1 GENERAL INTRODUCTION

1.1 Background and problem statement

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

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

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

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

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

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

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

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

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

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

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

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

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

1.2 Aims and scope of the study

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

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

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

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

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

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

1.3 Structure of the dissertation

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