1 GENERAL INTRODUCTION

1.1 Background

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

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

Ethiopia, located in the Horn of Africa, is a country with greatly varying landscapes ranging from high and rugged mountains, flat-topped plateaus, deep gorges, and incised rivers to valleys and rolling plains. These diverse physiographic features have contributed to the formation of diverse ecosystems characterized by a great species diversity. According to WCMC (1994), Ethiopia is one of the top 25 biodiversity rich

countries of the World. The flora of Ethiopia, for instance, is estimated to comprise between 6,000 and 7,000 higher plant species (Cufodontis' 1953-1972; Gebre-Egziabher 1991) and about 10 –12% of these are estimated to be endemic to Ethiopia (Brenan 1978; Thulin 1983; Gebre-Egziabher 1991). In general, the forest areas of Ethiopia have a high biodiversity and are of considerable economic and ecological importance to the nation.

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

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

A segment of Afromontane rainforest has long been recognized as the center of origin and diversity of wild *Coffea arabica* (Strenge 1956; Meyer 1965; Gebre-Egziabher 1990; Tesfaye et al. 2005). Currently, wild populations of *Coffea arabica* occur in many Afromontane rainforest fragments, which are geographically separated and isolated from each other due to settlements and farmland. Like other forests, these forest fragments are under continuous threat due to the expansion of agriculture and

commercial plantations (e.g., tea, coffee) and also to modifications of the forest coffee due to the use of wild coffee (Teketay 1999; Woldemariam et al. 2002; Senbeta 2004; Senbeta in press). Whatever the causes of deforestation might be, the bottom line is that conservation efforts are mandatory in order to maintain the remaining Afromontane rainforests. A diverse range of social, economic and ecological information about the forest is necessary to design suitable conservation and sustainable use approaches.

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

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

1.2 Objectives of the study

The general objective of the present study is to make a comparative inter-regional species diversity analysis of geographically separated Afromontane rainforests and to generate information for management decision-making regarding *in-situ* conservation of

the genetic resources in the forests with wild coffee populations. The specific objectives of the study are:

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

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

2.1 Forest vegetation of Ethiopia

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

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

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

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

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

2. **Transitional rainforest**

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

3. Afromontane rainforest

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

2.2 Phytogeographical description

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

The Afromontane region is an archipelago-like centre of endemism, which extends from the Loma Mountains and the Tingi Hills in Sierra Leone in the west to the Ahl Mescat Mountains in Somalia in the east, and from the Red Sea Hills in the Sudan Republic in the north to the Cape Peninsula in the south (White 1983). In addition to the large number of species common to most of these mountains, the Afromontane region

also varies in floristic composition, physiognomy and ecology and shows varying relationships with other phytogeographic regions (Coetzee 1978). Most Afromontane communities are found above 2000 m, but they can occur as low as 1200 a.s.l. in some places (White 1983). The Afromontane region contains about 4000 plant species, and about 75% of these are endemic or near endemic to the region. Very recently, this region was designated as the "Eastern Afromontane Hotspot," which is one of the 34 regions globally important for biodiversity conservation (Conservation International 2005).

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

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

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

2.3 Occurrence and use of wild *Coffea arabica*

2.3.1 Distribution of wild coffee

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

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

2.3.2 Coffee production systems

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