.0	0.0
61	*Microlepia speluncae*	Dennstaediac.	F	**2.4**	5.9	0.0	0.0	0.0
62	*Selaginella kraussiana*	Selaginellac.	F	**2.4**	5.9	0.0	0.0	0.0
63	*Vernonia glabra*	Asterac.	H	**2.4**	5.9	0.0	0.0	0.0
64	*Bothriocline schimperi*	Asterac.	H	**2.4**	0.0	9.1	0.0	0.0
65	*Cynoglossum amplifolium*	Boraginiac.	H	**2.4**	0.0	9.1	0.0	0.0
66	*herb species 8*		H	**2.4**	0.0	9.1	0.0	0.0
67	*Vernonia hochstetteri*	Asterac.	H	**2.4**	0.0	9.1	0.0	0.0
68	*Euphorbia schimperiana*	Euphorbiac.	H	**2.4**	0.0	0.0	0.0	11.8
69	*herb species 1*		H	**2.4**	0.0	0.0	0.0	11.8
70	*herb species 10*		H	**2.4**	5.9	0.0	0.0	0.0
71	*Asplenium hypomelas*	Aspleniac.	F	**1.2**	2.9	0.0	0.0	0.0
72	*Asplenium linckii*	Aspleniac.	F	**1.2**	2.9	0.0	0.0	0.0
73	*Blotiella glabra*	Dennstaediac.	F	**1.2**	2.9	0.0	0.0	0.0
74	*fern species 1*		F	**1.2**	2.9	0.0	0.0	0.0
75	*fern species 2*		F	**1.2**	2.9	0.0	0.0	0.0
76	*grass species 1*	Poac.	G	**1.2**	2.9	0.0	0.0	0.0
77	*herb species 3*		H	**1.2**	2.9	0.0	0.0	0.0
78	*herb species 4*		H	**1.2**	2.9	0.0	0.0	0.0
79	*herb species 5*		H	**1.2**	2.9	0.0	0.0	0.0
80	*herb species 6*		H	**1.2**	2.9	0.0	0.0	0.0
81	*herb species 7*		H	**1.2**	2.9	0.0	0.0	0.0
82	*Oplismenus hirtellus*	Poac.	G	**1.2**	2.9	0.0	0.0	0.0
83	*Pentas lanceolata*	Rubiac.	H	**1.2**	2.9	0.0	0.0	0.0
84	*Pilea bambuseti*	Urticac.	H	**1.2**	2.9	0.0	0.0	0.0
85	*Pteris cretica*	Pteridac.	F	**1.2**	2.9	0.0	0.0	0.0
86	*Scadoxus multiflorus*	Amaryllidac.	H	**1.2**	2.9	0.0	0.0	0.0
87	*Ajuga alba*	Lamiac.	H	**1.2**	0.0	4.5	0.0	0.0
88	*Cynoglossum coeruleum*	Boraginiac.	H	**1.2**	0.0	4.5	0.0	0.0
89	*Cyperus rotundus*	Cyperac.	G	**1.2**	0.0	4.5	0.0	0.0
90	*Cyperus spec*	Cyperac.	G	**1.2**	0.0	4.5	0.0	0.0
91	*Desmodium adscendens*	Fabac.	H	**1.2**	0.0	4.5	0.0	0.0
92	*Dichondra repens*	Convolvulac.	H	**1.2**	0.0	4.5	0.0	0.0
93	*Dichrocephala integrifolia*	Asterac.	H	**1.2**	0.0	4.5	0.0	0.0
94	*Didymodoxa caffra*	Urticac.	H	**1.2**	0.0	4.5	0.0	0.0
95	*Digitaria abyssinica*	Poac.	G	**1.2**	0.0	4.5	0.0	0.0
96	*Galinsoga parviflora*	Asterac.	H	**1.2**	0.0	4.5	0.0	0.0

97	*herb species 9*		H	**1.2**	0.0	4.5	0.0	0.0
98	*Kosteletzkya begoniifolia*	Malvac.	H	**1.2**	0.0	4.5	0.0	0.0
99	*Lantana trifolia*	Lamiac.	H	**1.2**	0.0	4.5	0.0	0.0
100	*Pollia condensata*	Commelinac.	H	**1.2**	0.0	4.5	0.0	0.0
101	*Satureja paradoxa*	Lamiac.	H	**1.2**	0.0	4.5	0.0	0.0
102	*Crassocephalum montuosum*	Asterac.	H	**1.2**	0.0	0.0	0.0	5.9
103	*Dorstenia soerensenii*	Morac.	H	**1.2**	0.0	0.0	0.0	5.9
104	*herb species 2*		H	**1.2**	0.0	0.0	0.0	5.9
105	*Laggera pterodonta*	Asterac.	H	**1.2**	0.0	0.0	0.0	5.9
106	*Mictactis bojeri*	Asterac.	H	**1.2**	0.0	0.0	0.0	5.9
107	*Adenostemma perrottetii*	Asterac.	H	**1.2**	x	0.0	8.3	0.0
108	*Desmodium salicifolium*	Fabac.	H	**1.2**	0.0	0.0	8.3	0.0
109	*Dorstenia brownii*	Morac.	H	**1.2**	0.0	0.0	8.3	0.0
110	*Habenaria malacophylla*	Orchidac.	H	**1.2**	0.0	0.0	8.3	0.0
111	*Pilea johnstonii*	Urticac.	H	**1.2**	0.0	0.0	8.3	0.0
112	*Pouzolzia parasitica*	Urticac.	H	**1.2**	0.0	0.0	8.3	0.0
Epiphytic species								
1	*Peperomia tetraphylla*	Piperac.	H	**97.6**	97.1	95.5	100.0	100.0
2	*Asplenium sandersonii*	Aspleniac.	F	**92.9**	85.3	95.5	100.0	100.0
3	*Peperomia abyssinica*	Piperac.	H	**91.8**	94.1	81.8	91.7	100.0
4	*Arthropteris monocarpa*	Oleandrac.	F	**69.4**	76.5	45.5	91.7	70.6
5	*Loxogramme lanceolata*	Polypodiac.	F	**69.4**	58.8	54.5	83.3	100.0
6	*Aerangis brachycarpa*	Orchidac.	H	**58.8**	70.6	36.4	50.0	70.6
7	*Drynaria volkensii*	Polypodiac.	F	**57.6**	50.0	59.1	66.7	64.7
8	*Polystachya cultriformis*	Orchidac.	H	**52.9**	61.8	54.5	41.7	41.2
9	*Vittaria guineensis*	Vittariac.	F	**50.6**	47.1	40.9	58.3	64.7
10	*Asplenium mannii*	Aspleniac.	F	**49.4**	58.8	45.5	58.3	29.4
11	*Diaphananthe adoxa*	Orchidac.	H	**49.4**	70.6	27.3	58.3	29.4
12	*Polystachya bennetiana*	Orchidac.	H	**44.7**	52.9	31.8	33.3	52.9
13	*Asplenium anisophyllum*	Aspleniac.	F	**35.3**	67.6	0.0	16.7	29.4
14	*Pleopeltis macrocarpa*	Polypodiac.	F	**29.4**	29.4	18.2	50.0	29.4
15	*Asplenium ceii*	Aspleniac.	F	**24.7**	26.5	18.2	8.3	41.2
16	*Lepisorus excavatus*	Polypodiac.	F	**18.8**	32.4	0.0	33.3	5.9
17	*Aerangis luteoalba var. rhodosticta*	Orchidac.	H	**17.6**	8.8	13.6	41.7	23.5
18	*Asplenium theciferum*	Aspleniac.	F	**17.6**	14.7	13.6	41.7	11.8
19	*Asplenium aethiopicum*	Aspleniac.	F	**14.1**	14.7	4.5	25.0	17.6
20	*Bulbophyllum josephii*	Orchidac.	H	**12.9**	17.6	4.5	16.7	11.8
21	*Scadoxus nutans*	Amaryllidac.	H	**12.9**	2.9	9.1	8.3	41.2
22	*Tridactyle bicaudata*	Orchidac.	H	**10.6**	0.0	4.5	0.0	47.1
23	*Peperomia retusa*	Piperac.	H	**9.4**	20.6	0.0	0.0	5.9
24	*Lycopodium dacrydioides*	Lycopodiac.	F	**5.9**	14.7	0.0	x	0.0
25	*Polystachya lindblomii*	Orchidac.	H	**4.7**	0.0	4.5	0.0	17.6
26	*Diaphananthe tenuicalcar*	Orchidac.	H	**3.5**	8.8	0.0	0.0	0.0
27	*Elaphoglossum lastii*	Lomariopsidac.	F	**2.4**	2.9	0.0	8.3	0.0
28	*Polystachya fusiformis*	Orchidac.	H	**2.4**	2.9	x	8.3	0.0
29	*Liparis deistelli*	Orchidac.	H	**2.4**	5.9	0.0	0.0	0.0
30	*Vittaria volkensii af*	Vittariac.	F	**2.4**	5.9	0.0	0.0	0.0
31	*Angraecopsis trifurca*	Orchidac.	H	**2.4**	0.0	0.0	16.7	0.0
32	*Antrophyum mannianum*	Vittariac.	F	**2.4**	x	0.0	0.0	11.8
33	*Lepisorus schraderi*	Polypodiac.	F	**1.2**	2.9	0.0	0.0	0.0
34	*Stolzia repens*	Orchidac.	H	**1.2**	2.9	0.0	0.0	0.0

35	*Diaphananthe fragrantissima*	Orchidac.	H	**1.2**	0.0	4.5	0.0	0.0
36	*Microcoelia globulosa*	Orchidac.	H	**1.2**	0.0	4.5	0.0	0.0
37	*Elaphoglossum deckenii*	Lomariopsidac.	F	**1.2**	x	x	8.3	0.0
38	*Arthropteris orientalis*	Oleandrac.	F	**1.2**	0.0	0.0	0.0	5.9
39	*Oberonia disticha*	Orchidac.	H	**1.2**	0.0	0.0	0.0	5.9

Table A 3 Frequency and abundance of woody species and climbers; Ko: Koma (34 study plots), Ka: Kayakela (22 study plots), Me: Meligawa (12 study plots), Ma: Mankira (17 study plots); all (all 85 study plots)

Species	**Family**	**Frequency (%)**					**Abundance**				
		all	**Ko**	**Ka**	**Me**	**Ma**	**all**	**Ko**	**Ka**	**Me**	**Ma**
Herbaceous climbers											
Culcasia falcifolia	Arac.	**42.4**	38.2	18.2	25.0	94.1	**491**	130	13	75	273
Tylophora spec	Asclepiadac.	**28.2**	14.7	59.1	25.0	17.6	**83**	12	53	15	3
Cyphostemma cyphopetalum	Vitac.	**27.1**	17.6	36.4	50.0	17.6	**40**	8	16	9	7
Asparagus racemosus	Asparagac.	**20.0**	11.8	18.2	0.0	52.9	**50**	11	7	0	32
Vernonia biafrae	Asterac.	**8.2**	11.8	0.0	8.3	11.8	**9**	5	0	1	3
Tragia brevipes	Euphorbiac.	**7.1**	17.6	0.0	0.0	0.0	**7**	7	0	0	0
Stellaria mannii	Caryophyllac.	**7.1**	5.9	9.1	0.0	11.8	**14**	4	2	0	8
Peponium vogelii	Cucurbitac.	**4.7**	11.8	0.0	0.0	0.0	**5**	5	0	0	0
Cayratia gracilis	Vitac.	**4.7**	5.9	9.1	0.0	0.0	**6**	4	2	0	0
Zehneria scabra	Cucurbitac.	**4.7**	0.0	18.2	0.0	0.0	**8**	0	8	0	0
Mikaniopsis clematoides	Asterac.	**4.7**	0.0	0.0	0.0	23.5	**18**	0	0	0	18
Dolichos sericeus	Fabac.	**3.5**	0.0	13.6	0.0	0.0	**5**	0	5	0	0
Ceropegia af sankurensis	Asclepiadac.	**3.5**	2.9	0.0	16.7	0.0	**8**	4	0	4	0
climber, herb.-sp. 3		**2.4**	5.9	0.0	0.0	0.0	**2**	2	0	0	0
Asclepiadac.-sp. 2	Asclepiadac.	**2.4**	5.9	0.0	0.0	0.0	**2**	2	0	0	0
climber, herb.-sp. 5		**2.4**	5.9	0.0	0.0	0.0	**4**	4	0	0	0
Cyphostemma adenocaule	Vitac.	**2.4**	2.9	4.5	0.0	0.0	**7**	1	6	0	0
Ipomoea tenuirostris	Convolvulac.	**2.4**	0.0	0.0	8.3	5.9	**10**	0	0	1	9
Ipomoea cairica	Convolvulac.	**2.4**	0.0	4.5	0.0	5.9	**15**	0	13	0	2
Mikania capensis	Asterac.	**2.4**	0.0	9.1	0.0	0.0	**16**	0	16	0	0
climber, herb.-sp. 1		**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
climber, herb.-sp. 2		**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
climber, herb.-sp. 4		**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
climber, herb.-sp. 6		**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Asclepiadac.-sp. 1	Asclepiadac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Asclepiadac.-sp. 3	Asclepiadac.	**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Asclepiadac.-sp. 4	Asclepiadac.	**1.2**	0.0	0.0	0.0	5.9	**1**	0	0	0	1
Oreosyce africana	Cucurbitac.	**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Passiflora edulis	Passiflorac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Microglossa pyrifolia	Asterac.	**1.2**	2.9	0.0	0.0	0.0	**2**	2	0	0	0
Mondia whytei af	Asclepiadac.	**1.2**	0.0	0.0	8.3	0.0	**2**	0	0	2	0
Marsdenia angolensis	Asclepiadac.	**1.2**	0.0	0.0	0.0	5.9	**3**	0	0	0	3
Psophocarpus grandiflorus	Fabac.	**1.2**	0.0	0.0	0.0	5.9	**4**	0	0	0	4
climber, herb.-sp. 7		**1.2**	0.0	4.5	0.0	0.0	**6**	0	6	0	0
Stephania abyssinica	Menispermac.	**1.2**	0.0	4.5	0.0	0.0	**17**	0	17	0	0

Shrubs										
Maytenus gracilipes	Celastrac.	**97.6**	94.1	100	100	100	**4,936**	1,499	1,104	496	1,837
Rytigynia neglecta	Rubiac.	**62.4**	76.5	50.0	58.3	52.9	**323**	209	43	37	34
Erythrococca trichogyne	Euphorbiac.	**55.3**	58.8	50.0	41.7	64.7	**222**	109	26	47	40
Pavetta abyssinica	Rubiac.	**40.0**	44.1	4.5	83.3	47.1	**221**	99	2	92	28
Maytenus arbutifolia	Celastrac.	**28.2**	8.8	77.3	33.3	0.0	**80**	11	53	16	0
Justicia schimperiana	Acanthac.	**23.5**	35.3	4.5	25.0	23.5	**2,251**	2,066	1	109	75
Rubus apetalus	Rosac.	**18.8**	26.5	9.1	8.3	23.5	**64**	32	3	1	28
Turraea holstii	Meliac.	**18.8**	0.0	0.0	0.0	94.1	**130**	0	0	0	130
Psychotria peduncularis	Rubiac.	**17.6**	0.0	40.9	0.0	35.3	**27**	0	18	0	9
Vernonia auriculifera	Asterac.	**16.5**	11.8	18.2	16.7	23.5	**36**	4	19	6	7
Allophylus macrobotrys	Sapindac.	**15.3**	0.0	59.1	0.0	0.0	**43**	0	43	0	0
Rhamnus prinoides	Rhamnac.	**11.8**	14.7	13.6	0.0	11.8	**17**	11	3	0	3
Acanthus eminens	Acanthac.	**8.2**	11.8	9.1	8.3	0.0	**204**	128	39	37	0
Vernonia amygdalina	Asterac.	**7.1**	0.0	27.3	0.0	0.0	**58**	0	58	0	0
Phyllanthus limmuensis	Euphorbiac.	**7.1**	0.0	27.3	0.0	0.0	**90**	0	90	0	0
Phyllanthus ovalifolius	Euphorbiac.	**5.9**	8.8	0.0	0.0	11.8	**28**	26	0	0	2
Triumfetta rhomboidea	Tiliac.	**4.7**	11.8	0.0	0.0	0.0	**6**	6	0	0	0
Rubus steudneri	Rosac.	**4.7**	11.8	0.0	0.0	0.0	**7**	7	0	0	0
Dombeya torrida	Sterculiac.	**3.5**	8.8	0.0	0.0	0.0	**3**	3	0	0	0
Grewia ferruginea	Tiliac.	**3.5**	5.9	0.0	8.3	0.0	**9**	4	0	5	0
Calpurnia aurea	Fabac.	**2.4**	2.9	0.0	8.3	0.0	**2**	1	0	1	0
Clerodendrum myricoides	Lamiac.	**2.4**	2.9	0.0	8.3	0.0	**4**	3	0	1	0
Cyphomandra betacaea	Solanac.	**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Premna schimperi	Lamiac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Solanum giganteum	Solanac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Rubus rosifolius	Rosac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Solanecio gigas	Asterac.	**1.2**	0.0	0.0	0.0	5.9	**4**	0	0	0	4
Small trees											
Vepris dainellii	Rutac.	**100**	100	100	100	100	**4,156**	1,000	1,446	775	935
Coffea arabica	Rubiac.	**97.6**	94.1	100	100	100	**26669**	6,979	14616	3,055	2,019
Chionanthus mildbraedii	Oleac.	**92.9**	97.1	77.3	100	100	**7,072**	2,790	1,738	1,082	1,462
Clausena anisata	Rutac.	**89.4**	91.2	86.4	91.7	88.2	**1,425**	582	339	158	346
Oxyanthus speciosus	Rubiac.	**88.2**	94.1	86.4	75.0	88.2	**1,301**	715	236	148	202
Rothmannia urcelliformis	Rubiac.	**88.2**	79.4	90.9	91.7	100	**2,268**	954	367	803	144
Galiniera saxifraga	Rubiac.	**81.2**	88.2	68.2	91.7	76.5	**1,490**	1,302	54	78	56
Psychotria orophila	Rubiac.	**80.0**	100	77.3	33.3	76.5	**1,768**	1,296	261	21	190
Dracaena fragrans	Agavac.	**80.0**	55.9	95.5	91.7	100	**6,619**	1,311	1,977	796	2,535
Pittosporum viridiflorum	Pittosporac.	**74.1**	79.4	59.1	66.7	88.2	**260**	131	53	38	38
Lepidotrichilia volkensii	Meliac.	**72.9**	94.1	54.5	75.0	52.9	**336**	193	77	45	21
Deinbollia kilimandscharica	Sapindac.	**70.6**	82.4	40.9	58.3	94.1	**1,154**	315	175	58	606
Teclea nobilis	Rutac.	**60.0**	85.3	81.8	0.0	23.5	**659**	457	187	0	15
Dracaena afromontana	Agavac.	**55.3**	79.4	13.6	41.7	70.6	**1,122**	836	57	140	89
Ehretia cymosa	Boraginiac.	**44.7**	41.2	45.5	25.0	64.7	**102**	30	24	15	33
Dracaena steudneri	Agavac.	**43.5**	35.3	40.9	58.3	52.9	**127**	47	36	26	18
Maesa lanceolata	Myrsinac.	**31.8**	29.4	36.4	50.0	17.6	**74**	30	21	9	14
Brucea antidysenterica	Simaroubac.	**21.2**	20.6	9.1	33.3	29.4	**21**	8	2	5	6
Ficus thonningii	Morac.	**9.4**	8.8	4.5	16.7	11.8	**8**	3	1	2	2
Ritchiea albersii	Capparidac.	**8.2**	0.0	31.8	0.0	0.0	**16**	0	16	0	0
Cyathea manniana	Cyathac.	**5.9**	11.8	0.0	8.3	0.0	**24**	13	0	11	0

Eugenia bukobensis	Myrtac.	**4.7**	0.0	0.0	0.0	23.5	**73**	0	0	0	73
Oncoba routledgei	Flacourtiac.	**2.4**	5.9	0.0	0.0	0.0	**8**	8	0	0	0
Schrebera alata	Oleac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Catha edulis	Celastrac.	**1.2**	2.9	0.0	0.0	0.0	**6**	6	0	0	0
Woody climbers											
Landolphia buchananii	Apocynac.	**100**	100	100	100	100	**2,095**	640	854	252	349
Jasminum abyssinicum	Oleac.	**96.5**	97.1	95.5	100	94.1	**952**	448	270	131	103
Hippocratea goetzei	Celastrac.	**94.1**	91.2	90.9	100	100	**904**	340	212	154	198
Tiliacora troupinii	Menispermac.	**82.4**	64.7	86.4	100	100	**923**	157	293	83	390
Embelia schimperi	Myrsinac.	**75.3**	58.8	86.4	75.0	94.1	**271**	105	56	49	61
Combretum paniculatum	Combretac.	**70.6**	67.6	59.1	75.0	88.2	**336**	119	84	42	91
Dalbergia lactea	Fabac.	**69.4**	76.5	59.1	50.0	82.4	**300**	137	82	29	52
Oncinotis tenuiloba	Apocynac.	**62.4**	50.0	68.2	41.7	94.1	**199**	113	24	34	28
Hippocratea africana	Celastrac.	**52.9**	44.1	68.2	33.3	64.7	**190**	77	58	14	41
Paullinia pinnata	Sapindac.	**41.2**	0.0	81.8	58.3	58.8	**174**	0	77	45	52
Gouania longi-spicata	Rhamnac.	**40.0**	41.2	40.9	41.7	35.3	**73**	33	15	17	8
Acacia brevispica	Fabac.	**36.5**	29.4	27.3	75.0	35.3	**185**	44	17	94	30
Marsdenia spec	Asclepiadac.	**23.5**	0.0	27.3	50.0	47.1	**82**	0	29	22	31
Cissampelos pareira	Menispermac.	**12.9**	8.8	4.5	8.3	35.3	**17**	4	4	1	8
Clematis longicauda	Ranunculac.	**10.6**	26.5	0.0	0.0	0.0	**15**	15	0	0	0
Solanum benderianum af	Solanac.	**8.2**	2.9	13.6	8.3	11.8	**10**	1	5	1	3
Urera hypselodendron	Urticac.	**7.1**	17.6	0.0	0.0	0.0	**13**	13	0	0	0
Schefflera myriantha	Araliac.	**5.9**	2.9	4.5	8.3	11.8	**7**	1	1	2	3
Sericostachys scandens	Amaranthac.	**5.9**	14.7	0.0	0.0	0.0	**24**	24	0	0	0
Phytolacca dodecandra	Phytolaccac.	**4.7**	8.8	0.0	0.0	5.9	**10**	8	0	0	2
Pterolobium stellatum	Fabac.	**3.5**	8.8	0.0	0.0	0.0	**6**	6	0	0	0
Clematis simensis	Ranunculac.	**2.4**	2.9	0.0	8.3	0.0	**2**	1	0	1	0
Cissus petiolata	Vitac.	**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
Clematis hirsuta	Ranunculac.	**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Tinospora caffra	Menispermac.	**1.2**	2.9	0.0	0.0	0.0	**4**	4	0	0	0
climber, woody-sp. 1		**1.2**	2.9	0.0	0.0	0.0	**11**	11	0	0	0
Trees (* with individuals > 15 m)											
*Bersama abyssinica**	Melianthac.	**95.3**	97.1	95.5	91.7	94.1	**477**	172	122	32	151
*Milletia ferruginea**	Fabac.	**81.2**	85.3	86.4	83.3	64.7	**608**	308	142	78	80
*Olea welwitschii**	Oleac.	**74.1**	85.3	63.6	75.0	64.7	**199**	113	24	34	28
*Syzygium guineense**	Myrtac.	**70.6**	88.2	54.5	58.3	64.7	**268**	192	32	28	16
*Phoenix reclinata**	Arecac.	**70.6**	79.4	72.7	25.0	82.4	**345**	204	45	8	88
*Allophylus abyssinicus**	Sapindac.	**69.4**	88.2	36.4	83.3	64.7	**329**	151	13	55	110
*Canthium oligocarpum**	Rubiac.	**65.9**	82.4	27.3	83.3	70.6	**295**	153	21	88	33
*Trilepisium madagascariense**	Morac.	**57.6**	0.0	95.5	91.7	100	**488**	0	267	83	138
*Apodytes dimidiata**	Icacinac.	**50.6**	52.9	59.1	50.0	35.3	**102**	58	24	10	10
*Elaeodendron buchananii**	Celastrac.	**50.6**	88.2	13.6	0.0	58.8	**508**	445	4	0	59
*Schefflera abyssinica**	Araliac.	**49.4**	50.0	40.9	41.7	64.7	**54**	22	11	5	16
*Pouteria adolfi-friederici**	Sapotac.	**48.2**	50.0	27.3	33.3	82.4	**87**	35	11	10	31
*Albizia gummifera**	Fabac.	**47.1**	50.0	50.0	41.7	41.2	**541**	369	58	55	59
*Ocotea kenyensis**	Laurac.	**45.9**	35.3	50.0	50.0	58.8	**402**	113	119	129	41
*Ekebergia capensis**	Meliac.	**40.0**	26.5	50.0	33.3	58.8	**60**	13	20	6	21
*Trichilia dregeana**	Meliac.	**38.8**	2.9	63.6	41.7	76.5	**89**	1	39	8	41
*Flacourtia indica**	Flacourtiac.	**35.3**	29.4	9.1	33.3	82.4	**73**	15	4	4	50
*Sapium ellipticum**	Euphorbiac.	**34.1**	17.6	50.0	41.7	41.2	**51**	10	21	6	14

*Macaranga capensis**	Euphorbiac.	**32.9**	47.1	22.7	25.0	23.5	**166**	69	11	76	10
*Albizia schimperiana**	Fabac.	**28.2**	20.6	27.3	58.3	23.5	**59**	27	9	15	8
*Polyscias fulva**	Araliac.	**27.1**	38.2	13.6	16.7	29.4	**26**	16	3	2	5
*Ficus sur**	Morac.	**25.9**	26.5	27.3	25.0	23.5	**39**	16	13	5	5
*Prunus africana**	Rosac.	**25.9**	20.6	13.6	33.3	47.1	**50**	15	8	10	17
*Alangium chinense**	Alangiac.	**24.7**	23.5	27.3	16.7	29.4	**41**	12	21	3	5
*Croton macrostachys**	Euphorbiac.	**24.7**	8.8	36.4	50.0	23.5	**45**	10	15	10	10
*Celtis africana**	Ulmac.	**23.5**	20.6	31.8	50.0	0.0	**52**	21	21	10	0
Fagaropsis angolensis	Rutac.	**18.8**	29.4	27.3	0.0	0.0	**36**	23	13	0	0
*Cassipourea malosana**	Rhizophorac.	**15.3**	32.4	4.5	0.0	5.9	**31**	28	1	0	2
Euphorbia ampliphylla	Euphorbiac.	**15.3**	26.5	4.5	16.7	5.9	**45**	35	1	8	1
*Ilex mitis**	Aquifoliac.	**15.3**	35.3	4.5	0.0	0.0	**54**	53	1	0	0
*Cordia africana**	Boraginiac.	**11.8**	5.9	9.1	25.0	17.6	**21**	5	7	5	4
*Ficus ovata**	Morac.	**10.6**	0.0	18.2	8.3	23.5	**13**	0	8	1	4
Celtis gomphophylla	Ulmac.	**7.1**	2.9	18.2	8.3	0.0	**6**	1	4	1	0
Albizia grandibracteata	Fabac.	**4.7**	0.0	18.2	0.0	0.0	**14**	0	14	0	0
*Ficus vasta**	Morac.	**3.5**	0.0	4.5	0.0	11.8	**3**	0	1	0	2
Hallea rubrostipulata	Rubiac.	**3.5**	0.0	0.0	0.0	17.6	**4**	0	0	0	4
*Vangueria apiculata**	Rubiac.	**2.4**	0.0	4.5	0.0	5.9	**2**	0	1	0	1
tree-sp. 2		**2.4**	5.9	0.0	0.0	0.0	**5**	5	0	0	0
tree-sp. 1		**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
tree-sp. 3		**1.2**	2.9	0.0	0.0	0.0	**1**	1	0	0	0
tree-sp. 4		**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
tree-sp. 5		**1.2**	0.0	4.5	0.0	0.0	**1**	0	1	0	0
Erythrina brucei	Fabac.	**1.2**	0.0	0.0	8.3	0.0	**1**	0	0	1	0
Mimusops kummel	Sapotac.	**1.2**	0.0	0.0	0.0	5.9	**1**	0	0	0	1
*Podocarpus falcatus**	Podocarpac.	**1.2**	2.9	0.0	0.0	0.0	**7**	7	0	0	0

Table A 4 Uses of selected tree species of by local farmers in Koma forest (Ensermu Kelbessa and Teshome Soromessa 2004); definition of abundance and successional classes according to section 7.3

Succ. class[1]	**Species**	**Timber**	**Construc -tion**	**Farm tools**	**Fuel- wood**	**Charcoal**	**Beehive- making**
	Common species						
S	*Bersama abyssinica*		x	x*	x		
S	*Milletia ferruginea*		x	x*	x	x	
S	*Albizia gummifera*	x	x		x		
S	*Allophylus abyssinicus*		x	2nd choice	x	x	
S/C	*Olea welwitschii*		x	1st choice	1st choice	1st choice	
	Occassional species						
C	*Pouteria adolfi-friederici*	2nd choice	x		x		
S	*Apodytes dimidiata*	x	x		x		
P	*Macaranga capensis*		x	3rd choice	x		
S	*Sapium ellipticum*		x		x		
S	*Ekebergia capensis*	x	x		x		
S	*Polyscias fulva*	x	x		x		x
S	*Prunus africana*	x	x		x	x	
P	*Euphorbia ampliphylla*	x	x		x		x
S	*Fagaropsis angolensis*		x		x		
	Rare species						
P	*Celtis africana*		x		x		
P	*Croton macrostachys*	x	x		x		x
P	*Cordia africana*	1st choice	x		x	x	
Total number of species mentioned by local farmers		13	47	13	43	7	not men- tioned

[1] *successional class: P (pioneer species), S (secondary forest species), C (climax species); *(Thirakul no date)*

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