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GLOBAL CONSERVATION STRATEGY FOR COFFEE GENETIC RESOURCES

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EXECUTIVE SUMMARY

Coffee plays a significant economic role globally as well as serving as a major source of foreign earnings in many producing countries. Produced in about 80 countries (Musoli et al. 2009), an estimated 125 million people in Latin America, Africa and Asia depend on it for their livelihoods (Osorio 2002). Despite challenges, world coffee production has grown steadily over the past 50 years, though it will be difficult to maintain this trend due to continued rise in production costs, as well as problems related to negative impacts of climate change and higher incidence of pests and diseases (ICO 2014). A key to meeting these challenges will lie in utilizing the coffee genetic resources conserved in field genebanks, in protected areas, and in the forest to develop improved varieties with drought stress tolerances, pest and disease resistances, high cup quality, and increased production. The need to develop a comprehensive strategy for the conservation of coffee genetic resources through a thorough evaluation of existing germplasm collections has never been more urgent (Krishnan 2013). Through engagement of multi-national stakeholders from various aspects of coffee production, processing, breeding, conservation and research, the goal of this Global Strategy is to ensure the conservation and use of coffee genetic resources for a positive, sustainable future of the crop and for those who depend on coffee for a livelihood.

A background study was done on the vulnerability of coffee genetic resources conserved ex situ and in situ, as well as on the main constraints to the use of these genetic resources. A survey of the status of major coffee collections was done, site visits were made to seven of these collections, and a study of the cost of conservation of the Centro Agronomico Tropical de Investigacion y Ensenanza's (CATIE) coffee collection was done. The main objective of these assessments was to assess the security of the current conservation system, its significant gaps, its resource requirements, and its significant constraints as well as opportunities from use.

Based on both the survey and site visits, conclusions can be drawn about the current global system for conservation of coffee ex situ collections. The first observation is that it is not a system. The current situation is a set of nationally focused collections that are isolated from each other and from external users. In most of the institutions involved, the aim of conservation of the collection is to make it available to its own breeding program. Generally, there were two types of accessions conserved in genebanks surveyed or visited. All but one of the genebanks conserved a set of 'international' accessions that have been widely shared across many genebanks in the past. This includes the accessions collected by FAO, IRD, and IPGRI in the past, those shared by CIFC-IICT in the past effort to manage coffee leaf rust resistance, a limited set of wild *Coffea* species (other than *C. arabica* or *C. canephora*), and the more important products of breeding programs that have been widely shared in the past. These are common and widely duplicated across the genebanks surveyed. Much is known about these accessions, and they have had some use, though information is scattered and mistakes may have occurred in labeling in the past. The other type of accession found in the current global system was local and unique. These had been collected from farmers and/or the forest but have not been widely shared, used, or securely conserved. They are linked to coffee genetic resources that remain in farmers' fields or in forests, some with in situ designation. They are likely to capture and maintain a wider range of locally adapted genetic diversity than the international accessions. These accessions are found in genebanks

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COFFEE PLAYS A SIGNIFICANT ECONOMIC ROLE GLOBALLY AS WELL AS SERVING AS A MAJOR SOURCE OF FOREIGN EARNINGS IN MANY PRODUCING COUNTRIES.

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such as EBI in Ethiopia for *C. arabica*, FOFIFA in Madagascar for Malagasy wild species, and CNRA in Cote d'Ivoire for *C. canephora* and other African species. These unique local accessions are mainly found in Africa, where they are facing many threats. The unique wild species found in the Asia-Pacific region are not currently conserved in ex situ collections.

Generally, in most institutions, conservation of the collection is secure due to the dedication and commitment of the institutes and their staff. Everyone is challenged, to some degree, to cover the annual cost for the routine conservation operations. The costing study for CATIE demonstrates the longer-term implications of neglect when funds are inadequate. Currently there is very limited sharing of accession-level information, especially outside the institution maintaining the material. The only significant sharing of information on accessions is through scientific publications. There is limited genotyping and evaluation of accessions. Constraints to germplasm conservation and use are related to lack of policies regarding ABS. There is little or no safety duplication, except for international accessions. Those few genebanks with unique local accessions have no safety duplication. The collections in Africa are still adding accessions with a continued focus on gap filling. They have links to protected sites but this needs to be formalized and strengthened. Outside of Ethiopia, designation of protected areas and monitoring does not give priority to coffee genetic resources, with very limited complimentary conservation in genebanks to increase security for in situ conservation and serve as sources of plant material for any reforestation efforts.

RESEARCHERS EXAMINE COFFEE FRUIT IN MADAGASCAR.

The current “system” is not sustainable, secure, cost effective, or rational. What is needed is a global system that will secure unique accessions as a global resource for use by future generations to ensure the sustainability of coffee production now and in the future. These accessions could be conserved in genebanks, in situ sites or both ex situ and in situ. The global community will need to operate together as a platform for collaboration on conservation, breeding, research, and enhanced use. To sustain the annual resources needed for long-term support for the ex situ conservation of a significant proportion of the genetic diversity, there will be a need to ensure long-term sustainable financial resources for the key ‘origin collections’. These origin collections would be the center of a global platform for collaboration that would link long-term conservation and use through partnerships and leadership in global actions. These origin collections will link to “user collections” that have a substantial set of accessions with a long-term commitment to conservation as well as other collections that are smaller and more focused. This would increase safety duplication and allow for a global genebank monitoring system. The future global system will allow for greater collaboration on improved conservation protocols, and include complementary strategies such as in situ to expand the degree of diversity conserved securely and to enhance the use of populations that are found in centers of origin. It will form the basis of a global mechanism to respond to urgent needs. It will contribute to enhanced use through more accessible information systems, more complete data on accessions that are relevant to users, an agreed framework for germplasm exchange, and better protocols for distribution to manage phytosanitary concerns.

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THROUGH THE GLOBAL CONSERVATION STRATEGY DEVELOPMENT, SIX HIGH PRIORITY ACTIONS HAVE BEEN IDENTIFED TO FACILITATE THE TRANSITION FROM THE CURRENT ‘SYSTEM’ TO A GLOBAL CONSERVATION SYSTEM FOR COFFEE.

Through the global conservation strategy development, six high priority actions have been identified to facilitate the transition from the current ‘system’ to a global conservation system for coffee. These are to (1) secure stable funding for long-term conservation of the origin plus CATIE collections through the Crop Trust Endowment Fund; (2) upgrade facilities and capacity of origin and user collections; (3) use of an ABS that will facilitate germplasm exchange and use; (4) establishment of the global platform for collaboration in coffee genetic resources conservation and use; (5) ensure the safety duplication of all conserved accessions; and (6) greater complementarity of ex situ and in situ conservation of coffee genetic resources. These actions are interconnected and dependent upon each other. It is clear that there is overall need to ensure conservation through stable funding and short term upgrading if we are to secure coffee genetic resources for use by future generations but enhanced utilization through better facilitated access and accession level information sharing are also very important.

To support this effort, there is also a need to recognize the collective responsibility that governments, producers, processors, and consumer have for this key resource. The current coffee value chain globally has inequity in terms of allocation of value to production by farmers in producing countries versus value addition for processing and marketing in consuming countries. Sustainability of the global commodity chain will depend upon research and development built upon the coffee germplasm conserved for future use. There is a need to find a way to balance out the share of the value addition in consuming countries to be used to support R&D and germplasm conservation in Africa, where the key species originated and still found in tropical forest. This support will need to come from industry and consumers.

GLOBAL CONSERVATION STRATEGY FOR COFFEE GENETIC RESOURCES

INTRODUCTION

Coffee plays a significant economic role globally as well as serving as a major source of foreign earnings in many producing countries. Produced in about 80 countries (Musoli et al. 2009), coffee production supports an estimated 125 million people in Latin America, Africa and Asia whom depend on it for their livelihoods (Osorio 2002).

A significant transformation of the world coffee market has occurred in the last 50 years. During the period between 1965 and 1989, the coffee market was regulated, with relatively high price levels, since upward and downward trends were corrected through the implementation of export quotas. The free market period began in 1990 and has seen two sub-periods of significantly low price levels, 1989 to 1993 and 1999 to 2004, the latter being the longest period of low prices ever recorded (ICO 2014). In the world coffee market, as is the case of many commodities, price volatility is a major concern for all stakeholders. In exporting countries, price volatility leads to instability in producer incomes and uncertainty of export earnings and tax revenues.

In importing countries, price volatility affects profit margins for roasters, traders and stockholders (ICO 2014). Consumers do not like it either. All of these factors lead to the coffee crop becoming less attractive throughout the supply chain, especially to growers, who will seek other, more remunerative crops to replace coffee. Despite these challenges, world coffee production has grown steadily over the past 50 years. It will be difficult, however, to maintain this trend due to continued rise in production costs, as well as problems related to negative impacts of climate change and higher incidence of pests and diseases (ICO 2014).

In the coming decades, climate change will have a huge impact on coffee production, especially of *C. arabica*, which is a climate-sensitive species. Noticeable effects of climate change, such as higher temperatures and lower and more erratic precipitation have already been documented in *C. arabica* producing regions. In recent years, droughts have become more frequent in coffee regions and are expected to increase in severity during this century. In certain areas, both drought and severe hurricanes will most likely become more frequent (Schroth et al. 2009). Direct impacts of climate change will result in stressed growth of coffee trees, limited flowering and berry development, poor yield and poor quality of the coffee beans. Severe outbreaks and spread of diseases (such as leaf rust, coffee berry disease, wilt, leaf blight), insects (coffee berry borer, leaf miners, scales) and nematodes will be experienced. The area affected by coffee berry borer in Central America has gradually increased over the past decade (Laderach et al. 2010). This will lead to a general decrease in the suitability of the current area of coffee cultivation with a shift of the cultivation of *C. arabica* up the altitudinal gradient.

For example, the coffee rust crises in Colombia and Central America (2008–2013) triggered many negative impacts on coffee production; on farmers' and laborers' income and livelihood; and on food security. Due to the coffee rust epidemic the production has been considerably reduced in Colombia (by 31 % on average during the epidemic years compared with 2007) and Central America (by 16 % in 2013 compared with 2011–12 and by 10 % in 2013–14 compared with 2012–13). These reductions have had direct impacts on the livelihoods of thousands of smallholders and harvesters. For these populations, particularly in Central America, coffee is often the only source of income used to buy food and supplies for the cultivation of basic grains. As a result, the coffee rust epidemic has had indirect impacts on food security (Avelino et al. 2015).

Schrotch et al. (2009) identified a comprehensive coffee development plan that will sustain biodiversity, ecosystem services and livelihoods in the face of climate change. The activities in the plan included promotion of biodiversity-friendly coffee growing and processing practices, incentives for forest conservation and restoration, diversification of revenue sources, integrated fire management, market expansion to develop a demand for sustainably produced coffee, crop insurance programs for smallholder farmers and strengthening capacity for adaptive resource management. Implementing adaptation strategies such as these will be critical in sustaining the coffee economy and livelihoods in many countries. None will be possible, however, without continued and indeed increased access to coffee genetic resources, to allow the development of new and improved varieties with drought stress tolerances, pest and disease resistances, high cup quality, and increased production under the new farming systems.

GENETIC BASE OF COFFEE PRODUCTION: OPPORTUNITIES AND CHALLENGES

The *Coffea* genus is a member of the Rubiaceae family, one of the largest tropical plant families. It is distributed in Africa, Madagascar, the Comoros Islands, the Mascarene Islands (La Réunion and Mauritius), tropical Asia, and Australia (Davis 2010, 2011, Davis et al. 2006 and 2011). Of the 125 species of *Coffea* (*Annex II*), only two are economically cultivated for the production of the coffee beverage, *C. arabica* L. (Arabica coffee) and *C. canephora* A. Froehner (robusta coffee). Arabica coffee accounts for about 60% of total coffee production and export and is associated with higher beverage quality. *C. arabica* has its primary center of diversity in the highlands of southwestern Ethiopia and the Boma Plateau of South Sudan, with wild populations also reported on Mount Marsabit in Kenya (Meyer, 1965; Thomas, 1942).

C. canephora has a much wider distribution, covering a large area stretching from West Africa (Ghana, Guinea, Ivory Coast, Liberia and Nigeria) through Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Uganda and northern Tanzania up to northern Angola (Davis et al., 2006).

Cultivation of *C. arabica* started in southwestern Ethiopia about 1,500 years ago. It is thought that coffee was introduced to Yemen from Ethiopia around the 6th century (Anthony et al. 2002), where practitioners of Sufism first recorded consumption around 1450 (Vega 2008). From Yemen, two genetic bases spread, known as Typica and Bourbon, giving rise to most of the present commercial cultivars of Arabica coffee grown worldwide. The two sub-populations of wild coffee introduced from Ethiopia to Yemen underwent successive reductions in genetic diversity. Introduction of coffee to Java, Amsterdam, and La Réunion at the beginning of the 18th century led to further reductions in genetic diversity. Several authors indicate that the Typica genetic base consists of a single plant cultivated in Amsterdam in the early 18th century, introduced from Java, whereas the Bourbon genetic base consists of trees introduced to La Réunion (then Bourbon Island) from Mocha, Yemen in 1715 and 1718. Coffee then spread rapidly to the Americas and Indonesia in the form of self-fertilized seeds, with intense reduction in genetic diversity, leading to a genetic bottleneck outside of its center of origin (Anthony et al. 2002).

COFFEE HYBRIDS GROWN AT CATIE IN COSTA RICA.

Originating from two different diploid wild ancestors (2n=2x=22), *C. canephora* and *C. eugenioides* S. Moore or ecotypes related to these species, *C. arabica* is an allotetraploid (2n=4x=44), that mainly (on average 90%) regenerates through self-fertilization (Lashermes et al. 1999; Fazuoli et al. 2000). This further contributes to low genetic diversity within the species (Anthony et al. 2002). The utilization of this narrow genetic base for variety development has resulted in Typica- and Bourbon-derived cultivars that have homogenous agronomic behavior characterized by high susceptibility to many pests and low adaptability. Most varieties of coffee have been developed in an effort to counter the impact of pest and diseases such as coffee berry borer, coffee berry disease, coffee leaf rust, etc. This has led to a compromise in yield and quality.

In contrast, *C. canephora* is cross-pollinated and is estimated to have 10 times the genetic variation of *C. arabica* (Lashermes et al. 2000a). The transfer of desirable traits from related, diploid species such as *C. canephora* into *C. arabica* cultivars has become a priority in coffee breeding (Lashermes et al. 2000a). Though *C. canephora* has been utilized in breeding programs, utilization of other taxa, such as *C. eugenioides*, *C. congensis* A.Froehner, and C. sp. Moloundou, has been neglected (Lashermes et al. 1999). Many of the traits conferring resistance to diseases and pests such as coffee leaf rust (Hemileia vastatrix Berkeley and Broome), coffee berry disease caused by Colletotrichum kahawae Bridge and Waller, and root-knot nematode (Meloidogyne sp.) not found in *C. arabica* have been found in *C. canephora* (Lashermes et al. 2000b). *Coffea* racemosa Lour. also constitutes a promising source of coffee leaf miner (*Perileucoptera coffeella* Guerin-Meneville) resistance (Guerreiro Filho et al. 1999).

These and other wild species, along with old and traditional varieties grown in farmers' fields in the center of origin of Arabica and robusta coffee represent the ultimate source of genetic diversity. Even though the genetic diversity of Arabica coffee is documented to be lower than the diploid species, in situ populations in its center of origin and diversity, south-western Ethiopia in particular, still have significant genetic variability for many agronomic characters (Teressa et al. 2010). It is these populations that will provide the genetic resources for future improvement of the coffee crop. However, threats to these genetic resources are immense and their loss would ultimately lead to significant genetic erosion of the coffee genepool. Countering the loss of genetic resources has been the main motivation behind implementation of collecting expeditions and establishment of ex situ field genebanks in many coffee producing countries.

Compared to the economic importance of coffee, current conservation efforts, both ex situ in genebanks and in situ in its natural forest ecosystem, however, are very poor and inadequate.

The accessions maintained in field genebanks do not represent the wide spectrum of genetic variability available within natural coffee populations in Ethiopia (Teressa et al. 2010). Coffee seeds are recalcitrant, making them difficult to store beyond two to three years. Limited alternatives have been developed for the long-term conservation of coffee germplasm other than in ex situ field collections (Vega et al. 2008).

EX SITU CONSERVATION

Plant genetic resources are the basis of food security (Nass et al. 2012). They serve as raw material for plant breeding and hence it is critical that these resources are *properly preserved and characterized for current and future demand and use (Nass et al. 2012). The sustainable use of genetic resources is based on the establishment and maintenance of collections in germplasm banks, mainly field genebanks in the case of coffee. These facilities allow ease of access by users such as plant breeders or other researchers, and extra security from loss (Van Hintum et al. 2000).*

Exploration for wild coffee species started in the sixteenth century, along with other tropical plants. Intense collecting in Africa occurred at the end of the nineteenth century and during the first part of the twentieth century, although mostly for herbaria rather than for living collections (Charrier and Berthaud 1985). Interest in coffee genetic resources and its conservation increased during the second half of the 20th century as awareness of the threats to these genetic resources due to deforestation, and the lack of variability in the crop increased (Anthony et al. 2007a).

The Food and Agriculture Organization (FAO), various French organizations (ORSTOM, CIRAD, the Museum of Natural History, Paris), and IPGRI therefore undertook extensive germplasm collecting in the 1960s, 70s and 80s (Charrier & Berthaud 1985). The individual collecting missions are listed in Table 1. The emphasis was on collecting *C. arabica* germplasm because of its economic importance, but a number of non-cultivated species were also collected, such as the subsection *Mascarocoffea* (from Madagascar), the subsection *Pachycoffea*, *C. congensis*, *C. eugenoides*, and the related genus *Psilanthus* (which is now subsumed under *Coffea*). In addition to these international collecting missions, local researchers within countries have performed their own collecting, such as in Ethiopia (Labouisse et al. 2008), Madagascar and Cote d'Ivoire.

TABLE 1. MAJOR COLLECTING MISSIONS OF COFFEA GENETIC RESOURCES FROM 1964-1989; SOURCE: ANTHONY ET AL. 2007A; VEGA ET AL. 2008.

YEAR/S OF EXPLORATION	COUNTRIES EXPLORED	PARTICIPATING ORGANIZATIONS	COUNTRIES HOLDING GERMPLASM
1964-65	Ethiopia	FAO	Ethiopia, Costa Rica, India, Peru, Tanzania
1966	Ethiopia	ORSTOM	Ethiopia, Cameroon, Côte d'Ivoire, Madagascar, Costa Rica
1960-74	Madagascar, Mauritius, Reunion Island, Comoro Islands	Museum of Natural History, Paris, France; CIRAD; ORSTOM	Madagascar
1975	Central African Republic	ORSTOM	Côte d'Ivoire, Central African Republic
1975-87	Côte d'Ivoire	ORSTOM	Côte d'Ivoire
1977	Kenya	ORSTOM; CIRAD	Kenya, Côte d'Ivoire
1982	Tanzania	ORSTOM; CIRAD	Tanzania, Côte d'Ivoire
1983-85-87	Cameroon	IPGRI (1983); ORSTOM (1985); CIRAD (1987)	Cameroon, Côte d'Ivoire
1985-88	Congo	ORSTOM (IRD); IPGRI; CIRAD	Congo, Côte d'Ivoire
1987	Guinea	ORSTOM (IRD); CIRAD	Guinea, Côte d'Ivoire
1989	Yemen	IPGRI; CIRAD	Yemen, Costa Rica, Brazil

Various coffee genebanks throughout the world hold accessions from these collecting missions as well as other material selected in plantations and by breeders. Coffee farmers supplied some of the materials because they displayed good agronomic performance or specific traits. FAO conducted an inventory of living coffee collections in 1960, followed by an update in 1978-79. In 1989, IBPGR published a directory of germplasm collections of industrial crops, of which coffee was one. The 1998 FAO report on the State of the World's Plant Genetic Resources documents 21,087 coffee accessions conserved worldwide (Anthony et al. 2007a).

The FAO WIEWS (2009-2011) database is the most comprehensive inventory of coffee germplasm held in living collections, but much of the information is out of date. Dulloo et al. (2009) did an inventory of a limited number of genebanks, who reported 41,915 accessions in field genebank collections worldwide.

Annex III provides the inventory of ex situ field collections held by various countries as reported by these references as well as from the survey conducted as part of the development of the present strategy.

Field genebanks that hold significant *C. arabica* collections are located in Africa (Cameroon, Cote d'Ivoire, Ethiopia, Kenya, and Tanzania), Madagascar, India, and the Americas (Brazil, Colombia, and Costa Rica). Field collections of Cameroon, Cote d'Ivoire, India, and Madagascar have good representation of *C. canephora*. A majority of the non-cultivated wild coffee species are held at the genebanks in Madagascar and Côte d'Ivoire, with Madagascar holding over 50 species of the section *Mascarocoffea* and about 30 species of diploid African coffee in Cote d'Ivoire (Vega et al. 2008).

Coffea accessions are also conserved ex situ in botanical gardens. A search of Botanic Gardens Conservation International's PlantSearch database (*https://www.bgci.org/plant_search.php*) found botanical gardens in 50 countries conserve 445 accessions. These accessions come from 26 species and some inter-specific hybrids. *C. arabica*, *C. canephora*, and *C. liberica* account for 81% of these botanical garden accessions. Of the 73 accessions with a species designation, eleven are conserved at only one botanical garden. When the status of global conservation is assessed with FAO-WIEWS, Genesys or individual publically available databases, four of these species have not been reported in any other collection. Thus, botanical gardens could be conservers of unique species or variety level diversity that needs to be considered globally and should be considered as part of the global system for coffee ex situ conservation.

VULNERABILITY OF *EX SITU* COFFEE GENETIC RESOURCES

PESTS HAVE THE ABILITY TO WIPE OUT AN ENTIRE COLLECTION IF NOT TREATED WITH CARE.

Even though considerable progress has been made in assembling and conserving genetic resources collections over the past four decades, many are now facing major problems (Van Hintum et al. 2000). Recognizing this, conservation of genetic resources is addressed by the United Nations Sustainable Development Goals, under Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture. Target 2.5 of SDG 2 states that: By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed (*https://sustainabledevelopment.un.org/sdg2*).

One of the big drawbacks of ex situ field collections of coffee is that they are often located in ecological conditions not ideally suitable for the performance or indeed survival of all the material, leading to genetic erosion (Dulloo et al. 1998). Loss of trees as a result of aging, inappropriate cultivation methods, and pests and diseases can cause genetic erosion (Anthony et al. 2007a; Anthony et al. 2007b; Vega et al. 2008). Over the years, substantial losses of coffee plants have occurred in several genebanks, which have resulted in loss of entire accessions. Using CATIE as an example, the main challenges faced include: 1) aging trees, most of which were established in the 1970s and are now over 40 years old; 2) suboptimal climatic conditions and elevation; 3) need for diversity of cultural practices due to the diverse nature of the collections, with cultivated and wild genotypes differing in their needs for shade, pruning, fertilizer application, etc.; and 4) lack of funding and other resources (Vega et al. 2008). The risk of disease transfer through germplasm exchange is associated with field collections (Dulloo et al. 2009).

In addition, loss of genetic integrity of diploid species due to inadequate propagation and regeneration protocols is a concern. Hybridization in ex situ collections may compromise the genetic makeup, integrity, and value of the collections (Maunder et al. 2003; Krishnan et al. 2013a). Cross contamination with pollen from other *Coffea* species has been observed in several wild coffee species at the National Center of Applied Research and Rural Development's (FOFIFA) Kianjavato Coffee Research Station (KCRS) in Madagascar, compromising the genetic integrity of the collections (Krishnan et al. 2013; Andrianasolo et al. 2013).

Due to lack of duplication of collections, their long-term safety is threatened (Anthony et al. 2007a). There is an urgent need for these genetic resources to be duplicated in other genebanks (Anthony et al. 2007a). One way to combat some of these problems would be to set up a core collection with accessions chosen to represent diverse genetic variability and duplicate this subset in diverse ecogeographic sites. To achieve this, the extent of genetic variability held in existing ex situ collections must be assessed (Dulloo et al. 1998).

Other ex situ conservation methods, such as in vitro slow growth and cryopreservation, has been utilized for coffee on a limited scale as a backup for field collections. Dussert et al. (2007) developed cryopreservation protocols for the core collection of the coffee germplasm maintained at CATIE. However, challenges have been faced during regeneration post-cryopreservation, with low recovery rates. Hence, currently, cryopreservation cannot serve as a replacement for field genebanks, though it could be considered as an alternative safety duplication method with more research.

IN SITU CONSERVATION

Conservation of plant species in situ offers the possibility of conserving a greater diversity of species and genepools in a dynamic environment allowing populations to continue to evolve (Engelmann et al. 2007). Wild coffee is found growing naturally as understory trees in the tropical forests of Africa, comprising a wide geographic range from Guinea in West Africa through Central to eastern Africa. Other centers of diversity include Madagascar, the Comoros Islands, and the Mascarene Islands (La Réunion and Mauritius) in the Indian Ocean (Davis et al. 2006), and with the inclusion of *Psilanthus* into *Coffea*, the geographic distribution is extended to tropical Asia and Australia (Davis et al. 2011). In situ conservation of their forest habitats has become critical.

One of the key threats to in situ populations of coffee is deforestation for agriculture, caused by human population pressures. The danger of climate change increases the urgency (Kufa et al. 2010). Through bioclimatic modeling, Davis et al. (2012) predict a 38% to 90% reduction in bioclimatically suitable space for indigenous Arabica coffee by the year 2080.

In Ethiopia, deforestation is one of the key factors leading to the erosion of coffee genetic diversity (Labouisse et al. 2008). Between 1971 and 1997, around 235,400 ha of closed and slightly disturbed forests were deforested in the highland plateau of southwest Ethiopia. Many international organizations have designed proposals for in situ conservation of *C. arabica*, but unfortunately implementation has been lagging due to financial constraints (Gole et al. 2002). Gole et al. (2002) identified constraints associated with establishing in situ reserves and action steps to be taken to develop a successful program. Elaborating on the importance on in situ conservation of coffee genetic resources, they described basic issues to be addressed, such as undertaking habitat characterization and ecological studies, mapping the distribution of the range of wild coffee populations, assessment of population genetic structure of different isolated populations, and developing design and management plans of conservation reserves.

- According to Woldetsadik and Kebede (as cited in Labouisse et al. 2008), four major coffee production systems of *C. arabica* exist in Ethiopia:
- Forest coffee system, where trees are protected and tended for convenient picking in the forest.
- Semi-forest coffee system, where trees are conserved in their natural forest habitat with some maintenance, such as slashing weeds, lianas and competing shrubs, thinning of forest trees and filling open spaces with local seedlings.
- Garden coffee system, where seedlings are transplanted from forest habitats closer to farmers' dwellings as smallholdings grown under a few shade trees usually combined with other crops and fruit trees.
- Plantation coffee system, which constitutes more intense management for maximizing the volume of production and productivity after land clearing, soil preparation, and seedling planting. In most cases, this system of production utilizes limited number of coffee lines selected for their performance by national research institutions.

Of these four systems, the first two constitute in situ genetic resources, where wild coffee genotypes are conserved through varying degrees of cultivation. The garden coffee system also conserves wild genotypes and landraces, but in more of an on-farm setting. In these traditional production systems of Ethiopia, large phenotypic diversity of the coffee trees has been observed (Labouisse et al. 2008).

In 2010, in an attempt to conserve the last remaining coffee forests in Ethiopia and to halt the loss of biodiversity, the Yayu Biosphere Reserve and the Kafa Biosphere Reserve became part of the United Nations World Network of Biosphere under the Man and Biosphere (MAB) reserve program. This is one of the last remaining montane rainforest fragments with wild *C. arabica* populations in the world. The biosphere reserve occupies 167,021 ha and is zoned into core areas (27,733 ha), buffer zone (21,552 ha) and transitional areas (117,736) with the core areas having high abundance of wild Arabica coffee and high species diversity. The core zone is protected area, the buffer zone is managed use area and the transition zone is highly used by the local people who are partners in the conservation activities in the other zones (Gole 2003). Two projects funded by the German Federal Agency for Conservation and German Federal Ministry of Education and Research are being implemented – conservation and use of the wild populations of *C. arabica* in the montane rainforests and a public awareness and environmental education project (UNESCO 2016a).

The Kafa Biosphere Reserve is located approximately 460 km southwest of Addis Ababa. One of the key management focal areas is the coordination of conservation initiatives with a focus on the protection of *C. arabica* genetic resources and its associated ecosystems (UNESCO 2016b).

Occupying an area of 759,399 ha, this reserve is within the East Afromontane Biodiversity Hotspot. The core area consists of 41,399 ha, the buffer zone 164,000 ha and the transition areas occupy 334,000 ha (Mesfin Tefle per. comm.). Various institutions such as Ethiopian Nature and Biodiversity Conservation Unit (NABU), Ethiopian Wildlife and Natural History Society (EWNHS) and University of Bonn, Center for Development Research (ZEF) are conducting ongoing research on the conservation of genetic resources of wild *C. arabica* in this biosphere.

Hein and Gatzweiler (2006) assessed the economic value of coffee (*C. arabica*) genetic resources in the Ethiopian highland forests. This valuation was based on the use of these genetic resources for 1) resistance to coffee berry disease and coffee leaf rust, 2) low caffeine content, and 3) increased yields. They factored in a discount rate of 5% and 10% to account for the time lag between the costs of the breeding programs and the realization of the benefits from growing enhanced cultivars. The assessment yielded an economic value amounting to about US$1,458 million at a 10% discount rate and US$420 million at a 5% discount rate. This study demonstrates the high economic value that can be derived from the use of coffee genetic resources and the need for immediate action to conserve these genetic resources by halting deforestation in the Ethiopian highland forests.

In the Kibale National Park of Uganda, The Wild Coffee Project (TWCP) used a unique approach to conserve *C. canephora* genetic resources through a market-based approach (Lilieholm and Weatherly 2010). This project aimed to support nature conservation and local communities through commercialization of sustainable harvests of wild coffee growing naturally in the park. Even though this project failed to gain international access to coffee markets, the lessons learnt could provide useful guidance for other market-based efforts linking forest resource conservation, local communities and international trade (Lilieholm and Weatherly 2010; *http://agro.biodiver.se/2010/06/learning-from-kibales-failure/*).

There is much work to be done in the area of in situ conservation of coffee, with more studies needed to define local abundance, rate of self-fertilization, population age structure, partitioning of genetic diversity, kinship and genetic polymorphism, and phenotypic diversity, including for specific agronomic traits. This will help determine optimum sites and population size for in situ conservation and assist with developing a sampling strategy for ex situ conservation (Labouisse et al. 2008). In addition to *C. arabica*, other *Coffea* species are also under threat in their natural habitats, and efforts to conserve these forests should also become a priority. Developing niche markets in the international specialty market by emphasizing the wild origin of the coffee could be an approach to command higher prices that could benefit the local communities and thus their stewardship in conserving these forests and the genetic resources held in them.

EXCHANGE OF COFFEE GENETIC RESOURCES

Genetic resources are subject to a number of international legal regimes that regulate access and benefit sharing (ABS). Germplasm exchange is also incentivized or discouraged by a variety of regulatory frameworks (IP and other proprietary regimes, biosecurity); collaborative networks (academic, public-private); and other organizations such as national agricultural research institutes, non-governmental organizations, and conservation entities. An expanded understanding of this wider ABS context needs to be considered for the future.

The Convention on Biological Diversity (CBD) calls for the “fair and equitable sharing of benefits arising out of the utilization of genetic resources” as well as the conservation and sustainable use of these natural resources. It recognizes national sovereign rights over genetic resources and the need for access through prior informed consent (PIC) on mutually agreed terms (MAT). Provider countries are encouraged to create conditions to facilitate access without imposing undue barriers to use. The CBD recognized the conservation and use of biological resources as an important component of sustainable development (Koester, 2006). Prip and Rosendal (2015) describe the development and implementation of the Nagoya Protocol for access and benefit sharing of genetic resources under the CBD.

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which came into force in 2006, is recognized by the CBD as a sector-specific ABS regime. Many crops of global significance to food security are included in the Multilateral System (MLS) of the ITPGRFA, which is the key to its ABS regime. Chiarolla, et al (2013) concluded that decoupling of benefit sharing from access and use by a specific provider in ABS regimes such as the MLS is based upon recognition of the incremental improvement from multiple sources that characterizes plant breeding. Due to the high rate of global interdependence and exchange, countries gain more from having access to a global pool of plant germplasm and from addressing benefit-sharing multilaterally (i.e. without any attribution of benefits to a specific provider country), rather than governing access and benefit-sharing bilaterally. Although the scope of the Treaty is all PGRFA, the MLS currently applies to 64 crops listed in *Annex I*, plus a number of international collections listed under Article 15 of the treaty. Crops that are recognized in this multilateral system have global significance as well as global interdependence. Exchange of material in the MLS operates on an accession basis. Germplasm transfer in the MLS is through the Standard Material Transfer Agreement (SMTA) in which the germplasm recipient is under an obligation to not claim ownership of the received material per se nor seeks intellectual property rights over the received material or its genetic parts or components. The recipient is entitled to claim IP or other restrictions on a product (i.e. a new variety) that incorporates the received germplasm. If such claims result in a restriction of further research and breeding on the received germplasm, the SMTA foresees monetary benefit sharing through the multilateral Benefit-Sharing Fund. The SMTA also encourages non-monetary benefit sharing, in the form of information exchange, access to and transfer of technology, capacity building.

Coffee is not included in the list of crops in Annex I of the ITPGRFA, except in the case of the CATIE collection, which is included in Article 15 as an international collection.

Thus, the CBD/Nagoya Protocol provisions on ABS apply for coffee germplasm exchange. There are ongoing discussions to extend the scope of the multilateral system by increasing the number of crops on the list, or indeed abolish it altogether. International exchange of coffee germplasm is facilitated by a number of intermediary institutions, some with an international mandate, others operating in national frameworks. CATIE hosts one of the largest international coffee genetic resource collection, the only one in the global public goods domain, comprising a large extent of the genetic diversity of *C. arabica* and good representation of *C. canephora* and *C. liberica* genetic diversity (Vega et al. 2008). CATIE agreed to hold the collection under the terms and

MATERIAL AT CATIE IN COSTA RICA BEING GROWN FOR DISTRIBUTION.

conditions of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) in an Article 15 agreement in 2006. In adherence with this designation, germplasm exchange falls under the ABS arrangements of the ITPGRFA, governed by the SMTA, with any benefit from use of these accessions flowing to the multilateral benefit-sharing fund. This collection represents a significant asset for current coffee breeding programs, as it is globally available for use. Many national breeding programs have already accessed a significant amount of this germplasm and hold it within their own ex situ collections. Thus, extensive ex situ collections have been developed from the past collection activities as well as the global exchange, especially in relation to the global effort to address coffee leaf rust.

Lightboune (2016) presented the results of cases studies on the relationship of food security, biological diversity, and trade policy in two global crops, soybeans in China and coffee in Ethiopia, that are not included in *Annex I* of the ITPGRFA. Both crops are of economic significance in international trade for the country in the center of origin for the crop, but in both crops, a significant amount of that diversity has been conserved outside these countries of origin prior to the coming into force of the CBD. The results of both case studies projected that the monetary value of the crop as a commodity for export outweighed the possible monetary benefits from access to its genetic resources. Increased export value to China for soybeans and Ethiopia for coffee depended upon increased production per unit areas from improved varieties for smallholder farmers. This gain from breeding depended upon breeding materials and genetic resources that needed to be accessed from outside the country. The monetary benefit of access to the countries' germplasm was limited by the availability of significant amount of its genetic resources held outside the country, thus limiting demand. This study of coffee germplasm in Ethiopia demonstrated the global interdependence of this crop in relation to genetic resource conservation and use. Lightboune (2016) concluded that if the current system of exclusion continues, the global community, including the countries of origin, would lose out. Thus, under these circumstances a country in the center of origin should consider including the crop in the MLS.

Halewood (2013) assessed the globally recognized effort to cooperate in the generation, pooling, conservation, and sharing of plant genetic resources and identified a number of options for recognizing the public, private, or common pool goods nature of plant genetic resources. Many of these have implications for the exchange of coffee genetic resources, both within the ITPGRFA as an Article 15 international collection or as an inclusion in the MLS in the future. It identified many dilemmas and challenges for its inclusion as a public good in the current systems but concluded that if some of the weaknesses could be addressed, the ITPGRFA might be an option to facilitate access and benefit sharing for crop such as coffee.

Prip and Rosenthal (2015) reviewed the use of Nagoya Protocol in provider and user countries. They concluded that while ABS regimes had existed for more than 20 years, they had not generated the types and amounts of benefits that had been expected. The reasons for the limited progress have included the complexity of the ABS concept, rapid technological developments, low capacity in the developing countries, a lack of commitment from developed countries and constantly evolving international and national implementation efforts. They felt, however, that there were signs of emerging progress, especially in relation to capacity building and awareness. Pisupati and Bavikatte (2014) argue that ABS should be approached as a business model that could incentivize a stream of revenue for conservation and sustainable use of biodiversity, rather as solely a regulatory system for preventing biopiracy. Prip and Rosenthal (2015) indicated that there was a need to do much greater research on how, and the extent to which, ABS is applied on the ground and its consequences for equity and conservation. This research is critical to develop clear ABS regimes and alternative approaches for crops such as coffee, especially if it continues to be excluded from *Annex 1*.

As part of this study, a Users' Survey was sent out to selected users of coffee germplasm to better understand how coffee genetic resources are being used. In general, the international collection held by CATIE in Costa Rica served as a key source of germplasm material for research and breeding programs. The use of germplasm in crop improvement programs addressed traits such as pest and disease resistance, yield, cup quality drought tolerance and physical traits such as bean size. Even though Arabica and Robusta varieties were of course the most frequently used materials, there was interest in using wild species in research and breeding programs. All respondents experienced challenges naviga-

COFFEE CAN'T BE FROZEN AND STORED IN GENEBANKS LIKE THE FREEZING ROOM FOUND AT CATIE PICTURED BELOW.

ting the policies and regulations with transfer of germplasm material between countries.

The Users' Survey identified that there is demand for easier exchange of germplasm for crop improvement between institutions and countries.

Clearly, any movement of plant materials between countries and/or regions should be done very carefully so as not to introduce a new pest or a different strain of pest to an uninfected region. Movement of coffee plant material is governed by national phytosanitary regulations that differ according to the risk assessed by each recipient country for each provider country. In some cases, this movement is not allowed due to significant risk to the local coffee production systems. Many countries require quarantine measures be taken as well. All of these regulations serve to further restrict the movement of coffee genetic resources and its use for varietal development.

One approach that has been used to manage the quarantine risk in crops like coffee, cocoa, and banana, is to utilize in vitro cultures that have been cleaned of diseases and viruses. Bioversity International and CacaoNet developed the Technical Guidelines for the Safe Movement of Cacao Germplasm in 2010 (End et al, 2010). This manual provides general recommendations for movement of cacao germplasm with an analysis of various options such as seed, budwood, bare-root plants, in vitro, pollen & open flowers, and flower buds. They provide a summary of pest risks by principal pests and by country and description of all known pests of cacao. A similar manual should be developed for coffee to enhance the movement and use of coffee genetic resources.

USE AND IMPACT OF COFFEE GENETIC RESOURCES

Early attempts to improve the performance of *C. arabica* depended mainly on selections of individual trees. In many coffee regions where both the Bourbon and Typica varieties were grown side by side, some degree of natural outcrossing has occurred leading to selection of higher yielding varieties such as Yellow Bourbon and Mundo Novo (Eskes and Leroy 2009). Increasing severity of rust lead to the planting of the rust resistant variety Coorg in the 1870s in India. Within a few decades, this variety became highly susceptible to rust, which was replaced in the 1920s by the offspring of a single rust-resistant tree, which was named Kent, which also lost its resistance in 10 years. These early programs resulted in the cultivars \`Mundo Novo\`, \`Caturra\` and \`Catuai\` from Brazil, \`Kents\` and S.795 from India, \`Blue Mountain\` from Jamaica, and several of these varieties are still under commercial cultivation. Subsequent derivatives of spontaneous crosses between *C. arabica* and *C. liberica* such as S288 and S795 have served as the basis for coffee breeding for rust resistance, with pioneer breeding work done in India which has been the basis for rust resistance studies carried out in Portugal at CIFC (Eskes and Leroy 2009).

The gradual spread of coffee leaf rust disease across the continents, Brazil (1970), Central American countries (1976), Colombia (1983), Papua New Guinea and Jamaica (1986) necessitated a shift the focus of arabica breeding towards rust resistance, worldwide. The appearance of Coffee berry disease caused by Colletotrichum kahawae in highlands of Eastern and Central Africa, first detected in Kenya during 1922 (McDonald, 1926) and its further spread to other countries in Africa like Angola, Cameroon (Muller, 1964), Uganda (Butt and Butters, 1966), Tanzania (Fernie, 1970) and finally in Ethiopia (Mulinge, 1973). In response to severe coffee berry disease epidemics in east Africa, breeding for host resistance in *C. arabica* to CBD was initiated in Kenya, Ethiopia and Tanzania about 40-45 years ago. This has resulted in release of resistant varieties such as Ruiru 11 in Kenya and Ababuna and other varieties in Ethiopia since 1985 (Van der Vossen & Walyaro, 2009).

Thus, in the period from 1950s to 1980s, the focus of coffee breeding was shifted to disease resistance coupled with productivity and quality. Its success could be largely attributed to the efforts of different coffee research groups across the continents to share and utilize valuable genetic resources (Meyer et al 1968, Guillaumet and Halle, 1978, Van der Vossen, 1985). During the period, several mutants of arabica coffee like \`Caturra\`, \`San Ramon\` and \`Villasarchi\` with agronomic significance and also the spontaneous hybrids of robusta and arabica like Hibrido de Timor (HdeT) and Devamachy (India) with high levels of disease resistance were identified. Exploitation of this new variability resulted in several compact cultivars viz., Catimor, Cavimor, Sarchimor, with high production potential and disease tolerance, suitable for high density planting. Thus, commercially cultivated arabica varieties across the coffee growing countries are predominantly derived from the natural interspecific hybrids and the cultivation of pure arabica varieties is very limited. The diversity/variability available within Arabica genetic resources have had limited scope for resistance breeding, although few collections were exploited for race specific breeding. In the future, these collections will provide greater scope for quality breeding.

Despite the challenges there have been successful use of coffee genetic resources in breeding programs. The Instituto Agronomico de Campinas (IAC) in Brazil initiated its breeding program almost 80 years ago, with about 90% of *C. arabica* areas in Brazil utilizing cultivars released by IAC (Nass et al. 2012). Another example of the successful use of coffee genetic resources in breeding is the development of the coffee leaf rust resistant multi-line variety, Castillo, by the Centro Nacional de Investigaciones de Café (CENICAFE), Colombia.

Since 2009, over half of the 600,000 ha planted with susceptible cultivars have been replaced with this new resistant cultivar. This has enabled a significant reduction of coffee leaf rust incidence nationally, from 40% in 2009 to 3% in 2013 (Avelino et al. 2015). In the context of changed climatic conditions and high flare up of diseases and pests, breeding for durable host resistance and climate resilient varieties is the current thrust of arabica coffee breeding. At present, the resistance breeding programs are centered on a few spontaneous tetraploid interspecific hybrids like HdeT (CIFC 832/1; CIFC 832/2, CIFC 2570 and CIFC 1343). Thus, from a breeding perspective, in addition to *C. arabica* and other diploid species, it is important to collect, characterize and conserve the variability among tetraploids generated as a result of natural introgression with diploid genomes. In this regard, re-exploration of Timor Island is one of the best options where the HDT derivatives are under commercial cultivation in the plantations. Further, the areas where arabica and diploid species like Robusta and *C. liberica* are cultivated in same vicinity provide the opportunity for identification of new spontaneous hybrids/new variability. Exploitation of diploid species (other than *C. canephora*), for arabica improvement is very limited. 'Aramosa' of Brazil and Ligenioides of India are few such varieties. Planting of diploid interspecific hybrids (F1s) in tetraploid fields has resulted in generating some interesting variability in India, by natural out crossing (S. Prakash, personal communications).

Conventional breeding of coffee presents challenges due to the long generation time of the coffee tree (i.e., approximately five years), the high cost of field trials (Lashermes et al. 2000b), and dependence on specific environmental conditions for selection. In cases where backcrossing is done over five generations, a minimum of 25 years after initial hybridization will be required to ensure that the desirable trait for improved quality or disease or pest resistance has been assimilated in the progeny (Lashermes et al. 2000b). The development of marker-assisted selection (MAS) provides an alternative to overcome the limitations of conventional coffee breeding (Lashermes et al. 2000b). The general principle of MAS is the use and selection of an identified molecular marker linked to a gene for a specific trait rather than selection for the trait itself (Lashermes et al. 2000b). In coffee, one of the main breeding objectives has been the transfer of desirable characters from diploid wild relatives into *C. arabica* cultivars without affecting quality traits (Herrera et al. 2002). The identification of markers linked to specific desirable characters represents an important starting point for early selection of seedlings with these specific traits through enhanced backcross programs (Noir et al. 2003).

Molecular genomics is expanding the scope for use of coffee genetic resources in breeding programs by facilitating the identification of sources of genetic variations previously unknown. Lashermes et al. (2009) concluded that the use of genomics will lead to rapid characterization of accession in genebanks; better management of germplasm resources; enhanced understanding of the genetic control of specific traits; identification of candidate genes or linked genes for important traits; and identification of accessions in germplasm collections with variants of genomic regions or alleles of candidate genes impacting a specific trait. The genotypic characterization of the genetic diversity of accessions held by collections can assist in their prioritization for conservation and utilization in crop improvement programs. Several genetic diversity studies of coffee collections have been published (Musoli et al. 2009, Teressa et al. 2010, and Zhou et al. 2016). Accurate genetic characterization of collections can lead to the development of core collections capturing optimal diversity, leading to improved germplasm management (Leroy et al. 2014).

In spite of the establishment of several genebanks in major coffee producing countries, each holding a diversity of germplasm materials, these resources are underutilized in breeding and research as documented in several countries. A comprehensive bibliography of the use and impact of coffee genetic resources held at Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) is available. The Centre National De Recherche Agronomique (CNRA) in Cote d'Ivoire has a publication listing all research conducted utilizing varied germplasm material held by the institution. To fully understand how all the other coffee collections are being used, a similar study needs to be undertaken for each genebank.

WHY A GLOBAL COFFEE CONSERVATION STRATEGY?

Compared to other major crops, coffee has lagged behind in the development of coordinated global or regional research and conservation programs. Vega et al. (2003) made a call for the establishment of an international coffee research development program to coordinate global coffee research efforts so as to avoid duplication of efforts and for the efficient use of scarce research funds. A meeting organized by the United States Department of Agriculture (USDA) in 2004 brought together scientists from the Centre de Coo-

A TABLE IS SET UP AT HACIENDA LA ESMERELDA FOR A ‘CUPPING’.

peration Internationale en Recherche Agronomique pour le Developpement (CIRAD, France), the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE, Costa Rica), USDA and representation from the Specialty Coffee Association of America (SCAA). The purpose of the meeting was to better understand how molecular biology tools could help the industry (Vega et al. 2008). Subsequently, in 2004, a call to establish an International Coffee Genomics Network (ICGN) was made by scientists from over 13 countries at the Association Scientifique International du Café (ASIC) conference in Bangalore, India (Vega et al. 2008).

Acknowledging the urgent need, the Inter-African Coffee Organization (IACO) and Bioversity International developed a proposal in 2009 to support the conservation and sustainable use of coffee genetic resources (IACO 2009).

The objectives of the proposal were: 1) to develop a conservation strategy; 2) to develop germplasm characterization, evaluation and documentation protocols; 3) to formulate a legal framework for property rights and access to germplasm and equitable benefit sharing; and 4) to establish two Centers of Excellence for capacity-building. Unfortunately, consensus among IACO member countries was not forthcoming and the project did not gain momentum and support (Kawuma, pers. comm.).

In 2010, after consultations with numerous stakeholders from the entire coffee value chain, the Global Coffee Quality Research Institute (GCQRI) was born, to address the needs of the coffee community through coordinated research. In 2012, GCQRI was incorporated as World Coffee Research (WCR), a collaborative, not-for-profit 501(c)5 research organization with a mission to grow, protect, and enhance supplies of quality coffee while improving the livelihoods of the families who produce it. The program is funded and driven by the global coffee industry, guided by producers, and executed by coffee scientists around the world.

In 2016, WCR and the Global Crop Diversity Trust spearheaded the development of the Global Conservation Strategy for Coffee Genetic Resources. The Global Crop Diversity Trust (Crop Trust) is an international organization working to safeguard crop diversity, forever.The Crop Trust is recognized as an essential element of the funding strategy of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), an agreement that has been ratified by 135 countries. In addition, the Crop Trust has spearheaded the rescue of nearly 80,000 crop varieties through collaboration with more than 100 institutions in more than 80 countries. Together with the Government of Norway and NordGen, Crop Trust funds the ongoing work of the Svalbard Global Seed Vault, a safe and secure back-up facility in the permafrost that conserves 860,000 samples of crops from all over the world.

Through engagement of multi-national stakeholders from various aspects of coffee production, processing, breeding, conservation and research, the goal of this Global Strategy for Coffee Genetic Resources is to ensure the long term conservation and use of coffee genetic resources for a positive, sustainable future of the crop and for those dependent on coffee for a livelihood. The Strategy will act as a framework for bringing together stakeholders at all levels – local, regional, national and global – in building long-term support through greater awareness, increased capacity, greater community engagement, and sustained funding.

STATUS OF THE MAJOR *EX SITU* COFFEE COLLECTIONS

Ex situ collections of coffee genetic resources conserve diversity for the long term but also increase the availability of these resources for the users. A number of field genebanks are located around the world, but limited assessments have been done of how these genebanks are currently operating, and the extent of the diversity conserved.

Annex III gives a compilation of reports on coffee collections from Bettencourt and Konopka (1988), Dulloo et al.(2009), FAO-WIEW database, Eira et al. (2007), Labouisse et al. (2008), and Phiri (2013). Altogether, the reports identify a total of 52 institutes holding coffee collections with at least 10 accessions. The numbers of institutes holding collections as well as the number of accessions are inconsistent across reports.

Bettencourt and Konopka (1988) assessed collections held by 16 institutes in 14 countries for a total of about 16,000 accessions. In general, the numbers of institutes with collections and the total number of accessions held have increased since the 1988 assessment. The genebank at USDA-ARS in Kona, Hawaii was reported to hold a collection in 1998 but there is no report on its status since then. The genebank at IAC in Brazil as well as at EIB and JARC in Ethiopia have significantly increased the size of their collections since 1998. Overall, there has been a 70% increase since 1998 in the number of institutes who have been reported to hold coffee collections *ex situ*. For example, Eira et al. (2007) report on all coffee germplasm collections held in Brazil, including three institutions with 3,535 accessions that had not been reported previously. Phiri (2013) reported on rehabilitation of genebanks in Uganda and Zimbabwe that had not been reported in the past. Thus, there is little evidence of significant loss of collections conserved *ex situ* since1988, but more evidence that the number of collections have increased significantly. This increase in the number of genebanks does not necessarily indicate an increase in the level of genetic diversity conserved overall since many of these increases could be due to duplication of accessions conserved by other genebanks or the increased conservation of related breeding lines.

In the assessment done by Bettencourt and Konopka (1988) on the status of *ex situ* collections, they documented the focal point or curator for the collections as well as the contacts for the institutions. They gave a general description of the inventory for each collection and the status of the collection. This consisted of a general description of the maintenance of the collection, safety duplication arrangements, availability, quarantine or phytosanitary requirements, a description of evaluation that have been done, and documentation systems. Most of the collections maintained accessions as trees but there were a few who used seed storage as well, such as IAC in Brazil, CATIE in Costa Rica, IRCC (now CNRA) in Cote d'Ivoire, PGRC (now EBI) in Ethiopia, CRF in Kenya, and TARO in Tanzania. All the genebanks except in the DRC distributed seeds once the institute or government gave approval. Most of the collections were duplicated at other genebanks, except CENICAFE in Columbia, JARC in Ethiopia, and TARO in Tanzania. No information was given on duplication for CATIE, University of Hawaii, and INERA in DRC. All of the collections had been evaluated for many important traits. The documentation systems were largely incomplete.

There has also been more limited assessment of collections, such as Eira et al. (2007) for Brazil or Phiri (2013) for three collections in Africa, but no comprehensive global survey has been done since 1988. Therefore, an assessment was done of coffee *ex situ* collections as input for this Global Coffee Conservation Strategy. The assessment consisted of a survey of the status of major coffee collections; site visits to7 of these collections; and a study of the cost of conservation for the CATIE collection. The main objectives of these assessments were to understand the security of the current conservation system, identify any significant gaps or redundancies, estimate its resource requirements, and assess the significant constraints as well as opportunities from use.

SURVEY OF COFFEE *EX SITU* COLLECTIONS

The survey was addressed to curators of coffee collections in 32 institutions around the world. We targeted not only big collections but also small and medium sized collections in coffee producing countries. We included collections conserving a diversity of *Coffea* species. We sampled collections located in different regions around the world to insure geographical representation. A total of 16 centers responded but not all of the genebanks completed the survey or all its questions. For example, the research team that visited the CENICAFE genebank in Colombia collected detailed information about the center that addressed specific questions in the survey but a formal survey was not completed.

The survey was divided into 10 sections. The initial sections asked for: updated contact information; basic data on the collection such as years of operation, composition and number of species represented; and legal and governance information. The next sections covered genebank operations such as: evaluation/characterization, information management, distribution/exchange, and risk management. In the last two sections, we collected information about staff, their training needs, and funding.

The total number of accessions held by the genebanks who responded is 21,026 (*Annex III*). The individual field genebanks cover areas from 1 to 51 ha. The oldest collections were established in the 60's, with more recent collections established in 2005 and 2015. Only 5 of the genebanks are specialized on conservation of coffee germplasm. The institutions that host collections are located in Africa (Kenya, Cote d'Ivoire, Ethiopia, Madagascar and Reunion), the Americas (Mexico, Costa Rica, Brazil, Colombia and Peru), Asia (India and Vietnam), and the Asia Pacific (Papua New Guinea and Australia) regions. All the institutions surveyed are legal owners of more than 90% of the materials of the collections. Only two institutions reported the existence of other legal owners of the collection. Most of the institutions are responsible for management decisions regarding the collection.

As expected, *Coffea* arabica has by far the largest number of accessions conserved (See *Annex II* for a complete list of *Coffea* species), but there is significant conservation effort devoted to other *Coffea* species. Some genebanks, like KALRO in Kenya, also had significant numbers of intra- and interspecific crosses. The total number of accessions in Table 2 differs from the total in Annex 2 because CENICAFE provided the total number of accessions but failed to disaggregate by type of material. Thus, we could not account for the 800 accessions from CENICAFE in this estimation, although CENICAFE does hold materials of *C. arabica*, *C. canephora*, *C. eugenioides*, *C. liberica* and some other wild materials.

TABLE 2. MATERIALS CONSERVED IN THE GENEBANKS SURVEYED

SPECIES	NO. ACCESSIONS	PERCENTAGE
C. arabica	11,415	57.2%
C. canephora	625	3.1%
C. liberica	94	0.5%
C. eugenioides	81	0.4%
Other Coffea sp.	7,756	38.8%
TOTAL	**19,971**	**100%**

Institutes in Africa highlighted the conservation of wild materials and the diversity of materials held in their field genebanks. Centers in the Americas, particularly in Brazil, in contrast, hold a number of important breeding materials.

The germplasm held in collections came from many sources, but the majority had accessions acquired from national collections, breeding programs, and other genebanks (Table 3). Six genebanks held material that had been acquired from the FAO/IPGRI collection trips.

TABLE 3. NUMBER OF GENEBANKS IN A REGION THAT ACQUIRED ACCESSIONS FROM DIFFERENT SOURCES

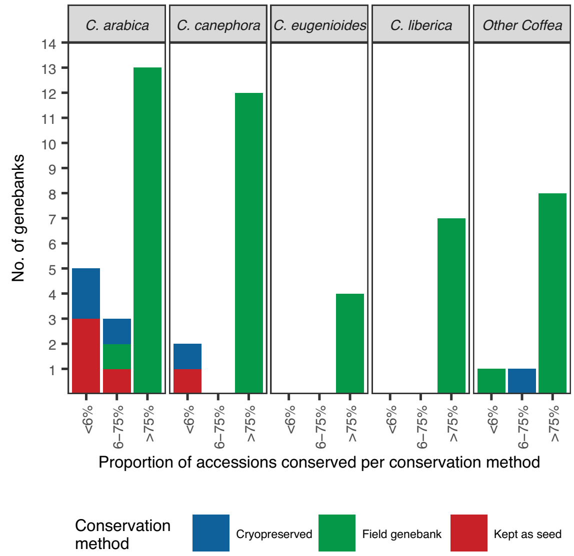
REGIONS	FAO / IPGRI	NATIONAL COLLECTOR	EXTERNAL COLLECTOR	INSTITUTIONBREEDING PROGRAM	ACQUIRED FROM OTHER GENEBANK	ACQUIRED FROM BREEDING PROGRAMS	UNKNOWN SOURCES	OTHER
ASIA / PACIFIC (2)	1	1	1	1	2	2	1	0
AFRICA (5)	2	5	2	2	2	3	0	0
AMERICAS (7)	3	6	5	5	6	5	4	4
TOTAL	**6**	**12**	**8**	**8**	**10**	**10**	**5**	**4**

Of the 21,026 accessions that are held by the genebanks participating in this survey, about 9.5% have been collected in the past 10 years, while 8.8% have been acquired in other ways in the same period. Most of the new acquisitions were by EPAMIG in Brazil, which is a relatively new genebank. Some of the gaps in the collections identified were Mascarocoffea species, domesticated materials from Yemen, and leaf rust differentials. There are some wild species that need to be collected from the wild in Kenya (*C. racemosa*, *C. rhamnifolia*, *C. pseudozanguebariae*, *C. fadenii*, *C. eugenioides*), Madagascar (see *Annex II*), Papua New Guinea (*C. brassii*), India (Psilanthus species recently classified under Coffea, like *P. benghalensis*, *P. travancorensis*, *P. wightiana*), Cote d'Ivoire (*C. liberica*, *C. stenophylla*, *C. humilis*), Reunion (endemic species from Reunion and from Mayotte), and Ethiopia..

Also, across centers, 1,314 accessions have been lost in this period, equivalent to almost 6.4% of the total number of accessions held. Eight of the 14 genebanks who responded to the survey question reported a decrease in the number of accessions; either the accessions were lost or they were removed from the collection. In most of the cases, the loss was less than 25% of the total number of accessions held in the genebanks. Seven genebanks increased the number of accessions by acquiring or collecting new accessions; four acquired more than 25% of the number of accessions held in the genebank.

The most widely used conservation method across collections for all Coffea species is field genebanks (Figure 1). Five genebanks report conserving up to 25% of their accessions of *C. arabica*, *C. canephora*, and other wild Coffea species using cryopreservation of seeds, embryos or other tissue or cold storage of seeds. CATIE used to maintain a small collection under cryopreservation, but USDA currently hosts it. The survey did not request specific information on the type of seed, embryo or other tissue that was being cryopreserved.

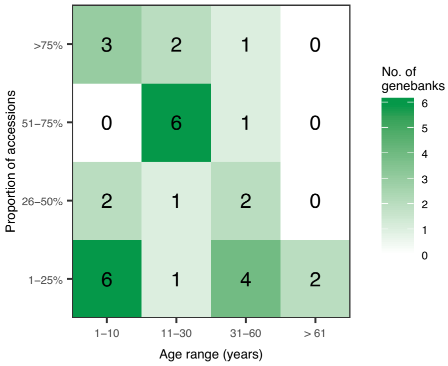
FIGURE 1. NUMBER OF GENEBANKS AND THE PROPORTION OF THEIR ACCESSIONS THAT ARE CONSERVED UTILIZING SPECIFIC METHODS ACCORDING TO SPECIES



In most cases, an accession started as a heterogeneous sample of seed harvested from the original population at the time of collection. A sample of this original seed is planted to establish the accession in the field genebank. Thus, the degree of diversity maintained from the original population is dependent upon the number of trees harvested during collection of seed and the number of seeds established as trees. This sub-sampling will have an impact on the long-term genetic diversity within an accession. For several genebanks, the ideal number of trees/accession is 10. On average, 71% of the accessions in the field genebanks are represented by at least 2-10 trees. There is, however, a significant proportion of accessions (11%) that only have 1 tree in the field, though there is significant variation across institutes. The genebank managers explain that the decision on the number of trees per accession is based on the recommendation in the literature but also the area available. Genebanks utilizing cuttings for replanting tend to have between 3-10 trees per accession. There is no agreement on the best practice on the number of replicates of trees within an accession. In general, the higher the number of trees per accession, the lower the risk of loss of genetic diversity but the higher the field maintenance costs. Institutes with older trees reduced the risk of losing an accession by having a higher number of replicates from cuttings or establishing more trees from seed.

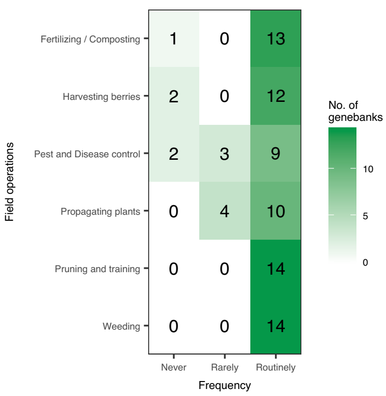
The age of trees has an impact on the production of flowers, pollen and seed. As trees age and die, there is a risk of loss of diversity within an accession. The need to replace trees can also lead to loss of genetic integrity of an accession from contamination or cross-pollination with unrelated neighbors. Of the 14 genebanks surveyed, seven have accessions with trees that are more than 30 years old. Ageing of trees is critical for a few of these collections, such as FOFIFA in Madagascar with more than 75% of the accessions with trees that are 31-60 years old or CATIE and KALRO in Kenya who have 5-9% of the trees that are >61 years old (Figure 2).

FIGURE 2. NUMBER OF GENEBANKS WITH A PROPORTION OF ACCESSION WITH TREES OF SPECIFIC AGE CLASSES



Field maintenance is the most important and resource demanding operation of a field genebank. Weeding, fertilization, pruning, pest and disease control, propagation and harvesting of berries are the most common agronomic practices in coffee. Weeding, pruning and training are routine operations for all the collections surveyed (Figure 3). Fertilization and/or composting are also a common practice, except in Madagascar. Pest and disease control, although important, is not done in all the centers. Some institutions indicated that they do not control diseases to allow breeders to observe which accessions are resistant or tolerant. Two centers do not harvest berries and four other centers rarely propagate plants. Genebanks fail to perform these practices routinely due to reasons that varied from limited funding, limited by organic certification schemes, or the need to fit with breeding strategies.

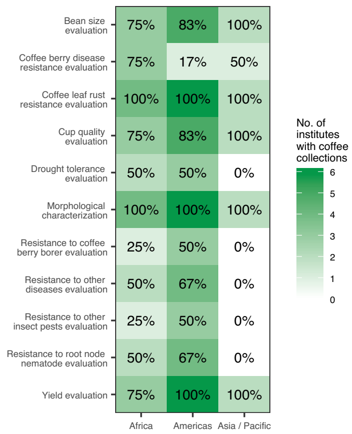
FIGURE 3. THE NUMBERS OF GENEBANKS THAT ROUTINELY, RARELY, OR NEVER CONDUCT THE SPECIFIC FIELD OPERATIONS



At least half of the genebanks state that they have written protocols for most key operations. Fewer than half have protocols for maintenance of the collection in vitro. Most of the genebanks indicated that the protocols would be available if requested.

All twelve institutes who responded to the question on characterization and evaluation stated that they do morphological characterization of the materials in the field (Figure 4). More than 80% of the institutions did evaluation of yield, bean size, cup quality and resistance to coffee leaf rust. Five out of 12 genebanks evaluate tolerance to abiotic stresses such as drought. Half of the genebanks evaluated resistance to root knot nematode. The other diseases evaluated for were resistance to bacterial blight, coffee wilt, canker (Ceratocystis fimbriata), and American leaf spot (Mycena citricolor). The major insect pest evaluated was for resistance to coffee berry borer.

FIGURE 4. THE NUMBERS OF GENEBANKS THAT PERFORM MORPHOLOGICAL CHARACTERIZATION OR EVALUATION FOR SPECIFIC TRAITS IN EACH REGION



Few genebanks are currently doing molecular characterization and therefore only a small number of accessions have been genotyped (Table 4). The average proportion of accessions characterized across centers was estimated using the number of accessions held at each collection. The average proportion of accessions assessed is very low but the results of these assessments are being widely shared in peer-reviewed publications.

TABLE 4. THE NUMBERS OF ACCESSIONS, THE NUMBER OF GENEBANKS, AND THE AVERAGE PROPORTION OF THE COLLECTION THAT HAVE BEEN GENOTYPED, AS WELL AND THE NUMBER OF PUBLICATIONS REPORTING ON THIS GENOTYPING

MARKERS	NO. OF ACCESSIONS	NO. OF GENEBANKS	(1) AVERAGE PROPORTION ACROSS COLLECTIONS	PUBLICATIONS
SSR	1,029	5	13.26%	> 18
AFLP	122	3	8.54%	4
RAPD	193	2	13.46%	2
SNPs	888	3	17.60%	5

(1) The average proportion across collections is the percentage reported for each marker type in each collection divided by the number of genebanks reporting.

Information maintained on accessions can include passport (including taxonomy), characterization, genotypes, images and evaluation data, but not all the centers have all this information for all accessions (Table 5). Most of the genebanks indicated that they have a database where they store mainly passport, taxonomy, characterization, and evaluation data. Some centers indicated they also have genotyping data and images. This database is often in the form of Microsoft Excel files that are searchable but with limited user friendliness. Only CATIE has a publicly available database through Genesys, *https://www.genesys-pgr.org/wiews/CRI001/overview*.

TABLE 5. THE NUMBERS OF GENEBANKS IN EACH REGION WHO HAVE ACCESSION LEVEL INFORMATION IN A SEARCHABLE DATABASE THAT CAN BE ACCESSED EXTERNALLY OR INTERNALLY.

INFORMATION		AFRICA (5)	AMERICAS (6)	ASIA / PACIFIC (2) PUBLICATIONS	NO. GENEBANKS
Accession level information	Characterization	2	5	2	9
	Passport	3	4	1	8
	Taxonomy	4	3	2	9
	Genotypes	1	2	2	5
	Images	1	1	2	4
	Evaluation	2	4	2	8
Is data in a searchable database?	Passport	3	3	0	6
	Is data in a searchable database?	2	2	0	4
The information/ database is:	Public	1	0	0	1
	Internal	3	5	2	10

Ten out of the 13 genebanks distributed accessions from their collection. FOFIFA in Madagascar indicated that it would currently distribute DNA or pollen samples but not live plant material. EBI in Ethiopia indicated that distribution outside the field genebank site was currently not allowed but they did allow researchers to utilize the material onsite, especially students from Jimma University. IRD in Reunion indicated they did not do distributions of the accessions due to "lack of staff". The genebanks were asked if they did distributions outside the country subject to the terms and conditions of international regulations like the Nagoya Protocol or ITPGRFA using the SMTA or institutional Material Transfer Agreements. UACH in Mexico and CIC in PNG did not indicate any of these agreement types for external distributions. CATIE and EPAMIG in Brazil utilized the SMTA while 5 genebanks indicated they only utilize institutional MTAs. ICAFE in Costa Rica stated that they use all three types of agreements. However, the annual distribution of accessions is low both within and outside the country in all the genebanks. The total annual distribution inside the country represents only 8% of the total number of accessions held in the genebanks surveyed. Outside the country, this figure is even lower, accounting for less than 1% of the accessions held in the genebanks. A couple of countries mention that they have not received requests for their materials from international institutions.

Coffee accessions are mainly distributed as seeds. There is no distribution of tissue culture materials. Very few centers distribute pollen, DNA samples or rooted trees. Across genebanks, farmers or farmers' organizations are the main users (39%). Distributions outside the countries are mainly done for research purposes. Distribution to breeding programs accounts for 15% of the total. There is no reported distribution of materials to industry, either inside or outside the country.

Coffee genebank collections are exposed to diverse risks, from extreme climatic events to lack of priority from local authorities (Table 6). Unstable funding limits the mitigation measures that the genebanks can take to manage these challenges. For instance, the collection in CATIE has a backlog in the rejuvenation of the accessions but funding limits their ability to address this. There are also significant number of pest or pathogen threats listed by the genebanks. Some of the prevention measures being taken against biotic and abiotic stresses include frequent monitoring, irrigation, fertilizer application, shade provision, chemical protection, integrated pest or disease management and trapping .

TABLE 6. THE RISK FACED BY COFFEE GENEBANKS

RISK	RESPONSES
Primary threats to the collection	• Extreme weather events, such as cyclones and hurricanes • Poor soil health • Pest and diseases (Coffee Leaf Rust, Coffee Berry Borer) • Funding, lack of resources • Accidental losses, fire • Lack of interest or commitment • Age of the collection • Organic certification
Primary diseases/ pathogens	• Fusarium • Root and bark diseases, • Coffee Leaf Rust • Coffee Berry Borer • Stem borer, Scolyte, • Coffee berry borer (Hypothenemus hampei) • American leaf spot (Mycena tricolor) • Nematodes

Eight out of 10 genebanks have safety duplication of their collection in another field site in the country, but no institution has a field genebank duplicate outside the country. Only three institutions use long-term seed storage as a safety duplication strategy, and only one has used cryopreservation to any significant degree. Currently, there is no institution using tissue culture to safety duplicate coffee genetic resource. All in all, the proportion of accessions safety duplicated across collections varies from 1 to 60%. There is no institution storing DNA samples to facilitate the use of the collection for molecular studies.

As expected trained scientific staff with higher degrees mainly manage the genebanks. There is a perception that genebank staffs are adequately trained in at least half of the genebanks surveyed (Table 7). Staff retention is not perceived as a limitation in at least four of the centers. On the other hand, four centers mentioned that their staff is close to retirement and there is a need to attract and train younger staff.

TABLE 7. THE AVERAGE NUMBER OF SPECIFIC TYPE OF STAFF ACROSS ALL GENEBANKS AND THE NUMBER OF GENEBANKS WHERE THEY INDICATED THE STAFF WAS ADEQUATELY TRAINED.

TYPE OF STAFF	NO. STAFF	NO. GENEBANKS WITH STAFF ADEQUATELY TRAINED
Research /Technical Staff (PhD)	0.92	6
Research /Technical Staff (MSc)	0.77	5
Research /Technical Staff (BSc)	0.69	7
Field staff	3.38	7
Other	6.46	6

Except for a couple of cases, the funding to cover genebank operations comes from the holding institution itself. For 7 of the 16 centers surveyed, funding has decreased in the last 5 years, while 4 centers report an increase in funding. Many of these institutions generate additional revenue from harvesting and selling berries (7 genebanks), processing and selling green beans (3 genebanks), and selling planting material to producers (4 genebanks). These activities on average could cover from 2 to 35% of the conservation costs, depending on the genebank. There were a few other activities that generated income, including an industry levy for exporting coffee, a commercial nursery, and ecotourism.

SUMMARY OF SURVEY RESULTS

In conclusion, the picture that emerges from the genebanks who responded to the survey is that the overall status of global *ex situ* conservation of coffee genetic resources is insecure, with limited knowledge or use of the accessions of these collections outside the institutes. These genebanks mainly hold accessions of Arabica acquired from the FAO/IPGRI collections in the 1960's, from other genebanks, and from breeding programs. A limited pool of Arabica accessions from Ethiopia is represented in most genebanks. EIB in Ethiopia has increased the diversity held from farmers' fields and *in situ* sites, but this is not globally available. Genebanks do continue to increase the number of accessions but to a very limited degree.

Coffee conservation is mainly done in field genebanks, with a limited use of complementary approaches such as seeds or cryopreservation of seeds, embryos or other tissue. The risk of loss of an accession from small number of trees or older trees is low for most of the genebanks. Field maintenance operations are adequate but the degree of weeding, pruning, or protection from pest depend upon having adequate funding for these operations. Collection of accession-level information, such as characterization and evaluation, is a standard practice across genebanks but there is limited access to this information both internally and externally to enhance the use of the accessions.

Most of the genebanks do intend to distribute accessions upon request, but it seems there are few requestors, nationally or internationally. There are also significant barriers to exchange, both with regards to ABS and phytosanitary regulations, as well as lack of access to accession level information The CATIE collection is accessible globally but still not well known. The IRD collection in Reunion is fairly global but there is limited accession level information available and no distribution due to limited staff.

Overall, the field genebanks face significant threats with very limited safety duplication at other sites as well as complementary use of cryopreservation or seed conservation. Most of the genebanks are facing future challenges with staff changes and funding. They depend upon the allocation of an adequate operational budget from the host institute. This annual allocation can be inadequate and insecure, with an increased risk to the long-term sustainability of the collection. There are some key collections that did not participate in the survey (Cameroon, Uganda, Tanzania, DRC, Angola, Guinea, and the Jimma Agricultural Research Center in Ethiopia), so their status is unknown to us at present. However, in the past they have been recognized as holding collections of unique local accessions.

VISITS TO COFFEE *EX SITU* AND *IN SITU* SITES

Site visits were conducted from July 17 to August 17, 2016 to seven coffee field genebanks, an in situ site for *C. arabica*, a private collection in Panama, and farmers' fields in Cote d'Ivoire.

The countries visited were Madagascar, Kenya, Ethiopia, Cote d'Ivoire, Costa Rica, Panama, Colombia and Brazil. The team was unable to schedule a visit to India but received a detailed report that it utilized. The site visit team would like to thank all their hosts in these visits. The objectives of the site visits were:

- To better understand the history of the collections and their current composition;
- To become more familiar with the management of the field collections and the various operations in its maintenance, rejuvenation, and distribution;
- To become familiar with the past use of the accessions and their future focus in terms of use within their own institute and by external users;
- To identify key gaps in their collections, including composition, exchange, and operations;
- To identify future opportunities for their collections and their genebank;
- To identify the various threats they were facing for the conservation and use of the accessions; and
- To identify the highest priority needs for coffee genetic resource conservation globally and/or within their collection

FOFIFA KIANJAVATO COFFEE RESEARCH STATION

MADAGASCAR

The field genebank in Kianjavato was established in 1954 with the main aim of improving *C. canephora* (robusta coffee) through selection, making improved genotypes available to coffee growers in the Southeast part of Madagascar, and serve as a resource on improved cultivation practices. Two additional genebanks were also established in Ilaka Est. in Vatomandry, where Mascarocoffea were duplicated, and in Fianarantsoa in the highlands at 1,300 meters for *C. arabica* and trihybrids. In 1960, the Food and Agriculture Organization of the United Nations (FAO) initiated collecting of wild Malagasy species for ex situ germplasm preservation, which was continued until 1974 by French teams such as the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) and the Institut de Recherches du Cafe, du Cacao (IRCC). From 1974 to 1982, the Malagasy government funded FOFIFA to conduct coffee research and germplasm preservation. From 1982 to 2002, government funding stopped and the collections were maintained as best as possible with limited resources; during this period many individual plants were lost.

Since 2002, the Ueshima Coffee Corporation (UCC) of Japan has funded approximately 90% of the maintenance of the field genebank, allowing the preservation of this valuable germplasm resource. This collaboration with UCC ended in 2012 and so once again the collection maintenance is dependent upon the government as well as the Biodiversity Ecovolarisation et Cafeiers (BEC) Foundation and projects with their main partners, Dr. Perla Hamon and Dr. Serge Hamon in IRD in France. To build awareness of Mascarocoffea and the collections, the Biodiversity Ecovolarisation et Cafeiers (BEC) Foundation has published a book about Mascarocoffea, which is available for purchase online at: *http://biodiversite-ecovalorisation-madagascar.e-monsite.com/*. There is some coffee production in the area and farmers do come to ask for seeds or plants. They even produce some controlled pollinated hybrid seed. These are mainly small development schemes that are short-term projects, unfortunately when they end there is little long-term benefits to coffee production locally in Madagascar.

They have expanded the conservation at the site to include other crop species of importance, such as vanilla, banana, pepper, guava, and other fruits. This is being planted adjacent and within the coffee accessions. They have initiated the development of educational opportunities with schools in the local community. They teach and do hands-on demonstrations with children on propagation and replanting in the forest. Generally, protecting the collection has resulted in the protection of the forest and the animals that move in from disturbed adjacent areas.

The Kianjavato collections consist of accessions of 44 species of endemic Madagascan Coffea spp. A few species have been lost in recent years, which include accession of C. humblotiana, C. mauritiana, C. vohemarensis and 9 spp. belonging to the Baracoffea group. These species do not grow well in the humid climate of Kianjavato since these are from the dry regions of Madagascar. There is a FOFIFA station in Mahajanga, in west Madagascar. The climate there would be much more conducive for growth of these species and they would like to be able to look into the possibility of establishing a genebank there for holding Baracoffea collections.

There were some *C. canephora* in Ilaka Est, which is about 250 km north of Kianjavato. This station existed for 47 years. The original *C. canephora* collection consisted of 79 selections and 3,000 clones. Mascarocoffea were also duplicated in this location, but they are not sure what condition they are in today. Since World Bank funding ended in 1985, the station has not been managed at optimal conditions, leading to encroachment by squatters who have cut down trees and planted other trees. No work is being done currently at this site. There are possibly only five species remaining after these collections were lost due to a typhoon and lack of funding.

At the Fianarantsoa site, north of Kianjavato at a higher altitude, the collection consists of 89 accessions of wild *C.*

arabica and 68 accessions of cultivated types. This site also consists of 22 back-up accessions of the FAO collections from Cote d'Ivoire and Ethiopia.

THREATS

- The biggest concern with this collection is the loss of genetic integrity caused by their method of replacing lost plants with trees propagated from open pollinated seeds. Hybridization has been documented among the diploid species and replacement plants have lost their original species genetic makeup, leading to genetic erosion.

- The collections at the two remaining sites are at risk due to the low level of support both nationally and internationally. Nationally, there is no priority for coffee improvement and the indigenous species conservation. Internationally, there is low level of interest in conservation or benefit sharing from the use of this wild germplasm.

- Deforestation is a serious threat for the species they conserve. Recollections are not possible for many of the accessions they hold since the forests have disappeared. Securing their conservation is imperative since they could be conserving the only live trees of these species globally. In addition, this collection will be a very important resource for reforestation in the future.

- Encroachment of research station by squatters as well as mining rights being given for gold and precious stones in the area adjacent to the research station.

- Loss of knowledgeable staff to retirement and better career opportunities.

OPPORTUNITIES

- With a couple of exceptions, all Mascarocoffea are caffeine free. They are focused on breeding for no caffeine with crosses with the Madagascan species. They feel that finding unique use of the Madagascan species is critical for their station and they intend to license the technology, if possible, to sustain conservation of the collection.

- Currently they do not distribute live plant material for research or exchange, but they will send DNA or pollen. They think that the global conservation system will work if sharing of funds, technology, and other benefits are distributed in a balanced way. Many genebanks are both conservers and users of genetic resources. They consider there is a need to ensure countries are able to benefit from any technology and material developed from the use of local germplasm in their own country development.

- The national criteria for protection of forests are the number of species not the diversity of any single species or the value of specific species, such as coffee. The staff has expertise in these very important indigenous species and should be involved in any of the planning for reforestation or protected areas. Thus, there is a need for an assessment to be made of the status of the Madagascan species in protected areas and do recollection, if still possible.

- No one knows about this collection in Madagascar so they do not have users, but the collection could be a very valuable source of germplasm for restoration and education efforts. While the accessions of this collection could be used for reforestation, not all grow well at the two current sites. It would be very useful to have other crop-focused stations of FOFIFA in the dry areas grow these species to help insure conservation.

- Clonal propagation can be used as an alternative to the use of seeds in reforestation schemes or as planting material in tourist gardens. The station has the facilities and expertise on clonal propagation that could be utilized for planting material, research, and education

- The station could be developed as an area for tourists showcasing the cultivation of coffee, vanilla, and other food plants. The protected site of the station is currently the home to local biodiversity that is disappearing in adjacent areas. They have facilities to host tourist as well. There is no tourism there yet or links with reforestation projects but this is a future opportunity.

- There is great interest amongst the staff to get involved in the education of students about the natural history of the area. This offers the station an opportunity to engage the local community and youth in conservation through education and outreach. Since 2014, school students have been coming to the station to learn about the importance of forests and reforestation. Students are taught propagation techniques. They could expand this effort to also serve as an education resource for local farmers.

PRIORITY NEEDS FOR THE NEXT 10 YEARS

- There is an urgent need to secure the conservation of the current collection at Kianjavato. FOFIFA and the Government of Madagascar need to allocate an adequate annual budget for operation and trained staff at this site. The site needs to be secured against encroachment and improvements made to facilities to allow for greater collaboration and use of the collection, its facilities, and its expertise. The establishment of additional field collections at FOFIFA stations in drier environments should be a priority to secure at-risk species.

- They have staff training needs for advanced degree and technical skills development in collection management.

- A thorough examination of accession records for the currently planted trees should be undertaken to determine what percentage of the original population still remains in the field. These trees could have originated as either trees established from the original in situ seed collection, or trees established from original trees by vegetative means. Based on this a replacement plan should be developed to replace possibly hybridized material through proper propagation techniques. In the future all replacement plants should be propagated either clonally (through cuttings or tissue culture) or through seeds generated by controlled pollination.

- There is a need to conduct research on propagation approaches such as cuttings or grafting since many of the wild species will not root from cuttings easily.

- There is a need to invest into documentation databases and global sharing of accession level information on the collection to encourage greater use.

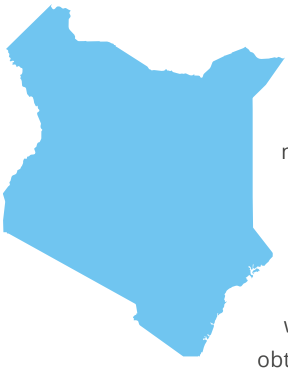
- An assessment needs to be made of the status of the Madagascar species in protected areas as well as other areas to determine their conservation status, both ex situ and in situ, and ensure they are securely conserved in the ex situ genebanks.

- The genebank currently has 44 species but Madagascar has 61 species known in country, 59 are described and 3 are not. Thus, there is a need to collect and conserve an additional 17 species as a secure back up for the wild populations and to enable use.

- The collection and its expert staff need to be actively engaged with ensuring the conservation of the Madagascar species in protected areas and in the genebank. This requires an outreach of the institute to organizations and government departments involved in monitoring species in protected areas and planning reforestation schemes.

KENYA COFFEE RESEARCH INSTITUTE

KENYA



Kenya has a long history with coffee research, which dates back to 1908. The center for coffee was initially housed at the Scott Laboratory, now the National Agricultural Research Laboratory (NARL), located 6 km from Nairobi City Center. A coffee field genebank was established at the NARL. In 1944, the Coffee Research Station was established on land that had been obtained from the Jacaranda Estate near Ruiru, which is about 25 Km from Nairobi. The coffee field genebank was then established at this site in the 1960's and has continued operations to date. The Coffee Research Foundation operated the research station until about two years ago when there was an institutional restructuring within the Ministry of Agriculture. They are now the Coffee Research Institute (CRI) within the Kenya Agricultural and Livestock Research Organization (KALRO) that operates under the State Department of Crops within the Ministry of Agriculture, Livestock, and Fisheries.

The Coffee Research Institute has programs in breeding, chemistry (soil nutrition, processing and quality), agronomy, plant pathology, entomology, crop physiology, extension and economics.

The objectives of the breeding program are geared towards yield, quality, adaptability, and biotic and abiotic stress tolerances. The genebank is part of the breeding program. They have two breeders amongst the staff. The Institute comprises of two centers (Ruiru and Kitale) and five sub centers (Meru, Koru, Azania, Kisii and Namwela). Some of the accessions are duplicated in one or more of these sites. The total number of accessions in their conservation collection is 256.

Current coffee production areas near the main station in Ruiru are being threatened by urban expansion with many of the coffee plantations or plantings being neglected and sold for housing estates. There are still some managed coffee estates around the research station but many are in transition to housing. The main constraints for production are coffee berry disease and coffee leaf rust. The estates still have trees of old varieties developed in the 1930's but they are susceptible to major coffee diseases and slowly being replaced by resistant varieties that have been developed by the Institute.

CRI is not directly working on in situ conservation, but has been involved in collecting the coastal species, *C. pseudozanguebariae*. They have 25 plants from the collection, but need to collect more since there is a high risk of loss of these species in the forest. The coastal plants are located within coastal forests and in a community with a sacred grove and hence are currently protected. There is need to engage the community in making them aware of the population and its importance as well as to map the area for monitoring and collection. The National Museum of Kenya has mapped the *C. arabica* population in Mt. Marsabit and has herbarium specimens with GPS coordinates though they are not involved in monitoring the sites.

The germplasm collection is utilized for research and breeding purposes internally but they do not distribute the conservation collections. CRI has an interest to access new germplasm and is willing to share its own varieties. There is a national process in place for exchange with the new seed variety act. They have developed a draft transfer agreement that is linked to the phytosanitary permit. Initially it will be 'a research only permit' but if something is found of value for commercialization, they have to have another agreement

that will license varieties with royalties. They want to obligate recipients to not share germplasm with others. This will reduce the need to track exchange to secondary recipients. Anyone who wants to use the germplasm must access it directly from CRI. It is clear that access to germplasm needs to be discussed and conserved at global level.

THREATS

- They have offered many services to farmers most of which were free since they had a 2% levy for each kilogram of coffee sold that went to research and extension. This has been repealed since April 2016, so now they will have to charge farmers for every service. It now leaves uncertainty for the budget of the institute and the conservation of the collection.

- They concluded that access to new germplasm for utilization is an issue since initially genetic resources were freely available and they had trust in each other. Now no one is exchanging germplasm.

- In the past there was recognition that coffee leaf rust was a global problem that needed a global effort. In Portugal, the Coffee Leaf Rust Research Center (CIFC) was established to do the screening to identify new races. They held the differential varieties that were used to define races for rust pathogen populations. These are not being shared now but access to this germplasm is critical for screening for new races of the rust pathogen. They assume that their approach to conservation is allowing new races to evolve since the resistant accessions can be overcome with recombination happening amongst different races. Within their collection, they have six accessions with differential resistance to races but they do not have them all. This was seen as a key risk for their collections as well as coffee production globally.

- The IRD-CIRAD collections hold very valuable material that was collected from former colonies. Accessions that were collected nationally are no longer duplicated in country although there are remnants left in the collection site and they are being recollected. They have a concern about how the original germplasm can be accessed to fill the gaps in the original national collection.

- Much of Kenya and East Africa is predicted to see higher temperatures and less predictable rainfall patterns, especially for the coffee production zones. The changes in climate are already reducing productivity of coffee in the region. The current shift of coffee production from central Kenya to new areas where new biotic stresses are a challenge require programs to proactively manage leaf rust and other disease risks. This risk for the long-term conservation of coffee genetic resources from climate change is high, both ex situ and in situ.

- The protected in situ sites are being impacted by human activity so they can now only recollect from a very limited population that is now very dispersed. For example, they have only been able to locate a single tree in the area where a population was originally collected.

- There is a need for further collection of varietal diversity from farmers. The farmers are replanting with new varieties that are derived from a single clone. Thus the diversity within the fields is being eroded.

OPPORTUNITIES

- There is a need to research alternative conservation approaches, especially to conserve accessions in limited space. This could be through grafting accessions to a Robusta rootstock for greater drought tolerance and to manage other root problems.

- They have approval from their Director General to sell seeds of commercial varieties left after local sales to buyers outside Kenya. They have developed an MTA, which is ready for use.

PRIORITY NEEDS FOR THE NEXT 10 YEARS

- Safety duplication of the conservation collection

- Maintenance and replacement of old trees in the conservation collection

- Cryopreservation of seed or embryos, especially of the conservation collection

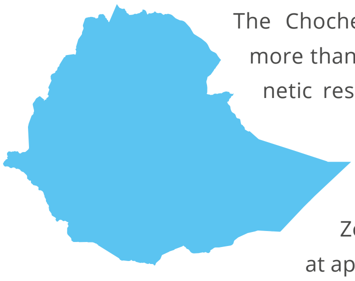
- Research and adoption of alternative conservation options

- Increase accession level information available and shared on the collection; including cup quality, genotypes, and CBD/ CLR resistance.

- Increased global sharing of accession level Information on accessions to facilitate the identification of useful accessions from others and to share their own germplasm. The access would have to be negotiated bilaterally, but coming to agreed standard terms could be possible with global discussion.

CHOCHE FIELD GENEBANK (ETHIOPIAN BIODIVERSITY INSTITUTE)

ETHIOPIA



The Choche Field Genebank was established more than 30 years ago to conserve coffee genetic resources of Ethiopia. It is the largest field genebank of the Ethiopian Biodiversity Institute. It is located in Oromia Regional State in Jimma Zone, Goma Woreda near Agaro Town at approximately 1,600 masl. It has a total area of 21 ha. It currently conserves 21 species of horticultural genetic resources, including *C. arabica*. Some of these, such as long pepper (Piper capense) and korarima (Aframomum corrarima) are conserved within the coffee accessions. These two species were also seen growing naturally with coffee in the understory in the Kafa Biosphere Reserve. The genebank mission includes conservation of indigenous germplasm and sustainable use.

The EBI has three locations at different agro-ecological conditions, Choche, Yayu, and Bedessa (Harar). In Choche, they currently have 4,592 accessions while in Bedessa, they have 830 accessions from the eastern part of Ethiopia, which is drier, and will not establish in Choche. All of the accessions at both locations were collected locally. Every year they make new collections from different areas. They collect from farmer's gardens, wild areas in forest, and commercial farms each year. They collect different plants from the same typology and agroecology so they identify the collection site and then sample for each accession. An accession is from one farmer plot but seeds are harvested from different plants to ensure they sample the local population. They collect seeds in Nov-December. In Choche, there are 39 new accessions from 2016 that still need to be planted.

They have established a new site in Yayu for collections from biosphere reserve and wild forest coffee areas from all over Ethiopia. They started last year with 72 accessions from the Yayu Biosphere Reserve.

The genebank does not distribute accessions since they have a sole objective to conserve and sustainably use local diversity. They have a key partnership with the Jimma Agricultural University. Distribution to local farmers is the responsibility of the Jimma Agricultural Research Center. EBI is open to distribution for research purposes but are not doing it now. They distribute for educational purposes. This has been done for research on the collection with students at Jimma University but the students come to the location to use the material and do the research.

Characterization, such as number of branches per plant, number of nodes, leaf color, etc., is taken once every 5 years. The accessions are not evaluated. In all cases, experts from EBI in Addis Ababa come to take data, study the plants, and maintain an internal database. They do not have coffee berry disease, coffee leaf rust or any other significant problems in the field collection. Thus they are not able to make observations on the accessions' reaction to these major biotic stresses.

THREATS

- They have a lack of skilled manpower with no local specialized staff, especially with advanced degrees.

OPPORTUNITIES

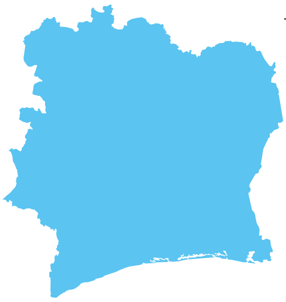
- They would like to increase sampling from more farmers in more local populations when they make collections. They would like to increase the number of accession of wild coffee collected from farmers.
- They would like to encourage more research on the collection with local scientists and EBI funds, and with foreign researchers with collaborative agreement. They would like to see EBI do more molecular characterization of the accessions. The Jimma breeding program is only working on improved varieties.
- They felt that accession level information on their collection should be available and shared to external users. If a user wants to access their accession, an agreement could be negotiated for sharing.

PRIORITY ACTIONS FOR THE NEXT 10 YEARS

- In the future they would like to see the field genebank focus on coffee only and move all the other horticultural crops to another location. This would allow for more space and time to devote to the coffee accessions.
- They also need to establish safety duplication of the collection at a new site. This is being planned.
- They would like to explore the option to do DNA conservation.
- They would like to explore the use of cryopreservation for long-term conservation in the future.

CENTRE NATIONAL DE LA RECHERCHE AGRONOMIQUE (CNRA) COFFEE GENEBANK

IVORY COAST



The coffee collections of CNRA were originally held by ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer, now known as Institute de Recherche pour le Développement – IRD). The collections were transferred to CNRA ten years ago. CNRA is organized regionally with five offices (Abidjan, Bouaké, Gagnoa, Korhogo and Man). The Divo station is in the Mid-West of the country, located in Gagnoa region. The Divo station hosts research programs in Cacao, Coffee and Cola. The research staffs working on coffee and cola are now stationed in their regional office of Man about 400 km from Divo. The move of the research program happened in December 2015. Only the collections are maintained here in 3,500 ha and used for research purposes as needed.

Collections were established from 1966 to 1987 with 8,000 accessions from 25 African species and a few cultivars from Brazil.

The collections are divided into two sections; 1) adapted to sun and 2) adapted to shade. They had a small *C. arabica* collection at a 3 ha site in Man at 1,800-meter elevation but 1,100 accessions were lost during the latest conflict when it was not possible to access the genebank site.

Accessions in the collection have come through prospecting in 8 African countries (Cote d'Ivoire, Guinea, Cameroon, Tanzania, Ethiopia, Kenya, Madagascar and DRC). The last collections in Guinea were made in 1987 but the status of the original samples is not clear. In addition, they have the FAO, ORSTOM and IPGRI collections. They recognize that this is essentially an international collection since different external entities have made these collections. Thus, they would consider exchanging germplasm using a MTA they use for other crops but no one has asked for any of the accessions.

They have some species of coffee collected from Cote d'Ivoire, but need to make more collections and do more research. In 2005 they did prospection for *C. canephora* from farmer's fields in three locations. In 2015, they expanded this to all coffee growing areas of Cote d'Ivoire. From this collection, they have an additional 350 accessions, which will be added to the collections list. *C. liberica* was once grown widely in Cote d'Ivoire but it was all destroyed by Tracheomycosis (coffee wilt disease caused by the fungus Gibberella xylarioides). Forest stands of *C. canephora* is found in the savannahs where it still needs to be collected from areas where it is now being threatened by deforestation. In the past, Cote d'Ivoire had 16 million ha of forest but now there is less than 2 million ha and so the risk is high for the loss of coffee genetic diversity. They currently have accessions from populations that no longer exist. Thus there is a need to fill the gaps in their collection to insure conservation of this diversity before it is lost.

The main objectives of collections are conservation and utilization. Some species are used in breeding programs, such as *C. pseudozanguebariae* for caffeine free breeding. They have worked with CIRAD on research projects, including the current research project on study of plant architecture in collaboration with IRD. In the Robusta geographic location project, they are doing multi-location trials using farmer's varieties and landraces collected from different locations. CNRA work with local farmers in transfer of technology. *C. canephora* material is produced to distribute to farmers. They have developed a good seed garden for these using hybrids of two robusta varieties. Plants are distributed as seedlings based on region and adaptability. They are developing interspecific crosses using the collections. They plan to develop Arabusta further.

THREATS

- They have two main pest/disease problems, coffee berry borer and coffee leaf rust.
- There is significant risk of loss of the collections from bush fires. About one-third of the collection has been safety duplicated at another site in Soubrea, 200 km from Divo due to the risk of bush fires in Divo. This second site was established in 2013.
- Loggers encroach and cut the big shade trees, leading to local deforestation. The shade is lost and there is additional damage to the coffee trees when the tree is cut and removed. This can lead to loss of an accession or a need to replant in the shade areas.
- There is no annual budget allocated exclusively for conservation. Currently this comes from CNRA coffee breeding budget that has been declining.
- Staffing is inadequate. They have two full-time staff taking care of the collection. In the past had eight. Some have retired and have not been replaced.
- There is inadequate training for the future conservation and use of the collection, especially need PhD students to

do research on the collection and to serve as basis for new staff in the future with knowledge of the collection.

- There is a risk of loss of in situ conserved coffee species from deforestation (country level).
- Coffee germplasm management system information is inadequate (CNRA)

OPPORTUNITIES

- They have developed new approaches for conservation and use of the collection that should be shared with other genebanks. They maintain budwood gardens of various species and cultivars in the nursery that have been grafted on Arabusta rootstock and kept as bonsai plants. These are maintained as mother stock. They use these plants for budwood to replant and for crosses since they do flower. They also do ploidy breeding in the nursery by using colchicine on the buds and graft the resulting shoot.
- They have not been involved in in situ conservation of the wild coffee found in Cote d'Ivoire. They do have expertise and knowledge to contribute to designation and monitoring of protected sites. They have *C. canephora* in their collections collected from wild populations from dry (savannah) areas of Cote d'Ivoire that could have traits for drought resistance. The original wild collection locations many not exist anymore. A survey of the collection site of their wild accessions could be used to assess the risk to these population and locations as well as to determine the degree of genetic erosion in the wild populations already.
- *C. stenophylla* is another wild coffee occurring in Cote d'Ivoire. Five populations have been identified. They have collected from two sites, and have not been able to collect from the other three sites. This species is adapted to almost all climatic conditions – dry areas, forests, and wetlands – and could have great implications for use in breeding.
- They do not have any private partnerships and this could be an area of opportunity for greater collaboration on breeding.
- They are open to germplasm distribution externally if there were requests and an ABS mechanism established.

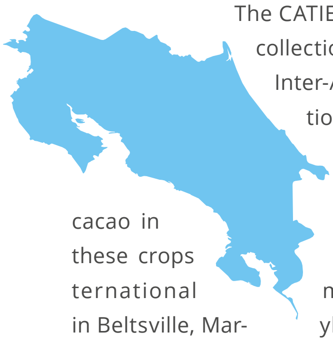
PRIORITIES FOR THE NEXT TEN YEARS

- Sustain conservation of the collection with dedicated budget, better-trained staff, and greater research on the collection by students.

- Characterization of the entire collection for coffee berry borer and coffee leaf rust resistance, genotypes, and biochemical traits. CNRA has the lab but it needs markers and chemicals to run analyses.
- Take advantage of the coevolution of rust with coffee in the field to find a dynamic source of resistance.
- CNRA experts to participate in the designation of in situ conservation sites involving the local communities. Collections should be made from populations at these sites to secure the diversity ex situ as well.
- Collecting to fill gap in West and Central Africa as well as complete collections for Cote d'Ivoire.
- Update their database and make it accessible internally and externally. There would be value in sharing information globally on coffee accessions and they would like to participate.
- Conduct a survey of collection sites of wild coffee accessions in Côte d'Ivoire to allocate remaining in situ conserved species
- Install an adapted germplasm information system using a software to preserve and manage information on coffee germplasm
- Propose an agreement for coffee germplasm exchange among institutes participating in the project

CENTRO AGRONOMICO TROPICAL DE INVESTIGACION Y ENSENANZA (CATIE)

COSTA RICA



The CATIE Botanical Garden and germplasm collections were founded in 1947 at the Inter-American Institute for Cooperation on Agriculture in Turrialba, Costa Rica. With the establishment of a research program in coffee and cacao in the late 1940s, field collections for these crops were established. In 1972, at the international meeting on plant genetic resources in Beltsville, Maryland, USA, CATIE was selected as the center for exploration, introduction, and conservation of germplasm as well as training for the Mesoamerican region. In May 2004, CATIE placed its germplasm collections under the auspices of FAO and on October 2006 signed an Article 15 agreement with the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), making the germplasm available for distribution globally for the diversification and improvement of the crops they conserved, which includes coffee.

The coffee collections at CATIE were established in the late 40s through the 90s. The first coffee accessions were introduced in 1949 with focus on coffee leaf rust resistance. Currently ninety-one percent of the conserved accessions belong to the species *C. arabica* or to interspecific hybrids involving this species. The other coffee species (*C. canephora*, *C. liberica*, *C. eugenioides*, *C. racemosa*, *C. stenophylla*, *C. pseudozanguebariae*, C. congensis, among others) are under-represented in terms of number and inherent diversity. The wild coffee trees collected in Ethiopia by FAO (Fernie et al. 1968) and ORSTOM (now IRD) (Guillaumet and Hallé 1978) constitute around 40% of the conserved accessions. The material from the IPGRI collecting expedition in Yemen (Eskes 1989) is only represented by a few (17) accessions. In contrast, the accessions originating from selection are numerous, representing 45.8% of the total and 58.6% of all trees in the collection. Finally, many intraspecific hybrids are also conserved. They have lost 53 accessions due to old age and pests and diseases. Their intent was to rescue them, but there was not enough material left for grafting or taking cuttings. Coffee collections occupy about 10 hectares. All 2,000 accessions have been morphologically characterized. They are still losing plants and the plants are also not very productive. All commercial varieties currently used in Central America that have rust resistance are derived from Catimor and Sarchimor accessions distributed by CATIE since the 1960s to the coffee institutes in the region.

In the 90's they started a breeding program using Latin American varieties and wild genotypes and species. The program developed 100 hybrids of which 20 were selected. Some have coffee leaf rust resistance and good cup quality. One of the recent cup taste winners in Costa Rica (Cup of Excellence 2016) was one of these varieties. Hybrids have shown a 58% higher productivity than conventional varieties under agroforestry systems and a 34% higher in full sun systems, with average yields of 75 fanegas (bags of 100 pounds of green coffee) per hectare (Bertrand et al., 2011). Five of the most productive hybrids are being multiplied by tissue culture and distributed to local farmers. They are working with an enterprise to produce up to 2 million plants/year within the next 3 years based on mother plants generated by somatic embryogenesis in CATIE's biotechnology laboratory.

Using two *C. canephora* accessions, T3561 and T3751, they developed the hybrid Nemaya, which is used as rootstock for *C. arabica* and *C. canephora*. This hybrid has nematode resistance and has a very strong root system. The region had problems with nematodes, which was at its peak in the 1990s, which led to the development of Nemaya, which is still being used.

Another interesting product of the CATIE coffee collection is the Geisha variety. It was originally collected from coffee forests in Ethiopia in the 1930s, sent to the Limungu research station in Tanzania, and from there brought to CATIE in Central America in 1953, where it was logged as accession T2722. It was distributed throughout Central America including Panama via CATIE in the 1960s after it had been recognized for tolerance to coffee leaf rust. The coffee came to prominence in 2005 when the Peterson family of Boquete, Panama, entered it into the «Best of Panama» competition and auction. It received exceptionally high ratings and broke the then green coffee auction price record, reaching in 2016 a value of $ 350 / pound.

In 2015, 800 wild accessions of *C. arabica* as well as other species and cultivars of Coffea were characterized molecularly by WCR. From these 800, 100 were selected as core collection representing all wild accessions. This core collection has been regenerated and duplicated in three sites in Costa Rica and at WCR's farm in El Salvador. They started a new breeding project last year with CIRAD and WCR to create new hybrids using Marker Assisted Selection (MAS). They are involved in WCR's multi-location variety trails through ICAFE since the station at Turrialba is not a good site for testing these varieties. The most recent work (2015-2016) in genetic improvement carried out in conjunction with WCR used 9 accessions of the CATIE's collection and 51 new hybrids were generated that would meet the request of the breeders of the coffee institutes of Central America who are looking for 2 coffee biotypes as future varieties for the region.

These materials are under evaluation and in the next few years may be available to coffee growers.

They get numerous requests annually for specific materials. Sometimes requests are for something new or they get requests for 50 accessions to plant in farms for evaluation. Requestors contact personally or via website. Due to its success in Panama, they have gotten a lot of requests for Geisha in recent years. They include Ethiopian accessions in tasting and when they get good ratings, they get requests for these accessions. They have collaboration with Illy Café to test for cup quality. Last year, material from Kenya won the national taste competition (Cup of Excellence 2015) and so growers request that for planting.

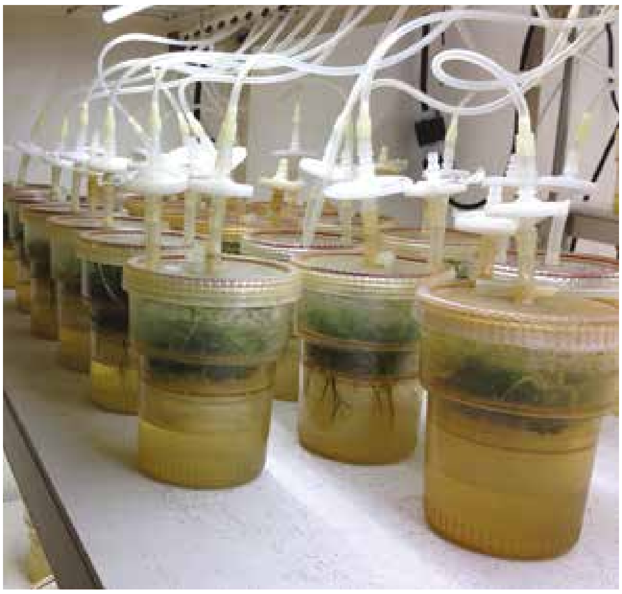
THREATS

- The trees are ageing, with many accessions with trees that are 50 – 60 years old. Thus, there is a backlog of replanting. The typical practice is to have three trees per accession but at present they have only one plant per accession for about 300 of the accessions. These are in the process of being replanted and the plan is to get everything replanted in the next three years.

- The site where the majority of the coffee collections are held has poor drainage leading to water logging. They have lost quite a few of the trees in this location. They have created drainage channels, but it would be best to relocate the coffee collections to another higher altitude location. If they relocate to a new site, during the rejuvenation of the collections, they will have to maintain two collections for at least 2-4 years until the new plantings have established. This will require additional staff.

- During the last two years, the incidence of leaf rust has increased and has resulted in the loss of trees, which has led to the increase in the number of accessions with one or two plants. Preventative treatment for leaf rust is costly.

- After leaf rust, the second most important disease in Costa Rica is American Leaf Spot (Mycena citricolor; Ojo de gallo). There is no resistance to this. In some areas, this is more devastating than leaf rust.



- There has been a lack of adequate operational funds for farm inputs such as fertilizer, pesticides, etc. The basic budget allocated for conservation now only pays for labor.

location of collection. There should also be duplication of interesting materials at another highlands site, possibly in collaboration with a private company.

OPPORTUNITIES

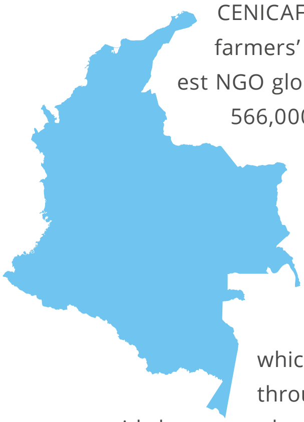
- They had a coffee cryobank with 300 accession cryopreserved that was maintained for 3-4 years. They did not have resources to continue to maintain these collections so they were sent to USDA's NCGRP in Ft. Collins. This successful use of cryopreservation needs to be expanded and shared with other genebanks.
- Some of the wild materials have shown good cup quality potential by winning regional coffee cupping competitions. This germplasm can be selected as a variety or used as a progenitor in future breeding programs.
- Due to the low price of coffee beans paid to farmers, they are looking for specialty coffee varieties with unique tastes to plant. Evaluations of the collections held by CATIE have already demonstrated that there are potential accessions to fill that niche.
- CATIE has established the infrastructure for biotechnology and this should be utilized for genotyping and other research to enhance the use of the collection. They would also like to reestablish the biotechnology course that has been suspended.
- CATIE host a number of other international organizations on site and this will facilitate the opportunities for collaboration.
- CATIE is confident that they could allocate a more ideal site near the farm, near the cacao collections, for the re-

TOP PRIORITIES OVER THE NEXT 10 YEARS

- Relocation and rationalize the collection to focus on conservation of unique material without genetic redundancy so that they can reduce area of holdings from 10 hectares to 5 – 6 hectares.
- Acquire or allocate a new field site for the long term maintenance of the coffee collections and start the relocation process with an initial focus on the rescue and planting of the most at-risk accessions.
- Develop a team of staff that is dedicated to the conservation of the coffee collections only. The optimal would be 4 field workers of which one or two are specialized in grafting.
- Safety duplication of the collection at an additional site outside Costa Rica
- Complete pre-breeding evaluation of all the collections.
- Molecular characterization of all of the accessions in the collections.
- Ensure stable annual funding for the routine maintenance of collections.
- Enhance use of collections for breeding for coffee leaf rust resistance, drought tolerance, heat adaptation, and taste with comprehensive accession level information sharing by CATIE and users.

CENTRO NATIONAL DE INVESTIGACIONES DE CAFÉ (CENICAFE)

MANIZALES, COLOMBIA



CENICAFE was established in 1927 as a private farmers' association. It is now one of the largest NGO globally. They have a membership of about 566,000 coffee growers in Colombia that produce on one million ha. The national coffee fund was established in 1940 that farmers voluntarily contribute to based on payment per pound. Every 10 years, the Federal government signs a contract with the Federation to administer funds which have four main objectives: 1) research through CENICAFE, 2) an extension service with local agronomists to improve production using research generated at CENICAFE, 3) a purchase warranty, and 4) marketing/promotion. Farmers who had the vision to fund research established CENICAFE in 1938. Extension started in 1948 with a focus on soil conservation and in 1959 became technology driven with the promotion of new approaches.

In the last El Nino in 2008, they started a program to replace old varieties by assisting farmers to make this shift with a credit program for replanting. An evaluation has been done for the impact of this credit scheme. There has been a positive impact on the coffee sector, especially for indicators on varietal adoption and production. The changes have brought about increased resilience for smallholder farmers and have reduced risk for the producers and the coffee sector.

Coffee varieties are a very important aspect of research and the most important focus for the Federation. Coffee rust has been the main focus but now they are concerned with coffee berry borer. Seventy-two percent of the area is planted to rust resistant varieties, as this was the main driver to develop new varieties. This effort was initiated 20-30 years before the disease arrived. They were able to do defensive breeding for rust resistance but still focus on breeding for high coffee quality and monitor new varieties to insure quality. They released resistant varieties 1-2 years before CLR arrived in Colombia.

The collection held by CENICAFE has been an important source of improvement and traits. In the past they have only used a small amount of the collection. They have done characterization of their collections for agronomic traits and performed regional experiments on adaptations. Only portions of their collections have been explored but now they are doing a wide evaluation of the collections, especially the Ethiopian accessions. They have a focus in the evaluation on genomics and conducting regional adaptation trials. They have conducted an

SSR assessment of the diversity in the Ethiopian collection for all 600 accessions using 49 SSR markers. They have also fully evaluated 300 accessions from Ethiopia for yield, rust, bean size, and cup quality at the genebank site. For the future, they conclude that there is still a lot to use.

THREATS

- The impact of higher temperature in the higher altitudes, less predictable rainfall, and more extreme weather events on coffee production due to climate change.
- Increases in pest and diseases incidence in the coffee production areas as well as in their research site, some due to climate change effects as well as the risk of newly introduced pests.

OPPORTUNITIES

- To fully utilize the Ethiopian collection in their breeding programs
- To utilize genomics to increase the use of their genetic resources as well as to increase the efficiency of their breeding programs

PRIORITY NEEDS FOR THE NEXT 10 YEARS

- There is a need to upgrade the accession level Information system with more comprehensive data on molecular characterization and evaluations. This information will be shared externally as well.
- Conduct evaluation and find new sources of resistance to CBB
- More fully utilize diversity from the Ethiopian collection in the breeding program.

INSTITUTO AGRONOMICO DO PARANA (IAPAR)

LONDRINA, BRAZIL

IAPAR was established in 1972 and the coffee genebank was established in 1975. Headquarters is in Londrina in the state of Parana. The campus is 300 ha, of which 40 ha are planted in coffee. They have six substations in Parana and partnerships with five farmers for F3/F4 generation testing. The coffee genebank was established from original coffee germplasm from IAC. This included accessions from the FAO/IBPGR collection, Catuai, Catuai x Sarchimor, Aramosa, BA10 and Icatu.

Coffee production in Parana was initially established in the early 20th century and by 1962, the state produced nearly 30% of the world coffee supply. On July 18, 1975, Parana experienced a black frost that devastated the coffee trees. The last significant frost was in 2000 and led to reduction in production area in the region. Farmers are now replanting. Many farmers had shifted to soybean production but are now migrating back from soybeans to coffee in Parana. Currently, the state is seeing a revival of coffee production with an increasing focus on specialty coffees. The production in this state is mainly in lower elevations given the sub-tropical location with mild temperature and adequate rainfall. The coffee production systems are mechanized.

The germplasm collection is maintained and used by the breeding program. It serves as a critical resource for the development of improved coffee varieties. They have numerous active breeding and research programs for resistance to nematodes (Meloiidogyne spp.) and resistance to coffee diseases such as Coffee leaf rust (Hemileia vastatrix); bacterial blight (Pseudomonas syringae pv. garcae); Phoma (Phoma costaricensis) is a soil fungus that attacks coffee leaves and fruits causing leaf spots and black spots on unripe fruits; Anthracnose (Colletotrichum gloeosporioides) is a new disease in Brazil that occurs in young fruits causing blackening of fruits. Currently they do not have Coffee Berry Disease (*C. kawanese*). Resistance to Coffee ringspot virus (CoRSV) is also a focus. Breeding for resistance to insects such as leaf miner (*Leucoptera coffeella*) where the resistance source is *C. racemosa*, which also has resistance to drought. Breeding for resistance to coffee berry borer (Hypothenemus hampei) utilize *C. eugenioides*, which has partial resistance to CBB. They are also interested to develop cultivars with different ripening cycles; tolerance to drought, heat and frost; tolerance to aluminum; new F1 Hybrids; improved beverage quality; and adaptation of cultivars for mechanized harvest. They have effectively utilized other coffee species as sources of resistance or tolerance. Thus the collection is conserved and utilized by the institute as an important resource.

They are part of a consortium called the Consorcio Pesquisan Café, which includes 50 institutions. There are 6-7 main institutions with breeding programs (IAPAR, IAC, EPAMIG, INCAPER, EMBRAPA Café) and universities. There are 10 national research projects through this consortium. IAPAR is coordinating the national program for resistance to nematodes.

Through their breeding programs, IAPAR have released numerous cultivars with various qualities such as high yield, resistance to nematodes, rust, bacterial blight and leaf miner, different ripening cycles, and tolerance to drought. For yield, breeding can take up to 30 years. At IAPAR, they have achieved that in 20 years. They combine testing, seed production, and demonstrations to farmers in the F6 generation and thus reduce the time required to release a variety. They provide extension services by making presentations to producers about new cultivars every year. New planting rate is about 1.5% annually. In Parana, producers have high trust in IAPAR.

THREATS

- Lack of local labor availability so they have to rely on students to do most of the data collection for the breeding program. Without students, it would be hard to maintain the coffee breeding program at IAPAR.

- Londrina is in a frost prone area. The last severe frost was in 2000. Frost happens every 5-6 years.

- Nematodes (Meloiidogyne spp.) infestations are severe in this region and half the plots at IAPAR have nematode issues.
- The site has acid soils with high soil aluminum toxicity.
- They are utilizing molecular markers for the SH3 gene, nematode resistance, and bacterial blight resistance to predict crosses and in selection. They anticipate using these markers for diversity studies in the Ethiopian accessions. They use SNP's and AFLP markers currently.

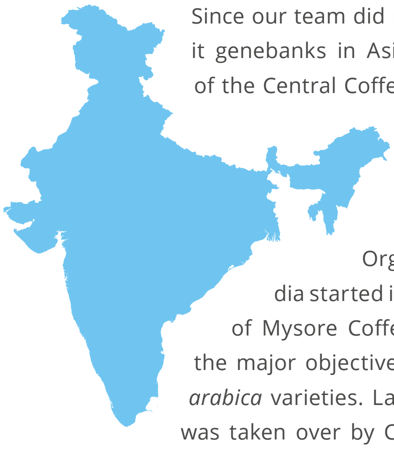
OPPORTUNITIES

- In 2017, they will establish replicated field trials to evaluate accessions from Ethiopian accessions.
- *C. benghalensis*, which is a no-caffeine species, has been used in breeding programs, but the no-caffeine trait has been hard to transfer.
- The hybrid Aramosa (arabica x racemosa) has been used in breeding programs to confer traits such as resistance to leaf miner, frost, drought, and bacterial blight and for early ripening.

PRIORITY NEEDS OVER THE NEXT 10 YEARS

- They are interested in acquiring more *C. arabica* germplasm, mainly from Ethiopia, and more accessions of other species. Strict Brazilian phytosanitary regulations as well as strict processes to obtain permission to export are making it difficult to exchange materials.
- Their main source of information about germplasm and traits is from literature. They recognize a need to share accession level data more globally but need to put accession level data in databases that can be shared and searched.

CENTRAL COFFEE RESEARCH INSTITUTE (CCRI)
INDIA



Since our team did not get an opportunity to visit genebanks in Asia, Dr. Nayani Surya Prakash of the Central Coffee Research Institute (CCRI) in India submitted a detailed report of the Indian collections as listed below.

Organized coffee research in India started in 1925 with the establishment of Mysore Coffee Experimental Station with the major objective of evolving rust resistant *C. arabica* varieties. Later, the Experimental Station was taken over by Coffee Board of India and renamed as Central Coffee Research Institute (CCRI). To start with, existing variability was collected from various Indian plantations and a gene bank with over 150 collections was established. This collection formed the basis for initial coffee improvement programmes and some of the collections such as the *C. liberica* introgressed lines, S.26 and S.31 were exploited in developing the early Indian selections, S.288 and S.795. S.795 was introduced into commercial cultivation in 1946-47 and is still a popular and preferred variety in India. The classical work of W.W. Mayne in identifying the existence of physiological races in leaf rust pathogen as early as in 1932 paved the way for characterization of diversity of rust pathogen from time to time.

Subsequently, the coffee gene bank was further strengthened with introduction of several exotic collections during 1954-55 with the mutual cooperation of different international institutes/agencies. In 1964, as part of FAO sponsored expedition, 80 wild *C. arabica* accessions representing different provinces of Ethiopia were collected and added to the genebank. Since the establishment of Centro de Investigação das Ferrugens do Cafeeiro (CIFC) at Oeiras, Portugal during 1955, CCRI has been closely associated with this institute on coffee rust research. This collaboration helped immensely for introduction of high yielding dwarf/semi-dwarf hybrids with tolerance to leaf rust, rust indicator clones and also the HdeT collections to the genebank that have been extensively used for breeding for rust resistance. Among the Ethiopian collections some of the land races like Cioccie, Agaro, Tafarikela, S.12 Kaffa and Geisha were used successfully in Arabica breeding.

To date, the CCRI genebank comprises of nearly 320 collections of *C. arabica*, 73 types of *C. canephora* and 17 diploid species of coffee including the three indigenous species *C. benghalensis*, *C. wightiana* and *C. travancorensis*. This germplasm collection has been the main source for coffee

CCRI

CCRI WAS FOUNDED IN 1925, BELOW IS A PHOTO OF THE ORIGINAL INSTITUTE.

breeding programme in India. Systematic evaluation of the germplasm collections with particular reference to rust resistance, production and quality parameters paved the way for identification of prospective collections with respect to different agronomic traits of interest. Some of the identified collections have been exploited in breeding and development of 13 improved *C. arabica* selections and 3 *C. canephora* selections for commercial cultivation in Indian coffee tracts. At present, over 95% of the area planted to *C. arabica* is occupied by CCRI bred selections. As the main focus of *C. arabica* breeding in India was rust resistance, the orientation of germplasm evaluation has been on identifying appropriate sources of resistance. Hence, the collections that manifested susceptibility have not been given importance. In order to address the new challenges, the breeding priorities are fast changing and there exists a greater scope for detailed characterization of the existing genetic resources for further exploitation in breeding.

THREATS

- Coffee leaf rust – The majority of the gene bank collections especially the pure *C. arabica* collections manifest high susceptibility to coffee leaf rust leading to defoliation, if proper control measures are not adopted.

- Coffee white stem borer - defoliation due to leaf rust is a predisposing factor for coffee white stem borer infestation, a light loving pest. The white stem borer infestation ultimately leads to death of the plant and is the major threat for maintaining the *C. arabica* germplasm in the Indian context.

OPPORTUNITIES

- Precise characterization of existing genetic resources for trait specific selection needs to be taken up. In the past, only rust resistance has been considered as a major criterion of selection for breeding purposes.
- Indian coffee tracts provide ideal conditions for disease/pest build up and flare-ups. This provides an ideal testing ground for resistance in the field.
- In India, *C. arabica*, *C. canephora* and *C. liberica* are cultivated in close proximity, leading to greater opportunities for identification of new variability. Several tetraploid interspecific hybrids introgressed with these diploid species (*C. canephora* and *C. liberica*) and few other diploid species with high levels of host resistance have been identified.
- The caffeine free species indigenous to India can be collected from native forests for conservation purposes.

PRIORITY NEEDS OVER THE NEXT 10 YEARS

- As a protective strategy, all important germplasm collections are being duplicated in two more locations in addition to CCRI.
- Development of a comprehensive catalogue on existing germplasm collections including the marker profiles.
- Application of genomics for improving the efficiency of conventional breeding.

VISIT TO OTHER SITES

The team also visited the Bonga Forest of the Kafa Biosphere Reserve in Ethiopia. This is one of the key management focal areas for the protection of *C. arabica* genetic resources and its associated ecosystems (UNESCO 2016b). Occupying an area of 759,399 ha, this reserve is within the East Afromontane Biodiversity Hotspot. We heard about various institutions such as Ethiopian Nature and Biodiversity Conservation Unit (NABU), Ethiopian Wildlife and Natural History Society (EWNHS) and University of Bonn, Center for Development Research (ZEF) that are conducting ongoing research on the conservation of genetic resources of wild *C. arabica* in this biosphere. In our short visit, we toured a site with participatory forest management in the transition zone in Kejaaraba. It was an area with 120 smallholder plots allocated individually but they also operate as a cooperative. The densities of the coffee plants were uneven but they had natural shade trees. They would take naturally germinating seedlings to fill gaps and they replant shade trees. It is under semi-management with some slashing and clearing of weeds and transplanting of coffee, but no shade control.

They also encourage or kept the long pepper (Piper capense) and forest cardamom (Aframomum corrorima) plants to harvest as well. The farmers harvest coffee by hand and then sundry. The harvest would be taken to processors to dehull and sell. The coffee is mainly grown for a niche market in Germany.

Next we visited a community area within the buffer zone in the Komba forest that expanded to the core zone. This area was recognized to have historical community right to access and use. They had a culture in this community of paying for access to the communal forest. This is still the tradition today. The community has traditional user rights, but the legal rights are with the government. The users sign an agreement with the government. The forest is fairly intact and the coffee is found at various densities. The area we visited had a high density of coffee and was close to the road. They do not manage the plants with gap filling or making changes in the natural density, they just harvest berries. The community does assign areas where farmers harvest coffee, sundry and sell to processors. Their allocation is related to the honey production sites and this is their priority. In this case individual trees for honey production are identified and managed. They slash the understory when they come to harvest. The community has 1,241 ha that includes buffer zone where they harvest plus 3,000 ha in core area. The buffer zone is within 150 meters to the core zone. The core area is not harvested; it is a sacred area so they protect this forest. The last stop was the Bitachega Cloud Forest where the density of coffee plants was very low in the very heavy shade. This has been nominated as a candidate for core designation. Coffee leaf rust is present but naturally maintained at low levels.

Some of the threats to all three areas that we observed were threats from expansion of production of alternative crops, such as tea, and the encroachment from new settlers. There is an increasing market for coffee produced in this area so farmers may wish to intensify their production with the replacement of wild plants with new varieties.

They might also increase plant density or reduce shade trees and this would change composition of other forest undercover species. There is a risk of loss of genetic diversity in all three zones. There is an effort being made to make collections from the protected sites and maintain ex situ at EBI in order to mitigate the risk of loss but also increase the opportunities to utilize this diversity.

We also visited Dr. Price Peterson, owner of Hacienda La Esmeralda, Boquete, Panama. He is a coffee grower and a private collector of coffee germplasm. He was involved in bringing the Geisha coffee to market. He has acquired a little over 400 accessions from CATIE and is growing them in an experimental field. The accessions were affected by coffee leaf rust but at least one accession was showing no sign of the disease. He is thoroughly convinced that the accessions he has are actually mostly duplicates of each other, though they seem to have unique characteristics. He has requested WCR for confirmation of the uniqueness of his collection from CATIE. He is willing be contribute to the global conservation system by providing a backup for the entirety of the CATIE collection at a higher elevation outside of Costa Rica. Thus, the global conservation and use community for coffee does include private growers or collectors as well as botanical gardens. They offer opportunities to manage the risk being faced by field genebanks.

SUMMARY OF SITE VISITS

The site visits not only increased our understanding of the status of ex situ and in situ coffee genetic resources conservation but also the current use of these ex situ collections as well as the future threats and opportunities. Each institute was asked to identify the priority actions they planned or needed to take in the next 10 years. All, except CATIE, are nationally focused collections that are currently isolated from each other and external users. In most of the institutions, the main objective of the conservation of the collection is to make it available as a tool for their breeding programs. The only collection held solely for conservation that we visited was the collection of EBI in Ethiopia.

In the institutes visited, there has been a long-term commitment to maintenance of the accessions despite the very low number of accessions that are used and the uncertainty of funds dedicated solely for conservation.

The conservation activities of the genebanks focus mainly on field maintenance, berry harvest, pruning/training/rejuvenation, and replanting through nursery operations. Frequency of these operations is dependent upon availability of labor and funds. Except for Ethiopia, there were no separate funds for conservation; the resources are tied to breeding program or botanical gardens. In most institutions, conservation of the collection is secure due to the dedication and commitment of the institutes and their staff but this is a risk. Finding a replacement when a staff retires is an issue. Changes in land use by institutions can require the relocation of the field collections since maintaining the allocation of large land areas into conservation plots are not seen as a priority. Everyone struggles with inadequate, unpredictable funding for conservation except for the breeding programs in South America. The most secure collections are those held by CENICAFE and IAPAR with their active breeding programs.

All genebanks visited, except EBI, hold a similar set of 'international' accessions of C arabica and *C. canephora* that have been acquired from past collection missions of CIRAD/ IRD or FAO/IPGRI collections, varieties shared through CIFC, or other breeding programs. Globally, these are fairly securely conserved with much duplication. There are also a few accessions of other species of value, such as *C. liberica*, *C. eugenioides*, *C. racemosa*, *C. stenophylla*, *C. pseudozanguebariae*, and C. congensis, that are widely conserved. Most collections seem to have derivatives of the same limited number of accessions of these species that have been collected from limited localities. A few collections in Africa, such as EBI for *C. arabica* and CNRA for *C. canephora*, have unique locally collected accessions that are not exchanged and thus not securely conserved with safety duplication.

The Institutes in Africa are still adding accessions with collections to fill gaps. They have links to in situ or protected sites but this needs to be formalized and strengthened. Designation of protected areas and monitoring should consider the populations of coffee species found in the forest. The genebanks have coffee genetic resources expertise. The information that was taken when collecting, characterizing, or evaluating their current accessions should be used to identify, designate, and monitor populations of coffee species for in situ conservation. In situ conservation has significant threats from degradation or loss of the forest due to human activities, policy, land use changes, and any intensification of coffee production systems in the centers of origin, especially in transition or buffer zones. There are many opportunities for in situ sites, such as new niche markets for local or wild coffees. The secure conservation of these sites will be enhanced with greater links to ex situ collections, especially for expertise, enhanced safety duplication, and enhanced value addition through use. There should be efforts made to secure the genetic diversity of the local populations with complimentary conservation in ex situ genebanks for future users that could include crop improvement as well as the maintenance of sources of plant material for future reforestation efforts.

The link of the Kafa and Yayu reserves and the EBI genebank in Ethiopia are worth sharing as a model to link in situ and ex situ collections in the future.

There were a number of threats identified for the ex situ collections visited. This included the low level of support for conservation from the institute, nationally, or globally. There were many more sources of funds available for research and breeding. This low level of support has resulted in inadequate maintenance of the collections such as a lack of controlled pollination for replacement trees, accessions with aging trees due to a backlog of replanting, and lack of consistent control measure for major pest. There were a number of risks related to staffing, either from the loss of knowledge with staff replacements, inadequate skills in staff, or lack of field labor. There were site-specific constraints such as water logging, nematodes, acid soils, frost, and bush fires. Many of the sites were facing treats from increasing pest and diseases incidence. There were threats to both ex situ and in situ sites from deforestation and other human activities such as encroachment, illegal logging, and land use changes due to urbanization or shift to alternative crops such as tea. The impact of the changing climate on temperature and rainfall at the conservation sites as well as the coffee production areas is a significant future threat. Finally, the lack of a mechanism for germplasm exchange globally is a threat to conservation with the current low use and visibility of the collections

The genebanks visited identified some key new opportunities for their collections. Active collaboration with other genebanks and breeding programs is an opportunity to share innovation and collectively address constraints. One area identified was the need for research on alternative propagation or conservation approaches. There are a few examples of techniques being used by individual genebanks that would be of benefit for sharing with other collections, such as the budwood gardens in CNRA, tissue culture protocols at CAT-

IE, and ploidy breeding techniques at CNRA and Madagascar. There are also opportunities from greater partnership with users such as the private sector, especially for evaluation or safety duplication. The genebanks visited also recognized the opportunities from more breeding effort being put on interspecific hybrids such as Arabusta or Aramosa. There was also recognition of the opportunities for increased collection of wild coffee to fill gaps. Genebanks also recognized opportunities from greater collaboration in educational programs for local schools, universities, and individuals.

Generally, there is an interest in more fully utilizing coffee genetic resources through making greater accession level information available and shared as well as developing ABS mechanisms for germplasm exchange. Biotic threats, such as coffee leaf rust or coffee berry borer, are the most important focus for germplasm use but drought and heat tolerance is becoming an important focus for the future. There is an interest to develop varieties that incorporate the caffeine free trait from other species. Constraints to germplasm conservation, exchange, and use are related to lack of ABS, long-term nature of breeding program, the low level of effort being put into breeding currently, low replant rates by farmers, and high cost of coffee production for farmers. The ABS needs to consider monetary and non-monetary benefit sharing for germplasm conserved ex situ as well as in situ or protected area support. For the future, there is a need to focus on increasing the knowledge and use of accessions within collections as a way to ensure long-term conservation.

The genebanks visited identified priority actions for the next 10 years that included:

- Establish new accession level documentation system that will hold all passport, characterization, and evaluation data on accessions and be shared globally to enhance use of the collections.

- Develop and implement access and benefit sharing agreements to enhance germplasm exchange.

- Sustain conservation of the field collections with an adequate dedicated budget for routine operations, better-trained staff, and more research being done on the collections by students, as the coffee researchers of the future.

- Address the need to replace old trees, increase replication, and safety duplicate accessions.

- Fully utilize collections of Arabica from Ethiopia that are currently in the public domain.

- Find new and more stable sources of coffee leaf rust resistance and CBB resistance.

- Increase the molecular characterization and evaluation of the accessions in the collections.

- Increase the use of genomics for conservation and in breeding.

- Increase the use of cryopreservation for seeds or embryos.

- To have greater engagement of the genebank with in situ conservation, including

- Assessment of status of current accessions in their original site and recollection for filling gaps or securing at risk populations.

- Participation in the designation of in situ conservation sites and better monitoring of at risk coffee species.

- Undertake collection to fill significant gaps, especially from localities at risk of loss.

COFFEE FROM HACIENDA LA ESMERELDA IN PANAMA IS BAGGED AND READY TO BE SHIPPED TO BUYERS FROM ALL OVER THE WORLD.

GLOBAL CONSERVATION STRATEGY FOR COFFEE GENETIC RESOURCES

COST OF CONSERVING AND DISTRIBUTING COFFEE GERMPLASM: CASE OF CATIE

As part of the development of this strategy, a study was done of the costs of conserving the collection of coffee genetic resources held by the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica.

The objective of this costing study was to have an approximate estimate of the annual investment needed for their field genebank. Ensuring the conservation and use of the genetic resources held are the two main goals of a genebank. A genebank needs to perform a number of operations in order to achieve these goals. Table 8 gives a list of key genebank operations that have been included in the costing study. We have placed the focus for costing on the routine genebank operations needed to conserve the genetic material and guarantee its integrity, but other genebank research operations, like molecular characterization, have also been costed.

TABLE 8. DEFINITION OF GENEBANK OPERATIONS IDENTIFIED FOR COFFEE COLLECTIONS

ACTIVITY	DEFINITION
Collection	Acquisition of germplasm through collecting activities
Acquisition	All activities leading to the accessioning of new materials in the collection, including quarantine
Propagation . Regeneration	Nursery, grafting, seed propagation, clonal propagation, field establishment. Routine propagation for replacement of dead or injured trees.
Field maintenance	Pruning, fertilization, pest and disease control, harvesting of berries, rejuvenation, and composting. It also includes costs of field preparation and accession labeling.
Morphological characterization	Data collection of morphological characteristics of each accession.
Molecular characterization	Verification or identification of the materials using molecular techniques.
Health testing	This activity involves the testing of plant health, often carried out upon acquisition or during regeneration process.
Distribution	Sending accessions upon request (e.g., preparation, shipment, etc.), which includes propagation of the materials.
Safety duplication	Replication of the accessions in another field collection.
Information management	This activity includes data entry, processing and management, including catalogue preparation and descriptor development. It also includes database management.
General management	This includes management activities, genebank manager and administration time as well as office and administration expenses in supplies and services.
Training/ capacity development	Activities related to the training of staff carrying out any of the activities of the collection management.
Research	Evaluation, breeding or other research that add value to the collection.

To do the costing we used an Excel file created to store genebank inputs used and cost, dividing the information by type of input (capital facilities and equipment, quasi-fixed, variable labor and variable non-labor).

- Capital Facilities: this category includes inputs that are not as sensitive to the size of the operation and include infrastructure, such as germplasm storage and genebank facilities and offices.

- Capital Equipment: refers to all types of equipment used for the genebank operations including field and office equipment.

- Quasi-fixed: refers to inputs that are more variable than fixed capital inputs but unlike variable costs, they are not easily apportioned when the size of the operation changes. To give an example, each genebank needs at least a regeneration expert independently of the number of accessions multiplied in the field each year. However, if the number of accessions increase dramatically there might be a need to increase the staff.

- Variable labor and non-labor: refers to inputs that are sensitive to size of the operation. Non-labor inputs can be supplies consumed on a regular basis, like energy, office and laboratory supplies. Variable labor inputs are mainly salaries paid to temporary workers and non-senior staff.

It is important to take into considerations the following points:

- To convert cost to nominal values we used the consumer price index (CPI) reported by the Central Bank of Costa Rica (*http://indicadoreseconomicos.bccr.fi.cr/indicadoreseconomicos/Cuadros/frmVerCatCuadro.aspx?idioma=1&CodCuadro=%202732*).

- The replacement cost of equipment has been estimated using purchase value, converting it to current value (2015) and annualizing it using its service life.

- To annualize costs, we used a discount rate that was 12% according to the value used by the Costa Rica Ministry of National Planning and Economic Policy (MIDEPLAN 2013, *http://documentos.mideplan.go.cr/alfresco/d/d/workspace/SpacesStore/8f0807f4-b051-4386-b748-a67f166bd2ca/preguntas_inversiones_publicas.pdf).*

- The overhead rate charged by CATIE is 14% and it was applied to all inputs except facilities.

- To estimate costs of operation we have included the costs of equipment used in the conservation activities.

The total annual expense in 2015 for CATIE to conserve and distribute coffee accessions and related species amounted to $ 372,724, which includes capital cost (expenses on building facilities: offices, laboratories, nurseries, greenhouses and equipment used for all genebank operations in the field, labs and office). CATIE has not acquired or collected new material, does not do seed health testing and does not hold an in vitro collection, therefore there are no costs reported for these operations in 2015. When all the capital facilities and equipment are excluded as an annual expense, the annual total cost is $249,451 (Table 9). The total routine cost of maintaining the coffee collection at CATIE is US$ 232,451, which includes staff and labor costs, supplies and services, and equipment used in these operations. Collection, molecular characterization, training of staff and research are non-routine operations and as such are not included in this estimation. From the total routine operational costs, about 54% of the costs correspond to field maintenance, while general management represent 15% of the expenditures

TABLE 9. SUMMARY OF THE COST (USD) OF CONSERVATION OF THE COFFEE ACCESSIONS, CATIE, 2015 (TOTAL OF 1,976 ACCESSIONS)

COST OF COFFEE CONSERVATION - CATIE	N° OF ACCESS.	TOTAL OPERATIONAL COSTS	TOTAL ROUTINE OPERATIONAL COST	SHARE OF TOTAL COST(%)
Collection	0	0	0	0
Acquisition	0	0	0	0
Propagation/ Regeneration - Seed/Cuttings	29	19,444	19,442	8.35
Propagation - In Vitro	0	0	0	0
Field Maintenance	1976	125,255	125,255	53.82
Characterization - Morphological	100	6,460	6,460	2.78
Characterization - Molecular	221	2,257	0	0
Health testing	0	0	0	0
Distribution	161	29,874	29,874	12.84
Safety duplication	100	4,529	4,529	1.95
Information and data management	1976	13,305	13,305	5.72
Training/ Capacity Development		4,770	0	0
General Management		33,845	33,845	14.54
Research		9,711	0	0
TOTAL		**249,451**	**232,451**	**100**

When looking at the average costs figure, it is important to consider that:

- Average costs are very sensitive to the number of accessions processed each year. For instance, management costs (general, training, documentation) would tend to be lower per accession with a larger number of accessions held at the genebank.
- The number of accessions processed each year does not necessarily depend on how efficient the genebank is. Distribution, for instance, depends very much on how active are the coffee research institutions that make use of accessions from CATIE.
- Note that significant cost variations across years can happen, especially if the year selected for costing was not a representative one. Technological changes or an unexpected number of introductions can have a significant impact on the total costs for that year. Ideally, cost information should be collected periodically to make more accurate costs projections.
- Each of the 1,976 accessions currently held in the genebank used to have 6-10 replicates in the field. More replicates increase the costs of field operations like maintenance and regeneration. More recently, the number of replicates has been reduced to 4. An accession is due for regeneration when the number of replicates in the field is reduced to one individual per accession.
- About 90% of the collection is older than 40 years. This has an impact on the rate of loss of trees in the field. Currently this rate is about 2% per year.

The 2015 cost estimations reflect a current scenario with limited resources, particularly for field operations. CATIE staff reported to have cut down the use of field supplies that dramatically reduced agricultural maintenance expenses. Moreover, since CATIE holds collections of other crops, the staff is often challenged with the need to allocate human and material resources among a number of different collections. To produce good quality seed, the genebank needs to have access to chemical supplies to control pests and diseases. Unfortunately, given a limited budget, the decision is often made to cut these expenses. Over the years, the number of annual chemical applications has been reduced. The consequence is lower seed production due to the attack of pests and diseases. In some accessions, the coffee berry borer (Hypothenemus hampei) can damage 30-60% of the total seed harvested.

Reviewing the inventory and correcting any labeling errors of the materials in the field is another activity that needs to be addressed rather soon. Ideally, field inventories would be done more frequently in order to keep track of the status of every accession and identify materials that are threatened. Currently, the major expense would be in field supplies, since the current number of field workers would be enough to complete the task. Barcoding would be a good option to improve both labeling and inventories.

The site of the CATIE coffee genebank is at lower altitude than optimal for many of the accessions. The parcel of land where the field collection is located also has poor drainage in part of the area. These conditions have had a negative effect on tree longevity, bean quality and adaptation of the materials. According to CATIE staff, losses of materials occurs mainly due to the age of the trees in the field, with about 90% of them being 40 years or older. Low funding of the collection limits field maintenance activities, appropriate agronomic management and increases the risk of losing materials. Since older materials are more sensitive to pests and diseases, the genebank needs to invest significant amount of resources in regeneration.

The current regeneration backlog at CATIE is about 720 accessions that need to be urgently replanted, but at a rate of 30 accessions per year this would take about 24 years or more. A crucial activity in regeneration is grafting. The aim is to maintain four to six trees to represent each accession in the field. However, since not all trees survive, CATIE staff has to make 3 replicates per individual. Consequently, it is necessary to have at least 12 successful grafts if the number of individuals per accession in the field is going to be 4 (3 replicates * 4 individual trees), or 18 successful grafts (3 replicates * 6 individual trees) if the number of individuals per accession in the field is going to be 6. A normal rate of success in grafting is 80%.

Thus to regenerate the 29 accessions reported in 2015, CATIE staff have to perform 500 grafts or more. In order to increase the number of accessions regenerated, the genebank would need to hire a grafter and a field worker.

With these additional staff, the genebank would be able to regenerate an estimated total of 150 accessions per year (equivalent to performing 2000 grafts each year) and could be up to date with the propagation needs in about 5 years. The most significant cost for propagating an accession is the time of the permanent staff (quasi fixed costs) dedicated to this operation. If we account for the additional labor costs of propagating 150 accessions and the additional costs of supplies, the total annual costs of propagation would be at least US$63,800 (or about US$320,000 in 5 years). This estimation has not considered the additional cost of equipment.

CATIE staff estimates that with a younger collection this loss rate would be reduced dramatically. The center is proposing a transfer of the collection to a new location as a way to renew the materials and reduce loss. The estimated transfer cost totals US$780,205 distributed over 4 years. This total includes only the costs of transfer from field preparation and propagation of materials. No other genebank operation is considered in this figure. The first two years would demand more resources as well as staff time. The first year would entail the preparation of the field and the materials, which would be planted in the second year. In the third year, the materials in the field would be monitored to make sure they have properly established and if not would be replaced. This work would continue and by the end of the fourth year the collections would be completely transferred.

Only CATIE's core collection is safety duplicated in the field and has been done in collaboration with World Coffee Research (WCR). In 2015, 800 accessions of C. arabica as well as other species and cultivars of Coffea were characterized using molecular markers by WCR. From these 800, 100 were selected as a core collection. This core collection was regenerated and duplicated in three sites in Costa Rica and at WCR's farm in El Salvador. The institute currently does not have plans to expand the size of the safety duplication. The institute does have plans to duplicate part of the collection in a higher location in Costa Rica for quality evaluation purposes. Safety duplication is a standard practice that is particularly relevant in the case of CATIE because the institute holds the only internationally available collection of coffee germplasm under the ITPGRFA.

The use of CATIE as study case for the costing relies mainly on the international public status of the materials conserved. Clearly, maintaining a coffee field genebank is an expensive activity but understanding the use of resources can help guide the conservation strategy and management of human and financial resources. So, while the actual cost may differ from genebank to genebank, the categories of cost for routine operations, the level of optimization of these activities, and the urgent need to upgrade facilities, staff, or operations is consistent across the genebanks that responded to the survey and were visited.

If we were to assume that the routine operational cost at CATIE was an average across the 32 major collections we surveyed, we would estimate that the annual routine cost for coffee ex situ conservation globally is at least 8 million USD. This is a bargain when you consider the opportunity value that these conserved genetic resources have to future production, processing, marketing, and consumption of coffee globally but this is also the annual cost for a global conservation system that is currently not cost effective, secure, rational or available to users.

GLOBAL CONSERVATION STRATEGY FOR COFFEE GENETIC RESOURCES

GLOBAL STRATEGY TO SECURE CONSERVATION AND USE OF COFFEE GENETIC RESOURCES FOR THE LONG TERM

Based on both the survey and site visits, conclusions can be drawn about the current global system for conservation of coffee ex situ collections.

The first observation is that it is not a system. The current situation is of a set of nationally focused collections that are isolated from each other and from external users. In most of the institutions involved, the aim of conservation of the collection is to make it available to its own breeding program. The collections held mainly for conservation that we visited were the collection of EBI in Ethiopia, FOFIFA collection in Madagascar, and CNRA in Cote d'Ivorie.

Generally, there were two types of accessions conserved in genebanks surveyed or visited. All but one of the genebanks conserved a set of 'international' accessions that have been widely shared across many genebanks in the past. This includes the accessions collected by FAO, IRD, and IPGRI in the past, those shared by CIFC-IICT in the past effort to manage coffee leaf rust resistance, a limited set of wild Coffea species (other than C. arabica or C. canephora), and the more important products of breeding programs that have been widely shared in the past. These are common and widely duplicated across the genebanks surveyed. Much is known about these accessions, and they have had some use, though information is scattered and mistakes may have occurred in labeling in the past. The other type of accessions found in the current global system are local and unique. These have been collected from farmers and/or the forest but have not been widely shared, used, or securely conserved. They are linked to coffee genetic resources that remain in farmers' fields or in forests, some with in situ designation. They are likely to capture and maintain a wider range of locally adapted genetic diversity than the international accessions. These accessions are found in genebanks such as EBI in Ethiopia for C. arabica, FOFIFA in Madagascar for Malagasy wild species, and CNRA in Cote d'Ivoire for C. canephora. These unique local accessions are mainly found in Africa, where they are facing many threats. The unique wild species found in the Asia-Pacific region are not currently conserved in ex situ collections.

Generally, in most institutions, conservation of the collection is secure due to the dedication and commitment of the institutes and their staff. Everyone is challenged, to some degree, to cover the annual cost for the routine conservation operations. The costing study for CATIE demonstrates the longer-term implications of neglect when funds are inadequate. Currently there is very limited sharing of accession-level information, especially outside the institution maintaining the material. The only significant sharing of information on accessions is through scientific publications. There is limited genotyping and evaluation of accessions. Constraints to germplasm conservation and use are related to lack of policies regarding ABS. There is little or no safety duplication, except for international accessions.

Those few genebanks with unique local accessions have no safety duplication. The collections in Africa are still adding accessions with a continued focus on gap filling. They have links to protected sites but this needs to be formalized and strengthened. Outside of Ethiopia, designation of protected areas and monitoring does not give priority to coffee genetic resources, with very limited complimentary conservation in genebanks to increase security for in situ conservation and serve as sources of plant material for any reforestation efforts.

The current "system" is not sustainable, secure, cost effective, or rational. What is needed is a global system that will secure unique accessions as a global resource for use by future generations. These accessions could be conserved in genebanks, in situ sites or both ex situ and in situ. The basic principles for this global conservation system for coffee are:

- Key collections capable of maintaining sufficient accessions to adequately cover the genetic diversity of the genepool should be managed sustainability for the long term with reliable resources for routine conservation activities, including international distribution.
- The conservation of coffee in all collections need to meet international genebank standards, ensured by a quality management system, including clearly documented standard operating procedures, safety duplication, and a comprehensive risk management strategy.
- Globally, accessions held in collections need to be rationalized to minimize unnecessary redundancies.

OVERLOOKING A LOCAL COFFEE FARM IN COSTA RICA.

- All accessions should be healthy and available to users in a timely fashion within the framework of an ABS with terms and conditions that facilitate germplasm exchange.
- The users of collections should be able to search for, select and order germplasm from the collections, and provide feedback on accession level information from characterization, evaluation or use through a comprehensive, integrated accession-level information system.
- There should be strong links of ex situ conservation with in situ and on farm conservation efforts.
- Global collaboration on conservation, breeding, and research should be promoted to enhance the conservation and use of coffee genetic resources.

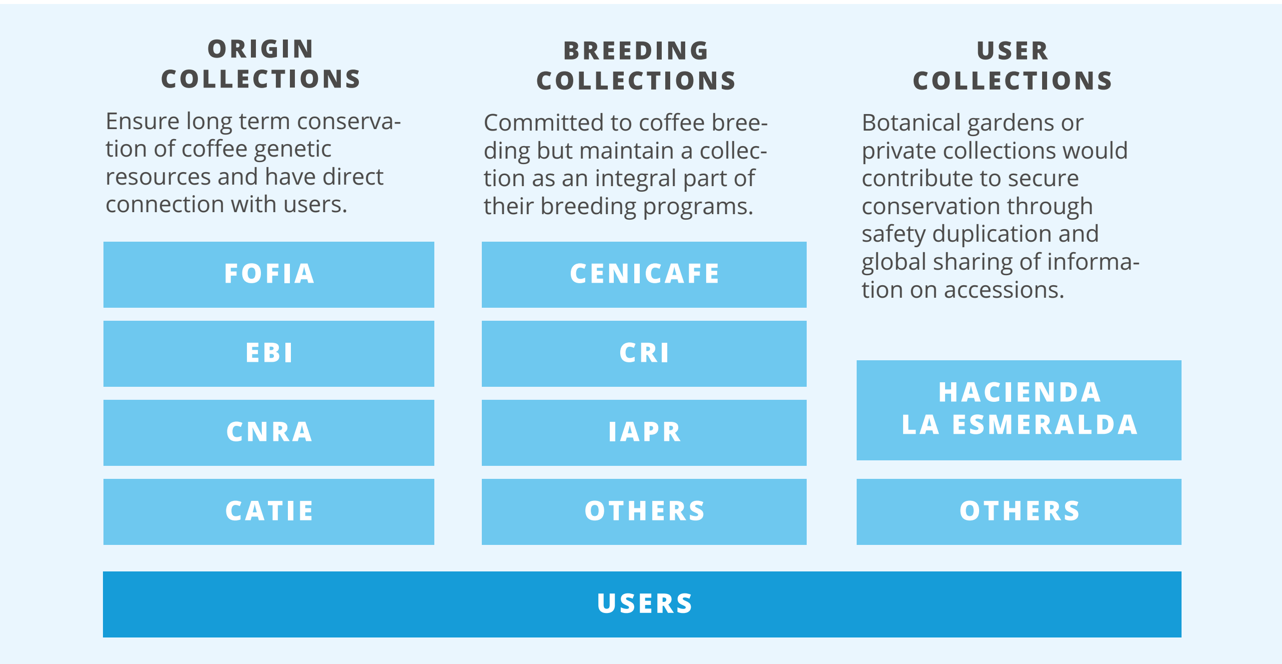
Global conservation strategies developed by crop communities, such as the ones facilitated by the Crop Trust since 2006, are a way to facilitate the process of transition from the current situation to a more global system that will secure long-term conservation and use. The strategy should include a clear description of the global system being aimed at, and agreed upon priority actions required with adequate resources to allow implementation. Constraints to germplasm conservation and use are related to lack of policies regarding ABS. There is little or no safety duplication, except for international accessions.

GLOBAL SYSTEM FOR EX SITU CONSERVATION AND USE

There are two categories of collection holders in the global ex situ conservation system for coffee, 'origin' and 'user'. From the survey and the visits, CNRA in Cote d'Ivoire, EBI in Ethiopia, and FOFIFA in Madagascar are classified as 'origin' collections. The origin collections hold mainly accessions collected from farmers' fields or forests in the centers of origin. These key collections mainly conserve local, unique accessions in complementarity to farmers' fields or in the forest in in situ protected sites. The main focus of these genebanks is long-term conservation but they could also be users of their own collections. They have opportunities to be directly engaged with in situ conservation efforts. Complementary to the true 'origin' collections is that of CATIE. Although it mainly conserves international accessions, this genebank has special status as the only international collection recognized by the ITPGRFA under Article 15. For the future, these key origin genebanks need to be linked to each other and made accessible to users. Their secure conservation needs to be assured. The role of the origin collections in the global conservation system is:

- Secure long term conservation of a significant amount of the local genetic diversity,
- Contribute to the secure conservation of the international accessions, especially those best adapted to their locality,
- Globally share all accession level information,
- Safety duplication of their collections, with other genebanks and/or in cryopreservation,
- Facilitate access and benefit sharing of their conserved germplasm,
- Engage actively with in situ conservation,
- Collaborate globally with each other and other genebanks for capacity building, conservation research, development of best management practices, characterization or evaluation of their accessions, and utilization,
- Through their interaction and activities, facilitate the development of the global system for conservation and use.

The global conservation system also includes user collections held by institutions that mainly have a commitment to coffee breeding, but maintain a germplasm collection as an integral part of their breeding programs. They hold international accessions of various species, breeding program products, interspecific crosses, and some local accessions from farmers and the forest. They have a commitment to conservation of most of their collections as a key input to the breeding efforts. Some of the institutes in the survey and the site visits have small, dynamic collections while others have demonstrated longer-term commitment to the accessions that they have acquired. Some also have an interest in conservation as a routine operation and as a research area. Examples are CRI in Kenya, CENICAFE in Colombia, and IAPR in Brazil as well as most of the genebanks who responded to



the survey. The key roles for the user collections in the global system are:

- Secure medium to long term conservation of international and unique accessions as part of a rational global system,
- Globally share all accession level information,
- Safety duplication of their collections with other genebanks or field sites and/or in cryopreservation,
- Securely conserve accessions they host that have been safety duplicated from original collections and other genebanks,
- Facilitate access and benefit sharing of accessions they conserve as well as utilize,
- Collaborate globally for capacity building, conservation research, and development of best management practices, characterization or evaluation of their accessions, and utilization,
- Through their interaction and activities, facilitate the development of the global system for conservation and use.

Other collections, such as those held by botanical gardens or private individuals can also be consider as part of this global system if they are willing to contribute to secure conservation through safety duplication and global sharing of information on accessions. They could also share germplasm and engage in research partnerships but to a limited degree globally.

For the various collections to collaborate globally to secure conservation, meet capacity development needs, conduct research or to facilitate use, there is a need to link the origin and user collection holders together as well as to coffee genetic resource users. The establishment of a global conservation and use platform will increase the opportunity and benefits for global collaboration. Generally, the key focal areas for the global platform could be to:

- Increase long-term support for the ex situ and in situ conservation of coffee genetic resources through collaboration, communications, advocacy, and funding
- Facilitate global accession level information sharing
- Establish a genebank monitoring system that is based upon a quality management system with key performance indicators. These indicators should relate to security of conservation, degree of safety duplication, availability of accession for distribution, degree of accession level information sharing and impact on accession use through distribution.
- Share innovative conservation approaches and research alternatives for increasing the cost effectiveness and security of conservation.
- Facilitate a global effort to conduct molecular characterization of genebank accessions to enhance the assessment and monitoring of genetic diversity within and across collections, enhance the use of genomics, define core collections, and facilitate rationalization of accessions.
- Facilitate the global or regional evaluation of accessions for high priority traits and the sharing of the accession level results.
- Identify and fill significant gaps in global collections that are at high risk of loss.
- Negotiate standard terms for access and benefit sharing to facilitate sharing and use of conserved germplasm, both ex situ and in situ.
- Set targets for global system and the conservation strategy.
- Facilitate global responses for emergency needs of at risk collections

The global platform should initially be setup virtually to primarily enhance knowledge sharing and partnership building. Membership by institutions and individuals should be voluntary. Members would register online and be required to share key baseline information on their collection, breeding program, or research effort. The platform should be led by a minimal secretariat to mainly manage the platform website and promote collaboration.The membership would operate through specialist working groups on the key focal areas such as those identified in the above list. Increased activities and support for actions in these focal areas will be the result of greater communications, joint planning, and knowledge sharing between collections and with users. The key question is how is its sustainability to be assured? One option would be to link the global platform leadership to existing global or regional organizations or industry partnerships. There are many options that can be explored for the form of the platform but its key function must be to secure long-term conservation and use of coffee genetic resources through action taken by a sustained partnership between conservers and users.

PRIORITY ACTIONS TO SECURE CONSERVATION AND USE

Currently, individual collections within institutes rely upon internal resources from the coffee breeding programs or the institution budget. In the past, there have been regional or global efforts in collection, enhanced breeding for specific high priority traits, or genetic diversity assessment. There have not been global efforts to secure the conservation of coffee genetic resources. Thus, there is an urgent need to find the resources needed to secure key collections, make investments into information system for individual genebanks and globally, establish the global platform for collaboration, and fill critical gaps in collections and capacity. To enhance this effort, there is also a need to recognize the collective responsibility that governments, producers, processors, and consumer have for this key resource. The current coffee value chain globally has inequity in terms of allocation of value to production by farmers in producing countries versus value addition for processing and marketing in consuming countries. Sustainability of the global commodity chain will depend upon research and development built upon the coffee germplasm conserved for future use. There is a need to find a way to balance out the share of the value addition in consuming countries to support R&D and germplasm conservation in Africa, where the key species originated and still found in the tropical forest. This support will need to come from industry and consumers. Through the global conservation strategy development, six high priority actions have been identified to facilitate the transition from the current 'system' to a global conservation system for coffee. These are described below, but have not been prioritized yet. These actions are interconnected and dependent upon each other. It is clear that there is an overall need to ensure conservation through stable funding and short term upgrading of facilities and capacity if we are to secure coffee genetic resources for use by future generations. In addition, enhanced utilization through better facilitated access and accession level information sharing are also very important.

1 SECURING STABLE FUNDING FOR LONG TERM CONSERVATION

The origin collections at the heart of the global conservation strategy for coffee require constant and long-term maintenance in the field. Even brief disruptions or variations in funding can leave materials at risk of permanent loss. Ensuring long-term support for routine conservation of the key 'origin' collections plus CATIE will best be done through the currently existing, international, permanent, self-sustaining Crop Trust Endowment Fund. This endowment fund is managed and governed by the Global Crop Diversity Trust, an international organization with a mission to ensure the conservation and availability of crop diversity for food security worldwide.

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Contributions made to this endowment fund by government, industry, or individual donors will be invested securely for the long term and to generate interest that will be used on an annual basis. Thus, the support provided by the Crop Trust Endowment Fund comes solely from investment income earned, leaving the endowment itself untouched. Each year, a portion of the fund's value will be paid out to ensure conservation through secure routine operations to maintain accessions held in these key genebanks. The conservation of coffee diversity in genebanks is by nature a very long-term task. Only stable, predictable support from an endowment fund can guarantee a global system of conservation for a resource that is conserved in such a manner as coffee.

The routine conservation needs for the four key 'origin plus CATIE' collections is estimated to require around USD 1 million per year, based upon the costing study of CATIE. To ensure this adequate annual support will therefore require a USD 25 million contribution to the Crop Trust Endowment Fund.This level will allow the Crop Trust to draw USD 1 million in average annual investment income from the Endowment Fund, at an average investment return of 4.0% per year, while also safeguarding the real value of the Endowment against inflation. As the endowment would provide the necessary funds on a yearly basis for the long term, there will be no need to seek additional funding year to year for the routine maintenance of the origin collections, as well as CATIE.

The Crop Trust Fund can only support collections that meet the eligibility requirements of the Fund Disbursement Strategy of the Crop Trust. Some of the key eligibility criteria are that the accessions held in the collection are of global significance; supportive of a rational, cost effective, and sustainable global system; and that the accessions held are available to users upon request under an ABS framework such as the ITPGRFA. Currently, only one collection, CATIE, would meet all these eligibility criteria. It seems that given the more international nature of the CNRA collection, especially the C. canephora accessions, it is possible that accessions in this origin collection could be made more readily available in the near future. Over time, it is hoped that the availability of the accessions held in Ethiopia and Madagascar could be resolved, since that is the only criteria that is lacking for their eligibility. Thus, the longer-term target for the Crop Trust Endowment Fund is to cover the annual routine operations cost for all four collections, although the longer-term need for the CATIE collection is unclear if C. arabica accessions were available from EBI in Ethiopia. The CATIE collection could be supported in the future as a long-term safety back up of significant African origin collections in a different continent.

Meeting the eligibility criteria of the Crop Trust Endowment Fund is an important first step for long-term support, but receipt of that support depends upon the eligible collection holder meeting international genebanks standards and operating in a routine manner.To judge this, a genebank must meet key performance targets for security, availability, safety duplication, and information sharing. Currently none of the four eligible collections would qualify to receive support from the Crop Trust Endowment Fund until they have meet these targets. Thus, annual funds would need to be resourced initially to upgrade the four collections to meet these standards and targets.

2 UPGRADE FACILITES AND CAPACITY

For the four origin genebanks, that includes CATIE, there will be a need to upgrade their operations, facilities, and build capacity to meet international standards and to facilitate their routine operations. Also in the survey and the visits, there was a recognition of urgent needs to upgrade facilities and capacity in both origin and user collections. This includes accession-level information systems that are linked globally, more secure genebank operations, and capacity building. The total cost of these upgrades will still need to be determined, but a global effort to address these needs and to increase safety duplication of accessions needs to be supported. Currently, many genebanks operate at less than optimal level with a high risk of loss of accessions, especially with the increased impact of climate change at the genebank sites. The development of a global initiative to assess the specific upgrade needs, determine the urgency of the actions required, and implement these upgrades with adequate resources is needed.

3 ACCESS AND BENEFIT SHARING FOR GERMPLASM EXCHANGE

There is a general recognition that increased germplasm exchange and use of conserved germplasm is needed. The current constraint to exchange is the lack of a clear ABS mechanism. Coffee is not part of the ITPGRFA as a crop listed on Annex I so it is assumed that an ABS will be formed around the terms and conditions of the Nagoya protocol. This is not being done in most cases in a manner that facilitates exchange or use of the collections in varietal development. Thus, the establishment of a legally binding ABS regime for the origin collections in congruence with the Nagoya Protocol and the ITPGRFA is a high priority action for ensuring their long-term conservation, but negotiating a general framework for this ABS amongst all genebanks is also a high priority to facilitate overall germplasm conservation and exchange.

4 LINKING COLLECTIONS THROUGH PARTNERSHIPS AND INFORMATION SHARING

There is a need to secure the resources to enhance the long term linking of collections and users for a secure global system. The establishment of the global platform for collaboration in coffee genetic resources conservation and use will be the priority. The initial focus of the global platform would be to facilitate global sharing of accession-level information through Genesys, an existing global accession level information-sharing platform.

5 SAFETY DUPLICATION

There is an urgent need to ensure the safety duplication of all conserved accessions. The role for cryopreservation or other complementary strategies needs to be explored globally through strategic research. Currently cryopreservation is only being used in a limited manner and its wide application is not clear, either globally or locally. In addition, efforts need to be made by individual collection holders to safety duplicate their accessions in additional field sites within and outside the country. Agreed international standards for safe transfers of coffee planting material and safety duplication for coffee genetic resources will be an important first step.

6 COMPLEMENTARY IN SITU CONSERVATION

Genebanks need to actively engage with in situ or protected area conservation. In some cases, species have disappeared from their original sites and the ex situ collections are the sole source of live materials. Efforts in reforestation or protection will be enhanced with the engagement of the expertise at and germplasm held by the genebanks.

GLOBAL CONSERVATION STRATEGY FOR COFFEE GENETIC RESOURCES

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ANNEXES

ANNEX I
ACRONMYNS

ABS . . . . . Access and Benefit Sharing

ACRN . . . . African Coffee Research Network

AFLP . . . . Amplified Fragment Length Polymorphism

ASIC . . . . Association Scientifique International du Café

BEC . . . . . Biodiversity Ecovolarisation et Cafeiers Foundation

CATIE . . . . Centro Agronomico Tropical de Investigacion y Ensenanza, Costa Rica

CBB . . . . . Coffee Berry Borer

CBD . . . . . Convention on Biological Diversity

CBD . . . . . Coffee Berry Disease

CENICAFE . Centro National de Investigaciones de Café, Colombia

CGIAR . . . Consultative Group on International Agricultural Research

CIFC-IICT . Centro de Investigação das Ferrugens do Cafeeiro, Portugal

CIRAD . . . Centre de Cooperation Internationale en Recherche Agronomique pour le Développement, France

CLR . . . . . Coffee Leaf Rust

CNRA . . . . Centre National de la Recherche Agronomique, Cote d'Ivoire

CRF . . . . . Coffee Research Foundation, Kenya

DRC . . . . . Democratic Republic of Congo

EBI . . . . . Ethiopian Biodiversity Institute

EPAMIG . . Empresa de Pesquisa Agropecuária de Minas Gerais, Brazil

EWNHS . . Ethiopian Wildlife and Natural History Society

FAO . . . . . Food and Agriculture Organization of the United Nations, Rome, Italy

FOFIFA . . . National Center of Applied Research and Rural Development, Madagascar

GCQRI . . . Global Coffee Quality Research Institute (now known as World Coffee Research-WCR)

IAC . . . . . Instituto Agronomico de Campinas, Brazil

IACO . . . . Inter-African Coffee Organization

IAPAR . . . Instituto Agronomico do Parana, Brazil

IBPGR. . . . International Board for Plant Genetic Resources (later known as IPGRI and now known as Bioversity International)

ICGN . . . . International Coffee Genomics Network

INERA . . . Institut National pour l'Etude et la Recherche Agronomiques, Democratic Republic of Congo (DRC)

IPGRI . . . . International Plant Genetic Resources Institute (now known as Bioversity International), Rome, Italy

IRCC . . . . Institut de Recherches du Cafe et du Cacao (now known as Centre National de la Recherche Agronomique), Cote d'Ivoire

IRD . . . . . Institut de Recherche pour le Développement

ITPGRFA . . International Treaty on Plant Genetic Resouorces for Food and Agriculture

JARC . . . . Jimma Agricultural Research Center, Ethiopia

KALRO . . . Kenya Agricultural and Livestock Research Organization

KCRS . . . . Kianjavato Coffee Research Station, Madagascar

MAT . . . . Mutually Agreed Terms

MLS . . . . Multilateral System

NABU . . . Nature and Biodiversity Conservation Unit (NABU), Ethiopia

NCGRP . . . National Center for Genetic Resources Preservation, Fort Collins, USA

NGO . . . . Non-Governmental Organization

ORSTOM . Office de la Recherche Scientifique et Technique Outre-Mer (now known as Institute de Recherche pour le Développement – IRD), France

PGRC . . . . Plant Genetic Resources Center, Ethiopia (now known as EBI)

PIC . . . . . Prior Informed Consent

SCAA . . . . Specialty Coffee Association of America

SMTA . . . . Standard Material Transfer Agreement

SNP . . . . . Single Nucleotide Polymorphism

SSR . . . . . Simple Sequence Repeats

TARO . . . . Tanzania Agricultural Research Organization

TC . . . . . . Tissue Culture

TWCP . . . The Wild Coffee Project, Kibale, Uganda

UCC . . . . . Ueshima Coffee Corporation

UC, Davis . University of California, Davis

USDA . . . . United States Department of Agriculture

USDA-ARS . United States Department of Agriculture – Agricultural Research Service

WCR . . . . World Coffee Research

ZEF . . . . . Center for Development Research, University of Bonn

ANNEX II
LIST OF COFFEE SPECIES

NO.	SPECIES	DISTRIBUTION
1	*Coffea abbayesii*	South-east Madagascar (Parc National d'Andohahela)
2	*Coffea affinis*	West Tropical Africa (Guinea, Ivory Coast, Sierra Leone)
3	*Coffea alleizettii*	Central Madagascar (Anjozorobe)
4	*Coffea ambanjensis*	North-west Madagascar (Sambirano Region)
5	*Coffea ambongensis*	West Madagascar (Mahajanga Province)
6	*Coffea andrambovatensis*	East Madagascar (Andrambovato)
7	*Coffea ankaranensis*	North Madagascar
8	*Coffea anthonyi*	West-central Tropical Africa (south Cameroon, north-west Congo)
9	*Coffea arabica*	North-east Tropical Africa (south-west Ethiopia west of the Great Rift Valley, Boma Plateau in South Sudan, Mt. Marsibit in Kenya)
10	*Coffea arenesiana*	East Madagascar
11	*Coffea augagneurii*	North Madagascar (exclusively confined to Montagne d'Ambre)
12	*Coffea bakossii*	West Cameroon (Mt. Kupe and Bakossi Mountains)
13a	*Coffea benghalensis var. bababudanii*	Western India (Bengal to Orrisa)
13b	*Coffea benghalensis var. benghalensis*	India, Nepal, Bhutan
14	*Coffea bertrandii*	South Madagascar (Taolanaro region)
15	*Coffea betamponensis*	East Madagascar (Reserve Naturelle Integrale Betampona)
16	*Coffea bissetiae*	West Madagascar (Mahajanga Province)
17	*Coffea boinensis*	West Madagascar (Mahajanga Province, Parc National d'Ankarafantsika)
18a	*Coffea boiviniana ssp. boviniana*	North Madagascar
18b	*Coffea boiviniana ssp. drakei*	North-west Madagascar
19	*Coffea bonnieri*	North Madagascar (Montagne d'Ambre and Mont Anjenabe)
20	*Coffea brassii*	Papua New Guinea (Central Province) and Australia (Torres Strait Islands, Queensland)
21	*Coffea brevipes*	West-central Tropical Africa (south Cameroon, Congo, Democratic Republic of Congo, Gabon)
22	*Coffea bridsoniae*	North-east Tanzania (East Usumbara Mountains)
23	*Coffea buxifolia*	Central Madagascar (Central Highlands)
24	*Coffea canephora*	West Tropical Africa (Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Nigeria); west-central Tropical Africa (Cabinda, Cameroon, Congo, Central African Republic, Democratic Republic of Congo, Gabon); north-east Tropical Africa (Sudan, South Sudan); east Tropical Africa (Tanzania, Uganda); south Tropical Africa (Angola)
25	*Coffea carrissoi*	Angola
26	*Coffea charrieriana*	Cameroon (Bakossi Mts.)
27	*Coffea cochinchinensis*	Cambodia and Vietnam
28	*Coffea commersoniana*	South-east Madagascar (Taolanaro region)
29	*Coffea congensis*	West-central Africa (Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Gabon)
30	*Coffea costatifructa*	East Tanzania (Rufiji District, Kilwa District, Mafia Isl.)
31a	*Coffea coursiana ssp. coursiana*	East Madagascar
31b	*Coffea coursiana ssp. littoralis*	East Madagascar
32	*Coffea dactylifera*	Democratic Republic of Congo (Central Forest District: Bambesa and Yangambi)
33	*Coffea decaryana*	West Madagascar (Reserve Naturelle Integrale Namaroka)
34	*Coffea dubardii*	North and north-west Madagascar
35	*Coffea ebracteolata*	West Tropical Africa

NO.	SPECIES	DISTRIBUTION
36	*Coffea eugenioides*	West-central Tropical Africa (Burundi, Rwanda, Democratic Republic of Congo); north-east Tropical Africa (Sudan and South Sudan); east Tropical Africa (Kenya, Tanzania, Uganda)
37	*Coffea fadenii*	Kenya (Teita Hills) and Tanzania (Pare Mountains)
38	*Coffea farafanganensis*	South-east Madagascar
39	*Coffea floresiana*	Lesser Sunda Islands
40	*Coffea fotsoana*	South-west Cameroon (Mbam Minkom)
41	*Coffea fragilis*	Madagascar
42	*Coffea fragrans*	Bangladesh
43	*Coffea gallienii*	North Madagascar (Montagne d'Ambre)
44a	*Coffea grevei ssp. grevei*	West Madagascar
44b	*Coffea grevei ssp. mahajangensis*	North west Madagascar
45	*Coffea heimii*	North Madagascar
46	*Coffea heterocalyx*	South-west Cameroon (Yaounde region)
47	*Coffea homollei*	East Madagascar
48	*Coffea horsfieldiana*	Java
49	*Coffea humbertii*	South-west Madagascar
50	*Coffea humblotiana*	Comoros
51	*Coffea humilis*	West Tropical Africa (south-west Ivory Coast, Liberia, Sierra Leone)
52	*Coffea jumellei*	North Madagascar
53	*Coffea kapakata*	West Angola
54	*Coffea kianjavatensis*	East Madagascar (Kianjavato)
55	*Coffea kihansiensis*	Central Tanzania (Kihansi River Gorge, Udzungwa Mountains)
56	*Coffea kimbozensis*	East Tanzania (Morogoro: Kimboza Forest Reserve)
57	*Coffea kivuensis*	East Democratic Republic of Congo (Lake Kivu area)
58	*Coffea labatii*	West Madagascar
59a	*Coffea lancifolia var. auriculata*	East Madagascar
59b	*Coffea lancifolia var. lancifolia*	East Madagascar
60	*Coffea lebruniana*	West and Central Tropical Africa
61	*Coffea leonimontana*	South-west Cameroon (Douala region)
62	*Coffea leroyi*	East Madagascar
63	*Coffea liaudii*	East Madagascar
64a	*Coffea liberica f. bwambensis*	Uganda
64b	*Coffea liberica var. dewevrei*	West-central Tropical Africa (Central African Republic, Democratic Republic of Congo); west Uganda; north-east Tropical Africa (Sudan, South Sudan)
64c	*Coffea liberica var. liberica*	West Tropical Africa (Benin, Ghana, Guinea, Ivory Coast, Liberia, Nigeria); west-central Tropical Africa (Annobon, Cabinda, Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Gabon); north-east Tropical Africa (Uganda); south Tropical Africa (Angola)
65	*Coffea ligustroides*	East Zimbabwe (Chirinda)
66	*Coffea littoralis*	North-east Madagascar (Iherana)
67	*Coffea lulandoensis*	Central Tanzania (Mufindi: Lulanda Forest Reserve)
68	*Coffea mabesae*	Philippines
69	*Coffea macrocarpa*	Mauritius
70	*Coffea madurensis*	Java (Madura Islands)
71	*Coffea magnistipula*	South-west Cameroon, west Gabon
72	*Coffea malabarica*	Western India
73	*Coffea mangoroensis*	East Madagascar (mostly in the Moramanga region)
74	*Coffea mannii*	West and Central Tropical Africa

NO.	SPECIES	DISTRIBUTION
75	*Coffea manombensis*	South-east Madagascar (Reserve Speciale de Manombo)
76	*Coffea mapiana*	South Cameroon
77	*Coffea mauritiana*	Mauritius, Reunion
78	*Coffea mayombensis*	West Tropical Africa (Nigeria); west-central Tropical Africa (Cabinda, west Cameroon, Gabon, west Congo, west Democratic Republic of Congo); south Tropical Africa (north-west Angola)
79	*Coffea mcphersonii*	North-east Madagascar (Iherana)
80	*Coffea melanocarpa*	Cabinda and Angola
81	*Coffea merguensis*	Myanmay, Thailand, Vietnam
82	*Coffea millotii*	East Madagascar
83	*Coffea minutiflora*	South-east Madagascar (Ivohibe-Faranfangana)
84	*Coffea mogenetii*	Northg Madagascar (Montagne d'Ambre)
85	*Coffea mongensis*	East Tanzania
86	*Coffea montekupensis*	South-west Cameroon (Mt. Kupe and Bakossi Mts.)
87	*Coffea montis-sacri*	East Madagascar (Mount Vatovavy)
88	*Coffea moratii*	West Madagascar (Reserve Tsingy de Bemaraha)
89a	*Coffea mufindiensis ssp. australis*	South Tropical Africa (south Malawai, west Mozambique, east Zimbabwe)
89b	*Coffea mufindiensis ssp. lundaziensis*	South Tropical Africa (north Malawai, north Zambia)
89c	*Coffea mufindiensis ssp. mufindiensis*	Tanzania
89d	*Coffea mufindiensis ssp. pawekiana*	North Malawi
90	*Coffea myrtifolia*	Mauritius
91	*Coffea namorokensis*	Madagascar
92	*Coffea neobridsoniae*	India
93	*Coffea neoleroyi*	Ethiopia, Uganda
94	*Coffea perrieri*	Madagascar
95	*Coffea pervilleana*	North Madagascar (incl. Nosi Be Isl.)
96	*Coffea pocsii*	East Tanzania (Morogoro: Kitulanghalo forest reserve; Bagamoyo: Zaraninge forest reserve)
97	*Coffea pseudozanguebariae*	East Tropical Africa (south-east Kenya, north-east Tanzania incl. Zanzibar)
98	*Coffea pterocarpa*	West Madagascar
99	*Coffea racemosa*	Southern Tropical Africa (Mozambique, Zimbabwe); southern Africa (KwaZulu-Natal); western Indian Ocean (Mozambique Channel Is.)
100	*Coffea rakotonasoloi*	East Madagascar (Reserve Speciale d'Ambatovaky)
101	*Coffea ratsimamangae*	North Madagascar
102	*Coffea resinosa*	East Madagascar
103	*Coffea rhamnifolia*	North-east Tropical Africa (south-east Somalia); east Tropical Africa (north-east Kenya)
104	*Coffea richardii*	East Madagascar
105	*Coffea sahafaryensis*	North-east Madagascar
106	*Coffea sakarahae*	South (central) Madagascar
107	*Coffea salvatrix*	East Tropical Africa (south-west Tanzania); south Tropical Africa (Malawi, Mozambique, Zimbabwe)
108	*Coffea sambavensis*	North-east Madagascar
109	*Coffea sapinii*	Democratic Republic of Congo
110	*Coffea schliebenii*	South-east Tanzania
111	*Coffea semsei*	Tanzania
112a	*Coffea sessiliflora ssp. mwasumbii*	North-east Tanzania (Dar es Salaan – Kisarawe region)
112b	*Coffea sessiliflora ssp. sessiliflora*	South-east Kenya
113	*Coffea stenophylla*	West Tropical Africa (Guinea, Ivory Coast, Sierra Leona)
114	*Coffea tetragona*	North-west Madagascar

NO.	SPECIES	DISTRIBUTION
115	*Coffea togoensis*	West Tropical Africa (south Ghana, south Togo)
116	*Coffea toshii*	
117	*Coffea travancorensis*	Southern India, Sri Lanka
118	*Coffea tricalysioides*	North Madagascar
119	*Coffea tsirananae*	North Madagascar
120	*Coffea vatovavyensis*	East Madagascar (Vatovavy)
121	*Coffea vavateninensis*	East Madagascar (Vavatenina)
122	*Coffea vianneyi*	South-east Madagascar
123	*Coffea vohemarensis*	North-east Madagascar
124	*Coffea wightiana*	Southern India, Sri Lanka
125	*Coffea zanguebariae*	East Tropical Africa (south Tanzania); south Tropical Africa (north Mozambique)

SOURCE: WCSP: WORLD CHECKLIST OF SELECTED PLANT FAMILIES (HTTP://APPS.KEW.ORG/WCSP/QSEARCH.DO)

ANNEX III
COFFEE EX SITU FIELD COLLECTIONS

Reported in Bettencourt and Konapka (1988), Dulloo et al (2009), FAO-WIEW database, Eira et al. (2007), Labouisse et al. (2008), Phiri (2013), and in the current study.

COUNTRY	INSTITUTION	BETTENCOURT & KONOPKA 1988	DULLOO ET AL. 2009	FAO WIEWS (1990-2011)	OTHER	GCDT-WCR SURVEY 2016
Australia	Queensland Government Department of Agriculture					67
Benin	Unite de Researche café et cacao (URCC)			28		
Brazil	Instituto Agronomico do Parana (IAPAR)		2,976	3,335		2,015
Brazil	Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG)		1,160		1,326[1]	1,596
Brazil	IAC, Instituto Agronómico de Campinas	305	5,101	4,152		
Brazil	Embrapa Café/ Instituto Capixaba de Pesquisa, Assistencia Technica e Extensao Rural (INCAPER)		375	200	375[1]	
Brazil	Univversidade Federal de Vicosa (UFV)				1,036[1]	
Brazil	Embrapa Café/ Fundacao Procafe				1,518[1]	
Brazil	Embrapa Rondonia			70	981[1]	
Cameroon	IRAD, Institut de la Recherché Agronomique	1,750	1,552			
Colombia	Centro Nacional de Investigaciones de Café Pedro Uribe Mejia (CENICAFE)	1,804	1,804	1,119		800
Congo	INERA, Institut National pour l'Etude et la Recherche Agronomique	58		58		
Costa Rica	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)	1,309	1,992	1,835		1,960
Costa Rica	Instituto del Café - Costa Rican Coffee Institute (ICAFE)			300		58
Côte d'Ivoire	Centre National de la Recherche Agronomique (CNRA)	6,990	8,003	7,500		6,900
Cuba	ECICC, Estación Central de Investigaciones de Café y Cacao			1,597		
Dominican Republic	Centro Norte de Investigaciones Agropecuarias y forestales (CENIAF)			14		
Ecuador	DENAREF, Departamento Nacional de Recursos Fitogenéticos y Biotecnología			229		
Ecuador	Estacion Experimental Pichillingue (EETP)			163		
Ethiopia	Ethiopian Biodiversity Institute (EBI)	522		1,273	5,196[3]	4,631
Ethiopia	Jimma Agricultural Research Center (JARC)	1,284	4,652	1,284	4,780[2]	
Ghana	CRIG, Cocoa Research Institute of Ghana			500		
Germany	Greenhouse for Tropical Crops, Institute for Production and Nutrition of World Crops, Kassel University (GHK)			10		
Guinea	CRAS-IRAG, Centre de Recherche Agronomique de Seredou			104		

COUNTRY	INSTITUTION	BETTENCOURT & KONOPKA 1988	DULLOO ET AL. 2009	FAO WIEWS (1990-2011)	OTHER	GCDT-WCR SURVEY 2016
Guyana	CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement			3,800		
India	Central Coffee Research Institute (CCRI)	611	575	575		353
Indonesia	Indonesian Coffee and Cocoa Research Institute (ICCRI)		1,637			
Kenya	Coffee Research Foundation (CRF)	634	2,507	513		800
Madagascar	Centre National de Recherche Appliquee au Developpement (FOFIFA)		171			407
Malaysia	Rice and Industrial Crop Research Center, MARDI (RIC, MARDI)			15		
Mexico	Banco Nacional de Germoplasma Vegetal, Departamento de Fitotecnia, Universidad Autonoma de Chapingo (UACH)			55		250
Mexico	INIFAP, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias			73		
Nigeria	National Center for Genetic Resources and Biotechnology (NACGRAB)			10		
Papua New Guinea	CIC, Coffee Industry Corporation Limited					90
Peru	Estacion Experimental Agraria Tulumayo (INIA-EEA.TUL)	99		99		169
Portugal	CIFC-IICT, Centro de Investigação das Ferrugens do Cafeeiro	82		71		
Puerto Rico	UPR, Estacion Experimental Agricola in Adjuntas, Universidad de Puerto Rico			70		
Reunion	Laboratoire des Ressources Génétiques et Amélioration des Plantes Tropicales, ORSTOM (ORSTOM-MONTP)			490		742
Rwanda	RAB, Station Rubona	139		139	182[4]	
Sri Lanka	Department of Export Agriculture (DEA)			15		
Taiwan	Chiayi Agricultural Experiment Station (TARI)			33		
Tanzania	Tanzania Coffee Research Institute (TaCRI)	94	110			
Thailand	Horticultural research Institute, Department of Agriculture (HRI-DA)			25		
United Kingdom	Millenium Seed Bank, KEW, Wakehurst (RBG)			10		
USA	Subtropical Horticultural Research Station,, USDA-ARS, Miami	304	300			
USA	USDA ARS - Kona HAWAI, US Department of Agriculture, Agricultural Research Service	33				
Uganda	NACORI, Coffee Research Center (COREC) part of National Crop Resources Research Institute (NaCRRI				120[2]	
Venezuela	INIA-Monages			51		
Venezuela	INIA - Táchira			254		
Vietnam	Ba Vi Coffee Center (CRC)			70		0
Vietnam	Coffee and Cocoa Research Institute			56		0

COUNTRY	INSTITUTION	BETTENCOURT & KONOPKA 1988	DULLOO ET AL. 2009	FAO WIEWS (1990-2011)	OTHER	GCDT-WCR SURVEY 2016
Vietnam	Plant Resources Center (PRC)-Subgenebank: **Northwestern Agro-forestry research and development center**					62
Vietnam	Plant Resources Center (PRC)-Sub genebank: **The Western Highlands Agriculture And Forestry Science Institute**			86		188
Zimbabwe	Coffee Research Institute			2	13[2]	
TOTAL		**16,018**	**32,915**	**30,283**		**21,026**

[1] EIRA ET AL. (2007) | [2] EIRA ET AL. (2007) | [3] LABOUISSE ET AL (2008) | [4] PHIRI (2013).

ANNEX VI
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Hernando Duque, Federación Nacional de Cafeteros, Colombia

James Drinnan, Department of Agriculture and Fisheries, Australia

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