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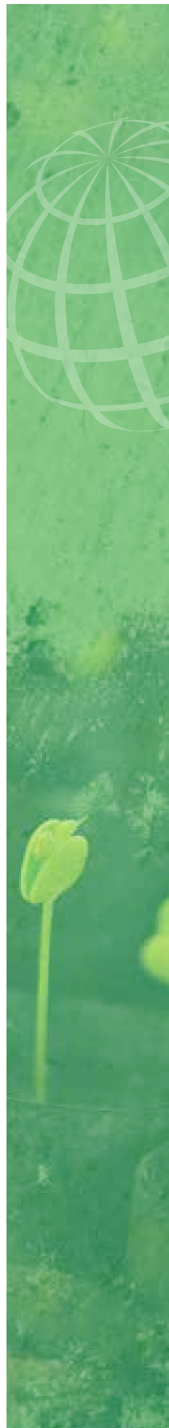
*THEMATIC STUDY*



# TREES, TREE GENETIC RESOURCES AND THE LIVELIHOODS OF RURAL COMMUNITIES IN THE TROPICS

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# Trees, tree genetic resources and the livelihoods of rural communities in the tropics


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# Contents

# About this publication

At its 12th Session in 2009, the Commission on Genetic Resources for Food and Agriculture (the Commission) requested the Food and Agriculture Organization of the United Nations (FAO) to prepare *The State of the World's Forest Genetic Resources*. It stressed that the preparation of this global assessment should be based primarily on country reports on forest genetic resources (i.e. heritable materials maintained within and among tree and other woody plant species that are of actual or potential economic, environmental, scientific or societal value), supported by thematic studies and other available information and knowledge on these resources.

Between 2009 and 2010, FAO, in collaboration with Bioversity International and the World Agroforestry Centre (ICRAF), informed and consulted the scientific community on the preparation of a series of thematic studies. Groups of experts were established for this purpose and the coordinators of the groups met twice in 2011-2012 to share information and to coordinate the work.

The Commission considered a draft of the global assessment at its 14th Session in April 2013 and, based on its findings, agreed on the *Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources* (Global Plan of Action). Subsequently, the FAO Conference adopted the Global Plan of Action at its 38th Session in June 2013. FAO then published *The State of the World's Forest Genetic Resources* (FAO, 2014a) and the Global Plan of Action (FAO, 2014b). In the same year, the expert groups also published the key findings of the thematic studies in a special issue of the journal *Forest Ecology and Management* (see Loo, Souvannavong and Dawson, 2014).

Several of the thematic studies included more analyses and in-depth discussions on various aspects related to the conservation, use and development of forest genetic resources than was possible to publish as scientific articles. Moreover, it was not possible to present in The *State of the World's Forest Genetic Resources* the wealth of information from the country reports and the thematic studies. Therefore, the Commission requested, at its 15th Session in 2015, FAO to make the country reports and the thematic studies available on its website.

This publication presents the thematic study on tree genetic resources and the livelihoods of rural communities in the tropics. It provides an overview of the significant benefits of harvesting non-timber forest products from natural and incipiently- or semi-domesticated forest landscapes. Furthermore, it discusses important products and services from a range of local and exotic trees, mostly semi-domesticated and under-researched, which are found growing in smallholders' agroforests. Finally, it also provides information on more widely researched woody perennial commodity crops that may be completely domesticated, are often exotic in their main production centres, and are grown by smallholders in agroforestry systems.

The content of this publication is entirely the responsibility of the authors, and does not necessarily represent the views of FAO, or its Members.

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# Executive summary

Products and services derived from trees in forests, on farmland and within other landscapes provide benefits to hundreds of millions of people in the tropics, but these benefits from the trees and their genetic resources have not been well quantified. This is the case, in part, because trade often takes place outside formal markets; there are a multiplicity of species, product sources and ways in which trees are used; and the value of genetic diversity within tree species has not been properly considered.

This study reviews what is known about the value of trees for tropical rural communities and considers the following:

- Non-timber products harvested from trees in natural and managed forests and woodlands.
- The various products and services obtained from trees planted and/or retained in agroforestry systems.
- The commercial products of tree commodity crops.

The study focuses, where possible, on the role of intra-specific genetic variation in determining the value of trees in supporting livelihoods in each of the above three contexts.

The more systematic, standardized approaches to quantifying non-timber forest product (NTFP) value applied in the last decade or so have illustrated the importance of NTFPs for marginalized households and for women's incomes. Analyses of wild tree foods from forests have considered the diversity of foods available but have also shown that availability does not necessarily mean that humans consume these foods. In the tropics, significant changes in fruit properties have taken place in many fruit trees over several millennia because of human selection that better conforms to the communities' food needs. Knowledge of these changes can help guide future domestications.

To improve the lives of rural people through NTFP harvesting, they need technical support in harvesting and processing, business support to establish enterprises, and they need market information to be shared, among other interventions. The ecological implications and genetic aspects of NTFP harvesting regarding productivity, sustainability, etc. have received limited attention and require further research.

Database searches indicate a wide range of agroforestry tree products (AFTPs) such as timber, medicine and fuel, which are commonly mentioned. Examples that show larger benefits from having trees on farms are soil fertility replenishment, timber production and fodder provision. There are specific opportunities to bring into cultivation food trees through participatory domestication methods, making use of the great biological diversity found within and between indigenous fruit tree species in tropical regions, and improving human diets by filling nutritional gaps.

Human-driven climate change and forest displacement mean that tree products and services will in future be sourced increasingly from farms. Key constraints to agroforestry, however, must be addressed in policies, markets, and in developing and delivering appropriate high-quality tree planting material and farm management methods. Delivery systems should involve small-scale, local, entrepreneurial tree seed, seedling and clone suppliers, supported with business and technical training and with starter germplasm.

Many tree commodity crops are grown by smallholders, often in locations away from the centres of origin of the tree crops. This emphasizes the importance of international cooperation in exploiting genetic resources for sustaining and enhancing commercial production of these crops. The value of wild resources of tree commodity crops needs to be

properly quantified. The geographic separation of origin and production centres for these commodity crops presents a dilemma for conservation, which also applies to other widely cultivated tree species.

Although tree commodity crops play an important role in supporting rural livelihoods, it will be necessary to better understand the complicating factors that result in land being converted to monoculture production systems, and to understand the impact of single-source incomes on a community's food and nutritional security. Commodity varieties that are highly productive in mixed farming systems are needed, making use of intra-specific genetic diversity to develop varieties that most favourably interact with the other components of the farming systems.

Chapter 1

# Introduction

The elemental role played by trees in rural livelihoods in the tropics is apparent in the many uses made of tree products in almost any community, for example, in construction, fencing, furniture, foods (edible fruits, nuts, leaves, gums, spices, oils, etc.), medicines, fibres, fuels and in livestock feed. Some tree products enter local, national and international markets, others are not sold but are used for subsistence and many are of particular cultural significance (Place *et al*., 2011). Some tree products, such as timber, have an investment role for smallholder producers, while others, such as edible fruit, have a security function, providing food during gaps in staple crop availability (Jamnadass *et al*., 2011). Similarly, the service functions of trees are readily apparent, such as the shade they provide for people, crops and livestock, and their soil stabilization properties that prevent soil erosion and protect rivers and streams. Tree-based production systems can also support biological, economic and social resilience under anthropogenic climate change (Thorlakson and Neufeldt, 2012).

It is not surprising that over a decade ago the World Bank (2008) estimated that forests and trees-outside-forests contributed in some manner to the livelihoods of more than 1.6 billion people globally. The varying level of dependence of different communities and how this changes with time, however, is often not well described or adequately acknowledged in rural development practice (Byron and Arnold, 1997). Partly, this reflects the ubiquity of tree products and services and the numerous ways they have an impact on livelihoods. It also reflects the many different sources of tree products and services, spanning agricultural land and forests, which are characterized in different ways by national government departments of agriculture and forestry, making comparisons difficult (de Foresta *et al*., 2013). These difficulties help explain why the values of tree products and services for local people have often been neglected at a national policy level. In the cases where good data on value are available, these often refer to large industrial markets for a narrow range of products, such as roundwood, which bear relatively little relationship to local community value, except through limited employment opportunities (FAO, 2010).

From a genetic perspective, tree resources exist at different levels of domestication of populations and species, while landscapes are themselves domesticated to a greater or lesser extent. A few forests may be considered completely natural. More often than not, some degree of human management has taken place to create anthropogenic forests (Clement, 1999; Belcher *et al*., 2005a). Some tree species, especially those producing fruit valued for human consumption, have undergone domestication within forest environments for several millennia and this process remains ongoing today. Wiersum (1997) proposed the use of the term "the co-domestication of forests and trees" to describe the processes involved when traditional societies manage forests and forest components. The level of domestication and the system within which tree production takes place are clearly inter-related. It is important to consider both together to understand how rural communities benefit from trees, and how future interventions can best support further livelihood gains.

In this study, we present an overview of the value of trees for tropical rural communities in the context both of tree domestication level and management setting. The first section of our review is concerned with the significant benefits of harvesting non-timber forest products that generally grow in natural and/or incipiently- or semi-domesticated forest landscapes. The second part is concerned with important products and services from a range of local and exotic trees, mostly semi-domesticated and under-researched, which are found growing in smallholders' agroforests. The third section of the review is concerned with more widely researched woody perennial commodity crops that may be completely domesticated, are often exotic in their main production centres, and are grown by smallholders in agroforestry systems as well as sometimes by larger growers in plantations. This last category of commercially-grown tree commodity crops is not often given much attention in discourses on forests and tree genetic resources (even when the major genetic resources of these crops are still to be found in forests), but their value to smallholders is often greater and better characterized than those of other woody perennials. Their consideration illustrates important wider principles. Further information on the value of trees and tree genetic resources in these three contexts is given in Dawson *et al.* (2014).

Chapter 2

# The benefits of non-timber forest product harvesting

## 2.1. Trade and use data

The category non-timber forest product (NTFP) is a broad one that covers any product of biological origin other than timber that is derived from forests and other wooded lands. It includes not only products from trees, with which we are concerned here, but products from other plants, animals and fungi. Three prominent examples of tree NTFPs – agarwood, gum arabic and shea butter – are described in Box 1, which illustrates their sometimes high value to local economies. At the time of their review, Pimentel *et al.* (1997) calculated very approximately that USD 90 billion worth of food and other non-timber forest products were harvested annually from forests and trees in developing countries. The Global Forest Resources Assessment (FRA) published in 2010 quoted a value of USD 19 billion for non-wood forest product (NWFP)[1] removals worldwide (based on 2005 figures), but data reported by countries and compiled for the FRA report were incomplete (FAO, 2010). Informal trade in unmonitored local markets, direct household provisioning, and the exclusion of wild-harvested resources from most large-scale household surveys (Shackleton *et al.*, 2007; Angelsen *et al.*, 2011; Shackleton *et al.*, 2011a), are all reasons why the FRA figure is an underestimate. The FRA figure does not, for example, adequately capture the importance of the many traditional medicines derived from trees, upon which local communities in low-income countries often rely for their healthcare needs (World Bank, 2001). The 2010 FRA report separately indicated a value of USD 17 billion annually for wood fuel (2005 figures), but again it is clear that this figure did not adequately capture the importance of tree-based traditional energy sources that enable perhaps two billion people worldwide to cook food (FAO, 2008). For example, in sub-Saharan Africa the use of wood fuel and charcoal are still increasing rapidly, despite attempts to move to alternative energy sources, with the value of the charcoal industry in the region estimated at approximately USD 8 billion in 2007 (World Bank, 2011). This compares with a wood fuel value given in the 2010 FRA report of only USD 1.4 billion annually for the continent of Africa (FAO, 2010).

If NTFPs are incorrectly valued, this is not just of academic concern: mis-valuation leads to inappropriate policies that, while conceived to support rural communities, ultimately disfavour them with poorly targeted interventions (Belcher and Schreckenberg, 2007; World Bank, 2008). Systematic methods for quantifying NTFP value are required, which consider the costs of harvesting and the impact on the resource and on market prices of widening extraction (Sheil and Wunder, 2002). If national governments are not to over- or under-state the value of NTFPs for livelihoods, they need to better understand how to interpret existing valuations (Sheil and Wunder, 2002, who illustrate mis-interpretations of NTFP value based on two influential studies:

[1] The term NWFP is similar to NTFP except it excludes wood products such as fuelwood, and the charcoal derived from it, that are, by definition, included in the NTFP category, although NTFP surveys often do not include fuelwood and charcoal in valuation (Killmann, 2010).

Box 1
**Three prominent non-timber forest products important to rural populations in the tropics: agarwood, gum arabic and shea butter**

**Agarwood** (taken from Jensen and Meilby, 2008; Jensen, 2009, Dawson *et al.*, 2014)
Agarwood, a fragrant resin that is used for incense and perfume, is embedded in the trunks, branches and roots of some trees of the genus *Aquilaria* in Asian forests. By some estimates, it is the world's most valuable non-timber forest product, with a global retail value of between USD 666 million and 2.3 billion annually (2004 figures). One member of the genus, *A. crassna*, is considered critically endangered as a result of unsustainable harvesting of wild populations. The resin is produced in response to wounding and it is not easily evident from the exterior of a tree that its wood will contain the resin. It has, however, been reported that in the Lao People's Democratic Republic some people have been trained as resin collectors so they can better identify the small fraction of trees suitable for harvesting, thereby reducing unnecessary damage to tree populations.

**Gum arabic** (taken from Touré, 2008)
Gum arabic, an exudate harvested from wild trees of *Acacia senegal* and *A. seyal* across dryland sub-Saharan Africa, is used as an additive in the global food and drinks industry. The Sudan[1], Chad and Nigeria are believed to be the biggest producers. The available data suggest that around 65 000 metric tons were exported from Africa in 2006. Export values, of USD 50 million in Sudan, 40 million in Chad and 21 million in Nigeria, were estimated for the period 2003 to 2007 inclusive. Gum arabic is shipped worldwide, with the European Union followed by the United States of America being the biggest importers. Sanctions imposed by the United States of America on the Sudan in 2000 specifically excluded a ban on gum arabic trade. Importing nations sometimes process raw gum and then resell it on world markets: between 2003 and 2007, re-exports from European Union countries led by France were considerable, possibly amounting to more than USD 500 million in value.

**Shea butter** (taken from Becker and Statz, 2003; Lovett, 2004; Masters and Addaquay, 2011)
Shea butter, extracted from the kernel of the shea tree (or karité, *Vitellaria paradoxa*) that grows in the semi-arid parklands of sub-Saharan Africa, has been traded for centuries and is important both locally and internationally. It has been suggested that more than 150 000 metric tons of kernels are harvested from wild and semi-wild trees annually. The fat is used locally for skin treatment and cooking, with shea butter estimated to be a food of regional importance for over 10 million households. Shea kernels and shea butter are widely exported from Africa, with an annual export value from Ghana alone of more than USD 30 million in 2008. Exported shea butter is widely used in both confectionery and skin product manufacture.

[1] Figures refer to the Republic of the Sudan and South Sudan combined.

Peters *et al.*, 1989b; Godoy *et al.*, 2000). Proper valuation also requires an understanding of the combinations of assets (social, physical, financial, etc.) required by local communities before they can build sustainable livelihoods (Scoones, 1998).

More research attention has been given to the systematic review and meta-analysis of case studies of NTFP value (Belcher *et al.*, 2005b, see also Table 1). This research indicates that the share of forest income from NTFPs as a proportion of total household income is often highest for the most marginalized households in societies, and that NTFPs are, for example, particularly important for women's incomes. The Poverty Environment Network (PEN, www.cifor.org/pen/) has gathered standardized quantitative socio-economic data on the role of tropical forests in poverty alleviation. Data have been collected from approximately 8 000 households located in 24 low-income nations in Africa, Asia and Latin

**TABLE 1**

Examples of reviews and meta-analyses of the importance of NTFPs for local communities (taken from Dawson *et al.*, 2014).

| Description of study | Findings | Reference |
|---|---|---|
| Review of 54 case studies (15 East Africa, 18 southern Africa, 14 Asia, 7 Latin America) examining rural incomes from forest products in 17 countries | Forest 'environmental income' was on average around one-fifth of total household income of the population sampled. Main sources of income were wood fuel, wild foods and animal fodder, with the poorest more dependent on them. Cash income constituted approximately half of total forest environmental income. | Vedeld *et al.* (2004) |
| Comparison of 61 case studies (17 Africa, 21 Asia, 23 Latin America) of the production and trade of NTFPs from 24 countries | NTFPs were important sources of income. Commercial trade drove intensified production and household specialization among forest-related peoples. The authors recommended that markets be developed and resources be sustainably managed accordingly. | Ruiz-Pérez *et al.* (2004)* |
| Expert opinion on a subset of 55 of the case studies of Ruiz-Pérez *et al.* (2004) (as above) | NTFP trade improved livelihoods, with the involvement of women having a positive effect on intra-household equity. However, trade sometimes increased inequality between households. Inability to make financial investments limited developments to increase product quality and quantity. | Kusters *et al.* (2006) |
| Comparison of 10 different plant NTFPs harvested by 18 local communities in Bolivia and Mexico | Supply chains provided economic safety nets, spread income across time and could provide stepping stones to a non-poor life. Harvesting was one of the few cash-generating opportunities for many women. Shifting from subsistence to commercial extraction sometimes reduced access to the poorest in society, due to harder-to-negotiate controls on harvesting. | Marshall *et al.* (2006) |
| Collection of data on bamboo from 22 countries (5 Africa, 13 Asia and the Pacific, 4 Latin America) | Total bamboo area was estimated to be more than 36 million ha, with India having the largest share. Almost a third of the bamboo area in Asia was reported as planted. Use was observed to be growing rapidly in Latin America and Africa. The annual export market for bamboo was observed to be USD billions. Volumes traded and used locally for building, furniture, food, fuel, etc. were expected to be much greater. | Lobovikov *et al.* (2007) |

* For individual case studies, see Kusters and Belcher (2004) for Asia, Sunderland and Ndoye (2004) for Africa, Alexiades and Shanley (2005) for Latin America.

America (Angelsen *et al*., 2011). Analysis revealed results consistent with the surveys described in Table 1, with detailed implications for policy interventions related to livelihoods, gender and tenure.

## 2.2. Harvesting NTFPs for food and nutritional security

Many tropical communities incorporate NTFPs into their diets to add variety to staple foods, and some are dependent on edible NTFPs outside staple crop production seasons (Arnold *et al*., 2011). Tree foods are often better sources of micronutrients, fat, fibre, protein, etc. than staple crops, and can play an important role in providing these key dietary components (Leakey, 1999; Vinceti *et al*., 2008). An analysis of wild food availability in 22 countries in Asia and Africa (36 studies covered) found a mean of 90 to 100 species with recorded food value per location, including many plant and animal products from forests and woodlands (Bharucha and Pretty, 2010). However, just because a wide range of wild food products are available, it does not follow that they will be consumed. For example, Termote *et al*. (2012) showed that although a wide variety of edible wild food plants were found around the city of Kisangani in the Democratic Republic of the Congo, these plants did not (with a few exceptions) significantly contribute to human diets, despite dietary deficiencies in the area. Lack of use in this case may have been due to the labour costs of collecting and processing the wild food plants, as well as limited community knowledge on the value of particular (potential) foods.

## 2.3. Ancient management of trees and palms for food

Mesoamerica and the Amazon have been centres for research on ancient forest management (Peters, 2000; Levis *et al.*, 2012). Southeast-Asian forests have also been widely studied in this regard (Wiersum, 1997; Michon, 2005), but African forests less so (Maranz and Wiesman, 2003). Research indicates that humans have manipulated a range of trees and palms[2] for food through selective harvesting, managed regeneration and cultivation for several millennia (Clement, 2004). In the case of the Amazon, it appears that several tree species were completely domesticated long ago, while others were widely cultivated in ancient times but not fully domesticated (Clement, 1999). Amazonian fruit trees and palms for which changes associated with ancient human management have been observed (especially in western Amazonia) include abiu (*Pouteria caimito*), Amazon tree grape (*Pourouma cecropiifolia*), araza (*Eugenia stipitata*), biriba (*Rollinia mucosa*), peach palm (*Bactris gasipaes*) and sapota (*Quararibea cordata*) (Clement, 1989). Significant changes in fruit size, proportion of useable product and ability to be propagated in areca (*Areca catechu*), coconut (*Cocos nucifera*) and date (*Phoenix dactylifera*) palms are attributed to ancient human selection (Clement, 1992). An expanding list of global studies on ancient domestications includes many more food trees (Clement, 2004).

After European colonial contact, Amerindian populations declined in the Amazon, resulting in an erosion of the rich tree crop genetic heritage they had previously established. Residual effects of pre-Columbian forest management remain in Amazonian forests, however, including high density aggregations of useful trees in apparently primary forests (Peters *et al.*, 1989a). These aggregations are often close to ancient anthropogenic soils known as 'dark earths', originating from past habitation and field management (Clement and Junqueira, 2010; similar soils are also observed in Asian forests, e.g. Sheil *et al.*, 2012). Brazil nut (*Bertholletia excelsa*) provides the most famous example, with the trees being found in dense stands (5 to 20 trees per ha) in proximity to dark earths and to other areas of pre-Columbian landscape transformation throughout eastern and central Amazonia, but not uniformly in western Amazonia (Shepard and Ramirez, 2011). Levels of aggregation and genetic analyses suggest Brazil nut was distributed across Amazonia within the last few thousand years (Clement *et al.*, 2010). The ancient human dissemination of germplasm of numerous Amazonian trees appears to have taken place both within the region and to locations outside it (Lentz, 2000).

New insights into ancient cultivation and domestication that help guide future management come from molecular marker analyses of patterns of genetic variation in fruit and nut trees (Jamnadass *et al.*, 2009). A review of such studies, as well as studies on other Amazonian crops, suggests that while the periphery of the Amazon Basin has had an important role in origins, centres of genetic diversity are generally located through the centre of the basin, along the major white-water rivers where large pre-Colombian human populations developed (Clement *et al.*, 2010). Taking this difference between the periphery and the centre into account is important in conservation programmes in the region. Molecular marker studies that compare and contrast tree stands in agricultural landscapes with those in forests can be particularly helpful in determining past human impacts and in providing recommendations for future conservation and use (Box 2).

## 2.4. NTFP harvesting and forest conservation

Further commercializing wild NTFP harvesting has been widely promoted by governments to support livelihoods and as an approach to support forest conservation. This is based on the theory that an

[2] Palms are not true trees. However, as woody perennials that are often found in forests and as plants that occupy ecological niches similar to trees, they are classified as trees for the purpose of this review.

Box 2
**Using molecular markers to determine cultivated tree origins: the case of *Inga edulis* in the Peruvian Amazon (taken from Hollingsworth *et al*., 2005; Dawson *et al*., 2008)**

Archaeological data suggest that inga species have been subject to domestication since ancient times. In the case of *Inga edulis*, perhaps the most widely planted agroforestry tree in Peru, the species is grown for the edible, sweet sarcotesta found around the seed, as well as to restore soil fertility, to provide shade for crops and as firewood. Due to domestication for fruit traits, the pods of *I. edulis* trees planted in smallholdings in the Peruvian Amazon are frequently longer and thicker than those on trees in neighbouring natural forests. To assess past domestication, geographically proximate planted and forest populations at each of five sites in the region were tested with molecular markers. Results indicated that cultivated inga was genetically differentiated from adjacent forest populations and was, therefore, unlikely to have originated from them, while different planted populations had different genetic compositions, suggesting multiple external sources of germplasm.

Existing recommendations for conserving *I. edulis* in the Peruvian Amazon region have promoted collecting seed from forests and planting these in neighbouring farms. Molecular data suggest, however, that due to differing genetic compositions this may be inappropriate, as it could result in the break-up of co-adapted gene complexes in both forest and farmland material. Although molecular markers also revealed that cultivated stands were less diverse than forest stands at each of the sites tested, farm stands were still relatively diverse. Inbreeding effects in farm stands, therefore, appear unlikely, and a valid conservation strategy in agricultural landscapes is, therefore, to focus on maintaining good collection and regeneration practices within existing stands without introducing new wild germplasm.

increase in resource value provides an incentive to local harvesters to manage the particular resource and the associated surrounding forest more sustainably. Experience shows, however, that the contributions of NTFP commercialization to sustainable harvesting and biodiversity conservation in a forest setting are generally questionable (Newton, 2008; Sunderland *et al*., 2011). In fact, higher livelihood outcomes are generally associated with lower environmental outcomes that include the over-exploitation of natural NTFP stands (Homma, 1996; Schippmann *et al*., 2002). Normally, therefore, increased trade will not reconcile development needs and forest conservation goals (Kusters *et al*., 2006). A focus on NTFP commercialization primarily for forest conservation objectives is unlikely to be successful. It is better to focus on livelihood benefits while trying to minimize conservation concerns (Belcher and Schreckenberg, 2007).

A pertinent example that has received wide attention is harvesting fruit from the wild argan tree (*Argania spinosa*), which is endemic to Morocco. Argan oil, extracted from the kernels of the fruit, is one of the most expensive edible oils in the world, sometimes selling for more than USD 300 per litre. Development agencies have aggressively promoted the win-win aim of simultaneously benefiting rural people and the health of the argan forest though further commercialization. However, while a booming market in argan oil has certainly contributed to the local economy and has led to better educational outcomes for school children, especially for girls, commercialization has also clearly contributed to forest degradation (Lybbert *et al*., 2011). One widely-quoted approach to alleviate pressure on natural NTFP stands in such situations is to promote cultivation as an alternative product source. As related below, however, the available evidence indicates that planting will not necessarily prevent wild stands from being over exploited (and may indeed have the opposite effect; Dawson *et al*., 2013).

In most cases of tree NTFP extraction, the links between the sustainability of harvesting and the population genetics of the tree have not yet been considered to any great extent, despite the importance of factors such as the method of collection, the type of breeding system and the level of between-individual connectivity in stands for supporting regeneration of the resource. When some consideration has been given (e.g. Alexiades and Shanley, 2005), the quoted impacts of harvesting on production through dysgenic selection, genetic erosion, etc. are mostly suppositions. How harvesting affects genetic diversity, and how this influences productivity in the short-, medium- and long-term, remain important topics for future research.

Chapter 3

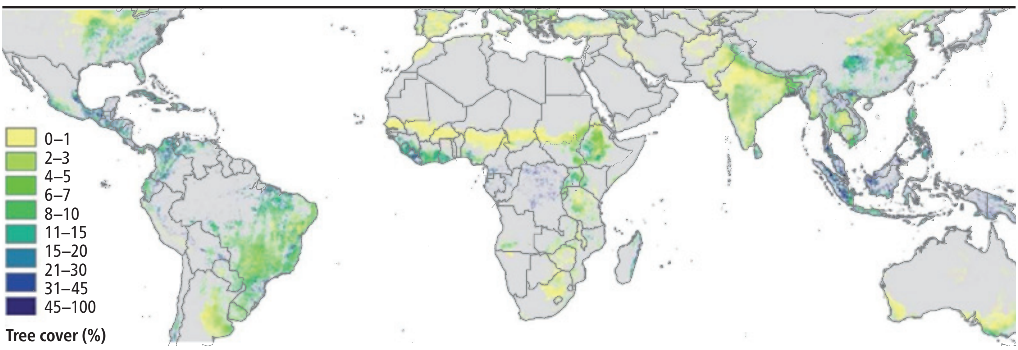
# The benefits of agroforestry practices

## 3.1. Farming trees to support livelihoods

Agroforestry – the integration of trees with annual crop cultivation, livestock production and other farm activities (Garrity, 2004) – is practiced by more than 1.2 billion people worldwide (Leakey, 2010). Agroforestry systems range from open parkland assemblages, to dense imitations of tropical rainforests such as home gardens, to planted mixtures of only a few species of trees and crops, with different levels of human management of the various components (www.worldagroforestry.org). Zomer *et al.* (2014) estimated that more than 900 million people, including many tropical smallholders, live in farm landscapes with more than 10 percent tree cover, where trees provide a variety of important products and services (Figure 1). When grown on farms, tree products are sometimes described as agroforestry tree products (AFTPs) to differentiate them from timber and NTFPs harvested from natural and anthropogenic forests and woodlands (Simons and Leakey, 2004). This distinction is useful because interventions to promote NTFP (and 'wild' timber) and AFTP use are clearly often different, although gradations between natural forests, anthropogenic forests and agroforests, etc. mean that sometimes there is no clear boundary between production categories (Byron and Arnold, 1997).

Based on a compilation of information in the Agroforestree Database (AFTD) maintained by the World Agroforestry Centre (ICRAF), an overview of the extensive range of trees that can be involved in supporting local peoples' livelihoods is given in Table 2. The most frequent function listed in the

**FIGURE 1**
Percentage tree cover on agricultural land in the tropics (mean 2008 to 2010) as based on a geospatial analysis of remote sensing-derived global datasets. Taken from an analysis by Zomer *et al.* (2014), to which reference should be made for the characteristics, assumptions and limitations of the data layers and methods used (figure provided by Ric Coe, ICRAF).




*Conforms to Map No. 4170 Rev. 19 UNITED NATIONS (October 2020)*

**TABLE 2**
The number of tree species in the Agroforestree Database (AFTD) mentioned as providing various tree functions of importance to smallholders' livelihoods, and the known geographic distribution of these species (modified from Dawson *et al.*, 2014). Based on the number of mentions summed across functions compared to the total number of species in the database (650), it is evident that many species perform several functions. Data illustrate that smallholders can use a wide range of both indigenous (I) and exotic (E) trees for a wide range of products and services.

| Function * | Origin | Region | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Africa | Oceania | South America | South Central Asia | Southeast Asia | Western Asia and Middle East | Total (regions) |
| Apiculture | E | 89 | 58 | 51 | 74 | 75 | 18 | 365 |
| | I | 88 | 26 | 32 | 34 | 46 | 16 | 242 |
| | E+I | 177 | 84 | 83 | 108 | 121 | 34 | 607 |
| Erosion control | E | 81 | 50 | 34 | 63 | 61 | 15 | 304 |
| | I | 94 | 20 | 23 | 57 | 56 | 17 | 267 |
| | E+I | 175 | 70 | 57 | 120 | 117 | 32 | 571 |
| Fibre | E | 85 | 58 | 40 | 73 | 82 | 14 | 352 |
| | I | 56 | 35 | 20 | 60 | 67 | 18 | 256 |
| | E+I | 141 | 93 | 60 | 133 | 149 | 32 | 608 |
| Fodder | E | 134 | 71 | 53 | 105 | 102 | 26 | 491 |
| | I | 161 | 30 | 43 | 112 | 89 | 35 | 470 |
| | E+I | 295 | 101 | 96 | 217 | 191 | 61 | 961 |
| Food | E | 137 | 81 | 68 | 113 | 115 | 28 | 542 |
| | I | 158 | 43 | 51 | 107 | 110 | 34 | 503 |
| | E+I | 295 | 124 | 119 | 220 | 225 | 62 | 1 045 |
| Fuel | E | 167 | 96 | 73 | 133 | 133 | 27 | 629 |
| | I | 190 | 51 | 53 | 110 | 116 | 35 | 555 |
| | E+I | 357 | 147 | 126 | 243 | 249 | 62 | 1 184 |
| Medicine | E | 167 | 101 | 86 | 149 | 158 | 30 | 691 |
| | I | 223 | 58 | 58 | 149 | 156 | 37 | 681 |
| | E+I | 390 | 159 | 144 | 298 | 314 | 67 | 1 372 |
| Shade/shelter | E | 139 | 78 | 60 | 109 | 105 | 20 | 511 |
| | I | 142 | 53 | 44 | 84 | 97 | 26 | 446 |
| | E+I | 281 | 131 | 104 | 193 | 202 | 46 | 957 |
| Soil improvement | E | 95 | 56 | 40 | 83 | 84 | 14 | 372 |
| | I | 99 | 27 | 33 | 60 | 70 | 12 | 301 |
| | E+I | 194 | 83 | 73 | 143 | 154 | 26 | 673 |
| Timber | E | 199 | 119 | 91 | 160 | 172 | 34 | 775 |
| | I | 220 | 73 | 67 | 153 | 175 | 36 | 724 |
| | E+I | 419 | 192 | 158 | 313 | 347 | 70 | 1 499 |
| Total (functions) | E | 1 293 | 768 | 596 | 1 062 | 1 087 | 226 | 5 032 |
| | I | 1 431 | 416 | 424 | 926 | 982 | 266 | 4 445 |
| | E+I | 2 724 | 1 184 | 1 020 | 1 988 | 2 069 | 492 | 9 477 |

* The AFTD is an open-access resource (www.worldagroforestry.org/output/agroforestree-database) that contains data on a wide range of products and services provided by trees. Data are presented on the number of species given in the database and are used for a particular purpose that can be found in a particular geographic region, based on whether they are indigenous or exotic in origin to a region.

# The AFTD contains global data on species distributions, summarized here into regions according to "https://en.wikipedia.org/wiki/List_of_sovereign_states_and_dependent_territories_by_continent for Africa, Oceania and South America and to www.nationsonline.org/oneworld/asia.htm for South Central Asia, Southeast Asia, and Western Asia and the Middle East. A factor determining the higher number of total references to Africa is the greater attention given to the region during the compilation of the database.

AFTD was trees for timber production, followed by medicine and then fuel. Most tree species were listed as having multiple uses, illustrating the range and flexibility of products and services that trees provide to support livelihoods and that potentially promote the resilience of production systems. Compilation indicates that both indigenous and exotic trees, in approximately equal proportions (in terms of the species in the AFTD), are important for smallholders. The value of indigenous trees is demonstrated well by the case of participatory tree domestication which is described below, while the value of exotics is seen clearly in the case of commercial wood production (Box 3), and in the cases of fodder provision and tree commodity crops (both explained further in the text below).

Box 3
### Smallholder production of exotic woods: examples from Viet Nam and Indonesia

Large commercial markets for wood produced by smallholders often depend on exotic trees, as illustrated by acacia and teak cultivation in Viet Nam and Indonesia, respectively.

**Acacia production in Viet Nam** (taken from Fisher and Gordon, 2007; Griffin *et al.*, 2011)

In the 1980s, exotic acacias from Australia were tested in species and provenance trials across Viet Nam to identify fast-growing materials suitable for industrial wood production. Provenances of *Acacia mangium, A. auriculiformis* and selected hybrid clones were chosen for wide planting, with hybrids now being the most widely grown material.

By 2011, approximately 700 000 ha of exotic acacia plantation had been established in Viet Nam, with half managed by smallholders and the rest by forest companies and state enterprises. So many smallholders have adopted acacia because of the short rotation of pulpwood and small saw logs (as little as five years), the availability of suitable land for planting, land reforms conferring unambiguous ownership of trees, access to industrial wood markets, the wide availability of appropriate germplasm for planting and simple farm establishment requirements.

Estimated annual returns to smallholders from wood sales of standing trees are approximately USD 100 million. Many smallholders have received substantial additional earnings from participating in wood harvest and transport. An estimated 50 percent of Viet Nam's 2010 hard wood chip export of 3.5 million dry metric tons was acacia, worth approximately USD 162 million. Value added by downstream wood processors, such as furniture manufacturers, has contributed strongly to employment and revenues. The cost of the research to identify and provide improved acacia germplasm to farmers has been rewarded many times over in the increased incomes earned by farmers and processors.

**Teak production in Indonesia** (taken from Roshetko *et al.*, 2012)

Teak (*Tectona grandis*) appears to have been transferred from elsewhere in Asia to Indonesia as early as the second century AD. Indonesia is now the second largest producer of teak timber globally. A state-owned enterprise is the largest manager of plantations, but these satisfy less than one third of the industrial demand of more than 1.5 million cubic metres per year. An estimated 1.5 million smallholders on Java manage approximately 440 000 ha of agroforestry systems where teak is the dominant tree crop. These teak production systems provide on average 40 percent of total household income (including teak sales to furniture manufacturers, and sales of agricultural crops and other timbers produced with teak). In other parts of Indonesia, teak is a lesser component of production in an additional 800 000 ha of smallholder agroforestry systems.

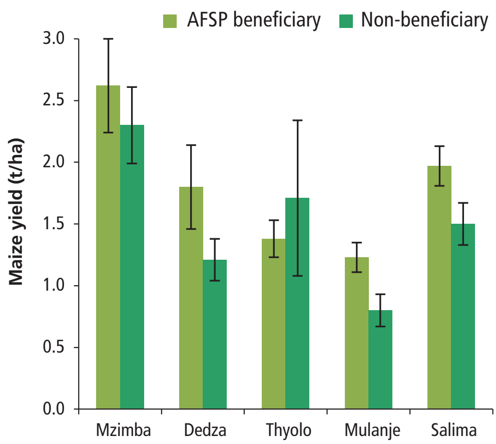
Teak trees planted by smallholders are generally of unknown provenance, with, for example, approximately 70 percent of farmers in Gunungkidul District, Yogyakarta collecting wildings for establishing new stands from poorly characterized existing local stands. Only around 12 percent of surveyed farmers in the district used higher quality germplasm, provided primarily by government reforestation programmes. As has been the case with acacia wood production in Viet Nam, substantial benefits to Indonesian smallholders would follow if they were able to access improved teak germplasm and if they adopted improved farm management practices.

As with harvesting tree products from natural forests and woodlands, the livelihood value of smallholder agroforestry tree cultivation and management is often poorly quantified. In a review of the value of agroforestry in Africa, however, Place *et al*. (2011) indicated soil fertility replenishment and fodder provision for farm animals as key examples with large benefits. Significant yield benefits for staple crops have been achieved by planting leguminous, nitrogen-fixing fertilizer trees to improve soil fertility, although the level of yield response varies by soil type and the particular agroforestry technology (Sileshi *et al*., 2008). As well as increasing average yields, planting fertilizer trees has been shown to stabilize crop production over drought years in southern Africa, and to improve crop rain use efficiency, both important for supporting food security in the context of anthropogenic climate change (Sileshi *et al*., 2011, 2012). An example of a soil fertility replenishment project in southern Africa is the Agroforestry Food Security Programme (AFSP) in Malawi, which has encouraged farmers to plant indigenous and exotic fertilizer trees. By 2011, the AFSP had reached approximately 180 000 farmers, leading on average (although not always) to improvements in maize yields, to more food secure months per year, and to greater dietary diversity (Figure 2; CIE, 2011). Improved green fertilizer technologies have wide relevance and appropriate approaches are being promoted through the tropics and elsewhere to substitute for or enhance mineral fertilizer application (Ajayi *et al*., 2011).

In addition to planting trees, supporting their natural regeneration in agricultural land can result in significant yield benefits for staple crops. The case of farmer-managed natural regeneration (FMNR) of faidherbia (*Faidherbia albida*) and other leguminous trees in dryland agroforests (parklands) in semi-arid and sub-humid Africa is a good example. Faidherbia has an unusual (reverse) phenology in that it flushes in the dry season, providing animal fodder and shade at a crucial period of the year, and sheds leaves in the wet season, providing extra nitrogen to growing crops through leaf litter at the same time as minimizing light competition with crops (Bayala *et al*., 2011). Encouraged by a policy shift that has awarded tree tenure to farmers, as well as by more favourable weather, since 1985 in Niger FMNR has led to the re-greening of approximately 5 million ha (Sendzimir *et al*., 2011). Improvements in sorghum and millet yields, and positive relationships with dietary diversity and household income, have been observed (Place and Binam, 2013). Nitrogen fixation illustrates how important it is to understand the interactions between trees and microorganisms. Considerable gains are possible in smallholder production through appropriate

**FIGURE 2**

Maize yields in five districts in Malawi with and without the intervention of the Agroforestry Food Security Programme. A review of the programme in five districts surveyed 283 households that were beneficiaries (participants in the programme who planted fertilizer trees) and 200 that were not. In four out of five districts, maize yields were on average higher for beneficiaries than non-beneficiaries. Bars represent 95 percent confidence intervals: in three cases (Dedza, Mulanje, Salima) the difference between categories was statistically significant (figure provided by Gudeta Sileshi, ICRAF).



Box 4
**The importance of symbiotic associations between trees and microorganisms**

A wide range of positive interactions exist between trees and other plants and microorganisms, and these must be taken into account when considering the productivity of agroforestry systems (Cardoso and Kuyper, 2006; Andrews *et al.*, 2010). Tropical trees form symbioses mainly with arbuscular mycorrhizal (AM) fungi, though there are also important ectomycorrhizal (ECM) associations. Nitrogen-fixing trees and shrubs are predominantly members of the Leguminosae, in symbiosis with the nodule bacteria rhizobia. However, leguminous tree species are also AM, and effective tree-AM-rhizobial associations can be formed. Important non-legume nitrogen-fixing trees such as beach she-oak (*Casuarina equisetifolia*) are actinorrhizal, forming root-nodule symbioses with the soil actinomycete *Frankia* (Sprent and Parsons, 2000).

Many short-term studies have demonstrated that rhizobial and mycorrhizal inocula vary in their ability to promote tree growth; variation is also found between tree species and provenances in their dependence and responsiveness. When seedlings of six African trees were inoculated with four different ECM inocula, for example, a significant effect of inoculation on early height growth was observed for only one species, but the same species and an additional four showed significant effects of inoculation on root growth and total dry weight seven months after planting (Diédhiou *et al.,* 2005). In another short-term study, Lesueur *et al.* (2001) identified a subset of six rhizobial and five AM isolates, from a wide range tested, with good potential for promoting growth in calliandra.

Less common long-term studies have also revealed important features about tree-microorganism interactions. In West Africa, Sanginga *et al.* (1994) reported the persistence of rhizobial inoculants and their beneficial effects in terms of nitrogen fixation and biomass production 10 years after inoculation in a leucaena (*Leucaena leucocephala*) based agroforestry system. In a three-year study of AM fungi in Mexico, Allen *et al.* (2003) showed that effects on tree growth depended on where inoculum was collected (soil from early or late successional forest) and the age of trees. Reddell *et al.* (1988) indicated that, in South Australia, inoculation of river she-oak (*Casuarina cunninghamiana*) seedlings with *Frankia* prior to planting out resulted in a doubling of wood production for two provenances (44 months later), while another provenance did not respond.

Inoculating trees long after planting can also influence production. When 10-year-old gum arabic trees growing in a nitrogen-deficient soil with poor indigenous rhizobia were inoculated with rhizobia, enhanced gum yields and a higher proportion of gum producing trees were reported in the year after inoculation (Faye *et al.*, 2006). The mean gum yield of inoculated trees was over 400 g compared to less than 300 g for trees that were not inoculated. The response to inoculation depended on sufficient rainfall prior to tapping.

inoculation with microorganisms in tree nurseries, and through other related measures, especially in heavily degraded lands and when tree species are introduced to new areas (Box 4).

In the case of the key example of fodder provision, more than 200 000 East-African small-scale dairy farmers grow trees and shrubs as a supplementary animal feed in response to one initiative (Place *et al*., 2009). The increase in milk yield achieved by these farmers has allowed them to provide more milk to urban consumers and to raise extra revenue from milk sales that equates to more than USD 100 per cow per year. Networks of small-scale seed dealers have evolved to supply the increased demand for fodder tree seed in the East Africa region; dealers improve their livelihoods through seed sales, and are also often themselves dairy farmers, so they can benefit twice if they also grow tree fodder (Wambugu *et al*., 2011).

Tree genetic composition has a significant impact on the amount of fodder produced and its feed utility. For example, in calliandra (*Calliandra* *calothyrsus*), a tree introduced from Latin America that is widely used for fodder in East Africa, leaf production varies widely among provenances, as does digestibility (Tuwei *et al*., 2003). During early modern calliandra introductions into East Africa in the 1970s and 1980s, little attention was paid to these attributes, as the tree was brought into the region primarily for wood fuel production. It was only later that the (more important) fodder application was widely recognized. Current widely-used calliandra germplasm in the region is, therefore, not optimal for fodder production; new seed introductions of improved fodder yield and quality would bring significant benefits for East Africa's dairy farmers (Lillesø *et al*., 2011). Genetic variation in fodder quality for most native African trees has not been studied, but significant provenance differences in leaf protein and the readily-digestible fraction of organic matter have been found when researched; for example, this is the case for the native African shrub combretum (*Combretum aculeatum*) (Fernandez-Rivera and Weber, 2000). This observation again illustrates the value of genetic selection when cultivating trees for fodder.

## 3.2. Agroforestry tree foods

The important role of smallholder cultivation of tree fruits in supporting food and nutritional security and incomes in sub-Saharan Africa was reviewed by Jamnadass *et al*. (2011). In Kenya, for example, a 2004 survey of more than 900 households found that over 90 percent grew fruits, with at least one-quarter growing banana (*Musa* spp.), avocado (*Persea americana*) and mango (*Mangifera indica*); over two-thirds of households that reported fruit production harvested from at least four fruit species, while over half sold some fruit (Frank Place, unpublished observations). Similarly, in a 2009 survey of more than 1 100 rural households in Malawi, at least half consumed mango and/or papaya (*Carica papaya*) and one-third consumed oranges (*Citrus sinensis*), among other fruits, most of which were harvested from their own farm trees (Ajayi *et al*., 2010).

Despite the presence of fruit in farmers' diets, average consumption of fruit in sub-Saharan Africa is low, especially in East Africa (Ruel *et al*., 2005). One reason is that poor households that must buy food to meet basic energy needs focus on staples such as maize and rice that are relatively cheap sources of concentrated carbohydrate. As incomes increase, however, expenditure analysis shows that households purchase more fruits (Ruel *et al*., 2005). As incomes grow in sub-Saharan Africa due to economic development, domestic markets for fruit should, therefore, grow by about 5 percent per year over the next ten or so years, taking into account human population increases and urbanization (Jamnadass *et al*., 2011). The potential for farmers to boost their incomes by meeting this increased demand by consumers for fruit is high, but it requires more efficient production and delivery to consumers than currently occurs. Women farmers in particular could further benefit, since harvesting and processing fruit are often seen as activities that fit within their domains of activity. As fruit production becomes more commercially profitable, however, businesses may be co-opted by men, so specific interventions may be required to maintain the involvement of women (Jamnadass *et al*., 2011). Any extra incomes women receive are more likely to be used to purchase other foods for household consumption than are incomes received by men, thus better supporting children's food and nutritional security.

Another opportunity to influence child nutrition in sub-Saharan Africa is through home-grown school feeding programmes that link schools with local agricultural producers of fruit, vegetables, etc. to promote diverse, nutritionally-balanced diets (WFP, 2009). Developing producer groups that can supply the rapidly-expanding supermarket sector in the region can support farmers and consumers, allowing farmers to better negotiate with retailers and meet supermarkets' quantity requirements and quality standards (Neven and Reardon, 2004).

Special potential for cultivating fruit trees in tropical nations lies in the great biological diversity within (see below) and between indigenous species that are found growing in forests and that have to date been under-researched and under-valued by the scientific community, by governments (Jamnadass *et al*., 2011) and (sometimes) by local people themselves (see the case above of Termote *et al*., 2012). In the past, decisions on which tree species farmers should be encouraged to plant were based on researchers' and extensionists' own opinions of what was important. Now, systematic procedures for species priority-setting consider the views of local communities, market intermediaries, consumers and policy makers (Maghembe *et al*., 1998; Faye *et al*., 2011). These procedures consider the different interests of male and female producers and consumers, since gender is a key factor in determining which tree species, cultivars and products are deemed valuable (Assogbadjo *et al*., 2008). Another way to set priorities for cultivating food trees is to consider the nutritional gaps present in communities and then devise portfolios of locally-available food tree species that can counter these deficits. Portfolios are designed to provide important nutrients throughout the year based on the nutritional profiles and harvest times of the constituent tree components (as illustrated in Figure 3 and Table 3; Jamnadass *et al*., 2011).

**FIGURE 3**

A fruit tree portfolio consisting of nine species fruiting at different times of the year, based on indigenous trees in Malawi (modified from Jamnadass *et al*., 2011). Some of the constituent species of a portfolio might be cultivated, while others might grow wild on farms, forests and woodlands. At least one species in the given portfolio is ripe every month, including those traditional periods of hunger that occur when there is a lull in the production of staple crops (around January and February in Malawi). Comparing Figure 3 with Table 3, approximately 50 percent of the vitamin C needs of an adult man could be met by consuming 100 g daily of the fruit pulp of either of two species, *Azanza garckeana* (azanza) or *Strychnos cocculoides* (bush orange) during the period from November to March. Consuming only 25 g daily of the vitamin C-rich *Adansonia digitata* (baobab) fruit pulp would provide all the vitamin C required for the rest of the year, excluding October.

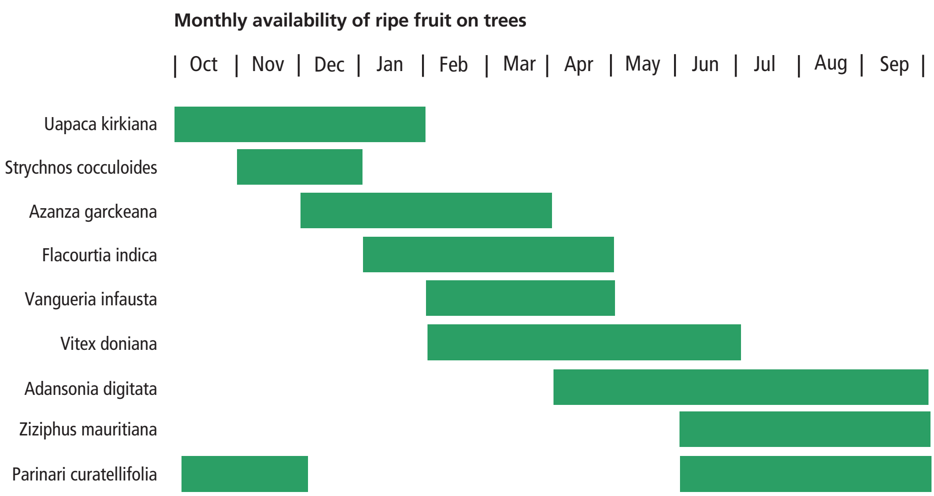


**TABLE 3**

Vitamin A and C content in the fruit pulp of nine tree species native to Malawi that were found growing wild and cultivated in farmers' fields. The vitamin content varies greatly among species, with small quantities of some fruits able to provide recommended daily intakes. Around 50 million children are at risk of vitamin A deficiency in Africa, which is the continent's third greatest public health problem after HIV/AIDS and malaria. Vitamin C is also important in the absorption of iron (Black *et al*., 2008). A diverse range of appropriately chosen species can provide vitamins throughout the year (compare with Figure 3).

| | Vitamin A | | | Vitamin C | | |
|---|---|---|---|---|---|---|
| | µg per 100 g | % adult male recommended daily intake in 100 g | Amount in g to reach recommended daily intake | mg per 100 g | % adult male recommended daily intake in 100 g | Amount in g to reach recommended daily intake |
| *Adansonia digitata* | 21 | 7 | 1 429 | 179 | 398 | 25 |
| *Azanza garckeana* | 67 | 22 | 448 | 21 | 47 | 214 |
| *Flacourtia indica* | 303 | 101 | 99 | 10 | 22 | 450 |
| *Parinari curatellifolia* | 357 | 119 | 84 | 10 | 22 | 450 |
| *Strychnos cocculoides* | 22 | 7 | 1 364 | 23 | 51 | 196 |
| *Uapaca kirkiana* | 67 | 22 | 448 | 17 | 38 | 265 |
| *Vitex doniana* | 175 | 58 | 171 | 20 | 44 | 225 |
| *Vangueria infausta* | NA | - | - | 17 | 38 | 265 |
| *Ziziphus mauritiana* | 35 | 12 | 857 | 14 | 31 | 321 |

All values shown are based on samples collected in Malawi (modified from Saka *et al*., 2008); however, vitamin content can vary significantly between trees of the same species (Stadlmayr *et al*., 2013). Recommended daily intakes (300 µg for vitamin A, 45 mg for vitamin C) are taken from WHO and FAO (2004) (for a male aged 19 to 65 years).

Some examples of food tree species determined by systematic priority-setting to be important to promote in sub-Saharan Africa are listed in the Appendix; similar lists can be described for other tree functions and for other locations. As preferences sometimes change with time, priorities must be revisited periodically (every decade or so: Clement *et al*., 2004). Anthropogenic climate change is another important consideration in determining what trees should be planted where (Dawson *et al*., 2011; Alfaro *et al*., 2014). Current and future potential vegetation maps plotted under different climate scenarios help to make planting decisions by showing where particular tree species may be able to grow well both now and in the future (van Breugel *et al*., 2011).

## 3.3. Choosing what trees to plant from available genetic variation

Consciously or unconsciously, human societies have selected for advantageous genetic variation in a range of trees over millennia (see above; Clement, 1992, 2004). Choosing not only the right tree species to cultivate, but also the right genetic material, is important because genetic variation in production traits can be high within and between wild and semi-wild populations (White *et al*., 2007). The appropriate selection and capture for cultivation of suitable genotypes from this existing diversity can provide large genetic gains that might otherwise be achieved only through costly and time-consuming breeding from a smaller gene pool of variation.

The limited evidence collected from a range of African tree fruits of importance to rural communities illustrates the high level of variation in yield, fruit size, shape and composition that can still be found in natural and semi-natural populations (Jamnadass *et al*., 2011). For example, a more than four-fold difference in average seed yield per fruit was observed between trees within wild populations of one species of the edible oil-producing genus allanblackia (*Allanblackia* spp.) in Cameroon (Figure 4; Jamnadass *et al*., 2010). In semi-domesticated safou (*Dacryodes edulis*) in the same country, locally selecting the best types could result in a five-fold or more increase in the economic value of the fruit compared to currently widely planted types (Waruhiu *et al*., 2004). Similarly, greater than two-fold variation between trees in the vitamin C content of fruit pulp was found in wild East African stands of marula (*Sclerocarya birrea*) (Thiongo and Jaenicke, 2000). These observations suggest that the targeted collection of superior trees from wild and semi-wild populations could vastly improve productivity. However, the extent of the genetic gain that can be achieved has to be confirmed in field trials that control for the environmental variation found within and between natural tree stands (Akinnifesi *et al*., 2008; Kalinganire *et al*., 2008).

Cloning fruit trees can capture gains in multiple traits simultaneously, accelerate production, and provide the uniformity in product required by some markets (Leakey, 2004). Different combinations of fruit traits can be captured in clones depending on end purpose (e.g. large fleshy fruit combined with small kernels for clones to supply the fresh food market, low fruit flesh and large kernels when oil is to be extracted from kernels for the oil market; Leakey and Page, 2006). To avoid the

**FIGURE 4**

Variation between individual trees in seed weight per fruit for *Allanblackia floribunda* (one of nine species in the genus *Allanblackia*). In this example, 40 fruits were sampled from each of 57 trees from a single population in Cameroon over a single season. The weight of the seeds varied substantially, suggesting the value of a targeted collection approach for selecting superior germplasm for farmers to plant (figure taken from Jamnadass *et al*., 2010).

manifestation of incompatibility mechanisms that prevent the fertilization of genetically identical or highly-related trees and that lead to abortion and limited fruit set, clonal planting may require using a mix of clones rather than single clones (Leakey and Akinnifesi, 2008).

Significant genetic variation in trees important for smallholders for a range of additional uses beyond fruit production, including for timber (Box 3, Sotelo Montes *et al*., 2006; Weber and Sotelo Montes, 2008), for fodder (see above) and for medicine (Kadu *et al*., 2012), has been observed (Ray, 2002; White *et al*., 2007; Mohan Jain and Priyadarshan, 2009). This genetic diversity is often exploited sub-optimally in small-scale production because growers are unable to gain access to improved germplasm (see more below; Lillesø *et al*., 2011). This limits yield, quality and profitability.

## 3.4. The participatory domestication approach

A new way of domesticating trees, referred to in the literature as the participatory domestication approach, was developed in close collaboration between scientists and farmers. The approach involves combining scientific advances in germplasm collection, tree selection, clone propagation, food processing, etc. with local communities' experiences of the trees. It has been used to bring a range of valuable indigenous fruit and nut trees into cultivation (Leakey *et al*., 2005, 2007; Tchoundjeu *et al*., 2006, 2008). Traditional knowledge is used in accordance with local benefit sharing under the Convention on Biological Diversity (Lombard and Leakey, 2010). By supporting the domestication of a range of different trees chosen by farmers who are guided in their choices by markets and other considerations, the approach is able to buffer the production and market risks that could result from focusing on an individual species (Tchoundjeu *et al*., 2010). An important aspect is the use of simple clonal propagation methods to reduce the time to maturity and provide fruit and nuts more quickly for farmers to consume and sell (Leakey, 2004).

The participatory domestication approach is applied by farmers in their own farms and tree nurseries. Farmers are motivated to participate not by subsidies but by a desire to learn and apply new skills. The strategy is usually focused initially on satisfying the domestic needs of households and then grows by producing planting material for sale to other farmers, and by commercializing tree products. Significant impacts have been achieved when the method has been applied in the humid forest margins of Central Africa, where indigenous fruit and nut trees are highly valued in the local economy (e.g. Ayuk *et al*., 1999; Awono *et al*., 2002; Degrande *et al*., 2006; Schreckenberg *et al*., 2006), and where natural and semi-natural tree populations containing variable phenotypes are still found in forests and partially cleared forest land close to farms (Box 5; Tchoundjeu *et al*., 2010). The approach is extended through rural resource centres managed by local communities that: train farmers in how to propagate and manage trees; maintain stock plants for vegetative propagation; link with smaller nurseries to provide germplasm more widely; and provide fruit processing facilities and business training. Centres are also venues for farmers to meet and form associations that allow them to market their products and obtain services more effectively (Asaah *et al*., 2011).

## 3.5. Agroforestry practices and tree conservation

Cultivating and managing trees in smallholder agroforestry systems are often seen as means to conserve their inter- and intra-specific diversity. This role of smallholder agroforests in conservation is based on two assumptions: first, that the trees planted and/or retained in agricultural landscapes by farmers are an important reservoir of local biodiversity; and, second, that cultivating trees as an alternative source of product reduces extractive harvesting from neighbouring forests and woodlands (Dawson *et al*., 2013). Evidence

Box 5
**Impacts of the participatory domestication approach in Cameroon (taken from Tchoundjeu *et al.*, 2010; Asaah *et al.*, 2011)**

Surveys of a programme promoting the participatory domestication of indigenous fruit and nut trees in Cameroon considered impacts on households' incomes, on farmers' health and nutrition, and on cultural and social well-being. Programme participants achieved increased incomes from the sales of fruits from locally-selected, clonally-propagated cultivars of species such as safou and bush mango (*Irvingia gabonensis* and *I. wombolu*), and from selling selected fruit tree nursery stock to other farmers for planting. Propagation methods taught for indigenous fruits and nuts were also being applied to exotic fruits. Revenues from some participating tree nurseries amounted to thousands of USD annually, depending on the size of the nursery and the length of time it had been in operation. Increased incomes were used to pay for school fees, health care and to help develop other small-scale enterprises. More fruit was evident in the diet of approximately 50 percent of local-adopters, while participatory domestication led to a reduction in human migration from rural to urban areas; this was because young people stayed in villages to engage in new farming activities and to benefit from new business opportunities. Farmers involved in participatory domestication gained respect in their communities, better communication skills and additional local responsibilities.

for the importance of agroforests as reservoirs of local biodiversity (termed *circa situm* conservation) in smallholdings is strong. For example, Garen *et al*. (2011) identified a total of 99 tree species utilized, planted and/or protected in farmland in Los Santos and Rio Hato, Panama. One-third of these species were valued by farmers for human food and similar proportions for wood and living fences. Similarly, Marjokorpi and Ruokolainen (2003) identified more than 120 tree species in forest gardens in two areas of West Kalimantan, Indonesia; farmers indicated that approximately 30 percent of the species were used for edible fruit and latex and in other non-destructive ways, while around 50 percent were used for timber and were otherwise harvested destructively. Again, Sonwa *et al*. (2007) identified 206 tree species in cacao agroforestry plots in three sub-regions of Cameroon, where farmers indicated 17 percent of species were used primarily for food, 22 percent for timber and 8 percent for medicine; food-producing trees were observed in higher densities in agroforests close to the urban centre of Yaoundé, indicating the importance of the sale of tree foods to urban populations. While some of the tree species in the examples above were of exotic origin and, therefore, their agroforest stands were not of much or any conservation value, in each of the above cases there were more indigenous than exotic species present (Dawson *et al*., 2013).

The positive role that tree species diversity (and intra-specific diversity) has been shown to play sometimes in increasing both overall productivity and resilience in farming systems (Steffan-Dewenter *et al*., 2007) supports opportunities for *circa situm* conservation. Current levels of farmland tree species diversity may not, however, be sustainable. For example, Rolim and Chiarello (2004) and Sambuichi and Haridasan (2007) demonstrated that shade cocoa production systems transition to lower and less valuable (from a conservation perspective) farmland tree species diversity over time. Furthermore, Lengkeek *et al*. (2005) and Kehlenbeck *et al*. (2011) indicated that exotic species of limited conservation concern could dominate species-rich agroforests in overall abundance terms. In some circumstances, exotic trees can significantly threaten local biodiversity by invading cultivated and natural ecosystems, and this has to be weighed carefully against the benefits from planting (see, e.g. Richardson *et al*., 2011 for the case of the useful, but sometimes invasive, Australian acacias; Ewel *et al*., 1999).

Another concern limiting the long-term conservation value of agroforests is the very low density of many tree species found within them. For example, of the 297 tree species identified in Central Kenyan farms by Lengkeek *et al*. (2005), more than 40 percent occurred at a density of less than 0.1 mature trees per ha. The presence of these (mostly forest-remnant) trees in the farm landscape is vulnerable to the decision-making processes of individual farmers on whether to cut or retain particular specimens, and their regeneration will be limited if cross-pollination is required but restricted by the absence of neighbours (Lowe *et al*., 2005).

Domestication processes always result in shifts in distribution and/or losses in genetic diversity in the organism being domesticated (Box 6), but impacts depend on the domestication method adopted, with the participatory approach described above providing a good balance between immediate productivity gains for trees and conserving sufficient genetic variation to support their longer term use (Leakey, 2010). When bringing previously wild tree species into cultivation in farmland, it is essential to increase their yields through selection, since otherwise more productive staple crops will dominate the cropping system. Such an outcome does not support the agrobiodiversity or resilience of farms (Sunderland, 2011). For smallholders' agroforestry systems to better support *circa situm* conservation, they must take certain measures such as broadening access to high-quality planting material of indigenous trees and (to support regeneration) encouraging pollen exchange between rare trees (Dawson *et al*., 2009).

The second proposition above, that cultivating trees provides an alternative source for tree products that then protects natural stands from

Box 6

**Domestication and the fate of genetic resources in cultivation**

To introduce several concepts important for his theory of evolution, Darwin (1859) opened his classic text *On the Origin of Species* with a discussion of domestication. He discussed "unconscious selection" and "methodical selection", the first practiced by local communities and traditional farmers, the latter now practiced by modern plant breeders. Darwin was fascinated by the increase in morphological variation in traits selected by humans, something quite evident in annual crops (e.g. brassica, maize, peppers, potato) and in domesticated animals (cattle, cats, dogs, etc.). We now know that such selection is accompanied by decreases in genetic variation measured as the number of alleles at loci across the wider genome, because each selection event samples only a small part of the total genetic variation present in a population. If the progeny of this selection event substitute the ancestral population, a significant loss of genetic variation results, as has been the case in modern plant breeding, where a genetically uniform variety can be planted across tens of thousands of hectares.

In traditional farming systems, selection also results in the loss of underlying genetic diversity but planting any particular selection over a relatively small area ensures that overall diversity still remains relatively high (Louette, 2000). Genetic model analysis of a participatory domestication project with peach palm in Peru, for example, showed that the risk of genetic erosion in a regional context was low (Cornelius *et al*., 2006). Overall, losses of genetic diversity through village-level tree participatory domestication programmes are rarely likely to be significant, and losses could be much greater if domestication leading to increased productivity did not take place, as the alternative could be loss of the tree from the entire landscape in competition with other agricultural production options.

Box 7

**Markets, cultivation and conservation: the case of allanblackia, a new tree crop (taken from Jamnadass *et al*., 2010; Dawson *et al*., 2013)**

The seed of allanblackia, a genus of nine species native to biodiversity hotspots in the humid forests of sub-Saharan Africa, yields edible oil with high potential in the global food market as a hard stock for producing spreads that are low in trans-fats (www.allanblackiapartners.org/). A private-public partnership is attempting to develop a sustainable allanblackia oil business that could be worth hundreds of millions of USD annually for local farmers. A supply chain for seed has been established in Ghana, Nigeria and Tanzania based on harvesting by local communities in natural forests and from trees remaining in farmland after forest clearance. Currently, oil volumes are small (hundreds of metric tons) but export and incorporation into commercial food spreads has begun. At the same time, the tree, wild until now, is being brought into cultivation by improving seed handling and developing vegetative propagation methods, and by selecting superior genotypes (see Figure 4). Large productivity gains appear to be possible under cultivation and this may afford greater protection for allanblackia in the wild, as collecting the latter will be relatively less profitable, though this would then disadvantage the very poor in communities who can collect wild seed but do not have farms on which to plant the tree. So far, tens of thousands of seedlings and clones have been distributed to smallholders.

Integrating allanblackia into small-scale cocoa (*Theobroma cacao*) farms is being promoted to support more biodiverse and resilient agricultural landscapes. As allanblackia trees grow, cocoa trees provide the shade they need; when they are grown, they in turn will act as shade for cocoa. The fruits of cocoa and allanblackia are ready for harvest at different times of the year and, when the allanblackia trees have matured, this will spread farmers' incomes. Whether or not the promotion of cultivation of allanblackia will take pressure off natural stands, by directing market demand for seed oil to planted sources, remains to be seen. If the production of allanblackia is co-opted by large commercial growers in plantations in locations outside the native range, it could, in theory, protect the natural resource base from harvesting, but local people would no longer benefit from cultivating the tree, countering development objectives.

over-harvesting, has been widely assumed (e.g. Lambert *et al*., 1997; Lange, 1998; Strandby-Andersen *et al*., 2008) and at first sight it would appear intuitive. With rare exceptions (e.g. Murniati *et al*., 2001), however, it is difficult to find evidence for cultivated stands supporting natural stand (*in situ*) conservation (Newton, 2008). There are several reasons why there may not be a positive link between cultivation and *in situ* conservation. One is that planting may result in placing less priority on sustainably managing natural stands. Clapp (2001), for example, reported that in Chile the timber plantations developed in the 1960s resulted in foresters viewing natural timber stands merely as 'stopgap' supplies that could be over-exploited while plantations were reaching harvest maturity. A second reason is that cultivation might stimulate the development of markets and infrastructure that unintentionally 'capture' wild resources (Cossalter and Pye-Smith, 2003; Angelsen and Kaimowitz, 2004). A third reason is that when it leads to a profitable business, planting trees could lead to forests and woodlands being (further) cleared to expand cultivation (see the case of tree commodity crops discussed below).

Detailed research to establish when and where positive *in situ* conservation results can be realized through smallholder tree cultivation is required, for example based on the allanblackia tree that is currently undergoing domestication in smallholdings surrounding forests where it grows naturally (Box 7). Market demands for product traceability and sustainability can help promote beneficial links between cultivation and *in situ* conservation (Strandby-Andersen *et al*., 2008). Such schemes are growing. Rainforest Alliance, for example, certified only 200 farms as reaching social and environmental standards in 2000; by 2011 the number of certified farms had surpassed 250 000, each on average 4.5 ha in area (Michelle Deugd and Edward Millard, Rainforest Alliance, www.rainforest-alliance.org, personal communications).

## 3.6. Global environmental services, resilience and local communities' livelihoods

Trees in forests, woodlands, agroforests and elsewhere provide important environmental services[3], including soil, spring, stream and watershed protection, animal and plant biodiversity conservation, and carbon sequestration and storage, all of which can ultimately benefit local communities' livelihoods (Garrity, 2004). Individual farmers can be encouraged to preserve and reinforce these functions in agroforests by payments for environmental services, but most methods of payment are inefficient (Roshetko *et al*., 2002, 2008; Jack *et al*., 2008). Of most importance in determining smallholders' tree planting and retention behaviour are the direct products and services they receive from trees (Roshetko *et al*., 2007a). An important advantage of smallholder agroforestry systems is that they can provide wider environmental services while directly supporting production (Leakey, 2001, 2010). Obtaining products from trees by non-destructive harvesting that does not significantly reduce tree growth (e.g. by collecting fruit) provides particular opportunities to fulfil both environmental service functions and production functions.

One example of a market opportunity that has the potential to mitigate global climate change and enhance energy security is smallholders cultivating trees for biofuel (FAO, 2008). However, a major omission, in common with most other schemes for tree environmental service provision, has been the little attention given to the genetic quality of the trees planted. Tree species have frequently been considered as single entities without recognizing the significant genetic variation that could be harnessed for improving livelihoods and for better providing environmental services. A good example is the small tree jatropha (*Jatropha curcas*), which in the decade at the start of this millennium was heavily promoted in Africa, Asia and elsewhere for biodiesel production (oil extracted from the seed; Achten *et al*., 2008). Jatropha originated in Latin America. But instead of returning there to obtain germplasm, wide modern planting in mainland Africa relied on seed from sub-optimal stands (from a biodiesel perspective) first introduced into Cabo Verde hundreds of years ago (Lengkeek, 2007).

Iiyama *et al*. (2013) demonstrated that yields from smallholder plantings of jatropha in Kenya were dismal compared to expectations, which was partly due to the use of inferior germplasm, as well as poor farm management and planting in inappropriate environmental conditions. They concluded that, without genetic improvement, jatropha should not be cultivated by smallholders as a commercial biofuel in Kenya. They determined that significant returns for Kenyan farmers, and a useful contribution to climate change mitigation, would only be possible with the coordinated introduction of more productive planting material that was environmentally matched to local conditions. At the same time, improved farm management methods would need to be disseminated and adopted.

Ecological and social resilience can be increased when the different tree, crop, animal, etc. components of agroforestry systems, and the interactions between these components, respond in different ways to the changes experienced in and by rural communities (Steffan-Dewenter *et al*.,

[3] Or 'ecosystem services'; the terms are generally used interchangeably.

2007). Placing trees within agricultural production systems is a useful risk reduction strategy in response to anthropogenic climate change and is an important component of a 'climate-smart' agriculture (Neufeldt *et al*., 2012). Agroforestry soil fertility improvement technologies can, for example, stabilize crop yields under drought conditions that will become more prevalent in some regions under anthropogenic climate change (see above). In the Niger, farmers explain that they prefer to have a number of tree species for each tree function (fruit, fodder, wood fuel, etc.) as this insures them against 'function failure' by individual species in the driest years (Faye *et al*., 2011). In western Kenya, subsistence farmers practising agroforestry (to control soil erosion, to improve soil fertility and to provide wood fuel, etc.) identified more coping strategies when they were exposed to climate-related hazards than those farmers who did not (Thorlakson and Neufeldt, 2012).

Kristjanson *et al.* (2012) explored the relationship between food security and farmer innovation in the context of a range of changing circumstances in Ethiopia, Kenya, Uganda and Tanzania. A strong positive relationship was found between household food security and adopting new farming practices, although it was not possible to determine whether this was because innovative households are more food secure as a result of innovation, or if more food secure households are better placed to subsequently innovate. Many of the 700 households surveyed by the authors were practising agroforestry, but generally they were only planting small numbers of trees, which indicates a need to understand why there had not been wider uptake. Possibly, the relatively long investment period generally required before benefits are received from tree planting is an important factor. Efforts must be made to reduce this period and/or to otherwise finance planting.

A diversity of trees in farmland and neighbouring natural forest fragments, where present, supports populations of pollinator species such as insects and birds that are essential for the production of many crops (Garibaldi *et al*., 2013). Many fruit trees cultivated widely by smallholders rely on insect pollinators for production (Klein *et al*., 2007), while diverse farms that provide an alternative habitat for pollinators can support the regeneration of food plants in neighbouring forests (Hagen and Kraemer, 2010). Since many pollinators of crops and trees are ectothermic, they will likely be affected by climate change, and if their phenologies change and range shifts occur, ecosystem functions could be impaired; however, a range of trees, crops and pollinators helps to insure against this risk.

Chapter 4

# The benefits of smallholder tree commodity crop production

## 4.1. Quantifying smallholder production and value

Although market data for tree products important to tropical rural communities is generally sparse, tree commodity crops are something of an exception, with data on the export value of several crops complied by national governments and FAO's Statistics Division (FAOSTAT). Total global export values for 12 tree commodity crops grown widely in the tropics are given in Figure 5, amounting to more than USD 90 billion in 2010. Approximately 90 percent of this value was made up of only five commodities: palm oil (derived from oil palm, *Elaeis guineensis*), coffee (primarily from *Coffea arabica*, values for green coffee only

**FIGURE 5**

Global export values of a range of tree commodity crops over a 20-year period, 1991 to 2010. Data were extracted from FAOSTAT (www.fao.org/faostat/) and are combined figures for all nations providing information. Data for mangoes, mangosteens and guava are pooled in FAOSTAT. Given values include re-exports (i.e. import into one nation followed by export to another). Some commodities, such as coffee, cocoa and coconut, are exported in more than one form and total export values are, therefore, higher than those shown here (for each of these commodities only the most important form by export value is given). Domestic trade for a few of the commodities listed, such as mango and avocado, could be much greater than their international trade (Mohan Jain and Priyadarshan, 2009). The graph shows there was a significant increase in export values for crops during the decade leading up to 2010. The most notable feature was the sharp rise in the value of palm oil exports, reflecting a massive global expansion in palm oil production.

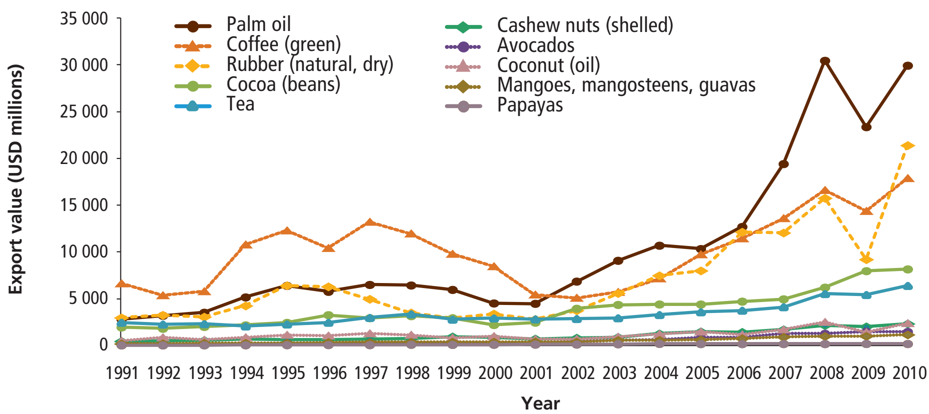
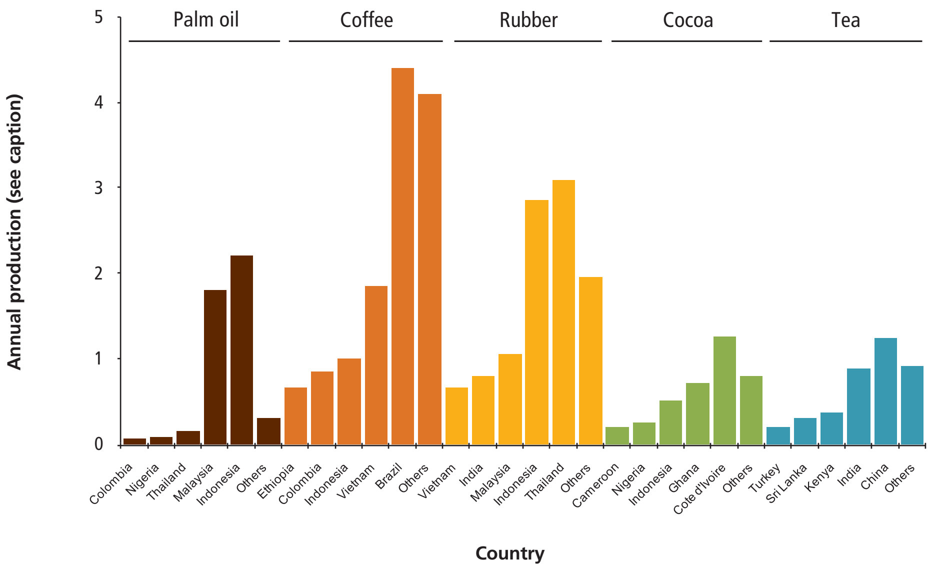


**FIGURE 6**

Average annual production figures for five tree commodity crops (taken from UNCTAD, 2011). The data shown are based on the following years: palm oil, coffee and cocoa, 2008/2009–2010/2011; rubber and tea, 2007–2009. Units of production are as follows: palm oil, 10s of millions of metric tons; coffee, 10s of millions of 60 kg bags; rubber, cocoa and tea, millions of metric tons. The graph shows five key production countries for each commodity.




are shown), rubber (from *Hevea brasiliensis*), cocoa (beans, from cacao, *Theobroma cacao*) and tea (primarily from *Camellia sinensis*). These five commodities are produced across the tropics, with Indonesia and Malaysia reported as the most important nations for palm oil, Brazil for coffee, Thailand and Indonesia for rubber, Côte d'Ivoire for cocoa and China for tea (Figure 6; UNCTAD, 2011). Indonesian figures for 2011 (Table 4) illustrate how each of these five tree commodities is grown to a significant extent by smallholders. Using national producer price data available for Indonesia in FAOSTAT databases and based on estimated production volumes, the total 2011 farm-gate value for Indonesian smallholders of palm oil, cocoa and coffee production were more than USD 2 billion, 1.5 billion and 1 billion, respectively.[4]

Unfortunately, many countries do not differentiate between smallholders and larger scale plantation growers in the way that Indonesia does when they report tree commodity crop production. Illustrative data on particular crops, however, demonstrate the importance of small-scale production. For example, approximately 30 percent of land planted with oil palm in Malaysia is believed to be managed by smallholders (Basiron, 2007). Ethiopia has approximately 700 000 smallholder coffee

[4] Our calculations, based on the 2007 producer price for palm oil, and the 2010 producer prices for cocoa and coffee.

**TABLE 4**

Estimates of smallholder production of five tree commodity crops in Indonesia for 2011

| | Smallholder area (thousands of ha) | % of total area | Smallholder production (thousands of metric tons) | % of total production |
|---|---|---|---|---|
| Palm oil | 3 315 | 42 | 7 774 | 39 |
| Coffee | 1 255 | 96 | 679 | 96 |
| Rubber | 2 935 | 85 | 2 104 | 80 |
| Cocoa | 1 641 | 94 | 828 | 92 |
| Tea | 56 | 46 | 40 | 26 |

Figures for the percentage of the total area planted by smallholders and their percentage of total production are given. Estimates are based on historic records, current trends and actual data collected and reported for the year (Department of Agriculture, personal communication).

growers and Kenya has around 400 000 (Place *et al*., 2011), while smallholders produce more than two-thirds of coffee worldwide (www.ico.org). The equivalent figure for cocoa is 90 percent and there are estimated to be six million cocoa farmers in the tropics (www.icco.org). Natural rubber has seen a trend toward smallholder production as large estates have switched to less labour-intensive crops such as oil palm; some estimates suggest that more than three-quarters of rubber production worldwide between 1998 and 2003 came from holdings of less than 40 ha, with most from smallholdings of 2 to 3 ha (http://unctadstat.unctad.org/). Again, around 75 percent of tea grown in Sri Lanka and 50 percent grown in Kenya is reported as coming from smallholdings (http://unctadstat.unctad.org/).

As production of the above tree commodity crops constitutes the most significant proportion of farm takings for tens of millions of tropical smallholders, investments in genetic improvement and better farm management of these crops have wide benefits (Mohan Jain and Priyadarshan, 2009). The successful promotion of higher-yielding rubber clones and better managing plants to reduce input costs and retain some biodiversity in rubber agroforests have led to greater profits for many Indonesian smallholders (Wulan *et al*., 2006; Roshetko *et al*., 2007b). The rising price of cocoa in world markets has led to increased interest in upgrading smallholders' cocoa production methods in Indonesia, Côte d'Ivoire and elsewhere, through private-public partnerships involving the chocolate industry. Interventions have included delivering higher-yielding varieties to replace or rehabilitate (through grafting) farmers' old cacao trees, improving farm management methods, and enhancing market access through group sales and certification (www.worldcocoafoundation.org).

## 4.2. Tree commodity crops and the international transfer of genetic resources

Tree commodity crops illustrate the importance of the international exchange of tree genetic resources to support smallholders' livelihoods (Koskela *et al*., 2014). Figure 6 indicates that palm oil is produced commercially primarily outside the centre of origin of the palm, which is West Africa, as also are coffee, rubber and cocoa compared to the plants' origins (originally from East Africa, Brazilian Amazonia and western Amazonia, respectively). Most tea is produced in the region where the plant originated (Asia), although it is also an important cultivated commodity in places

Box 8

**International transfers of tree commodity crop germplasm: oil palm, coffee, rubber and cacao (taken from Mohan Jain and Priyadarshan, 2009)**

Oil palm seedlings were taken from West Africa to Bogor Botanical Gardens in Indonesia via Mauritius and The Netherlands in the 1840s. From Bogor, material spread within Indonesia and the 'Deli dura' type reached and spread in Malaysia. A Deli dura crossed with a pisifera type is now the most common material planted worldwide. Malaysia first organized a major collection of *E. guineensis* germplasm in Nigeria in the 1970s for breeding programmes. The related species *E. oleifera* was collected from Central and South America in the 1980s in a Brazilian, Malaysian and French collaboration for on-going breeding work.

Modern arabica coffee cultivars are derived from two base populations known as Typica and Bourbon that were transported from East Africa throughout the tropics in the early 1700s.

The natural rubber industry in Southeast Asia was based on seedlings transferred to Sri Lanka and Singapore in the 1870s from the Brazilian Amazonia via Kew Botanic Gardens in the United Kingdom. Malaysia and Brazil collaborated on collections in the 1980s to supplement this material.

Cacao was introduced into Indonesia by the Dutch from Venezuelan sources in 1560 and by the Spanish into the Philippines in 1600. The French introduced cacao to multiple locations from the mid-seventeenth century onwards, and the patterns of transfer and introduction thereafter were complex. Forastero cacao trees were apparently established from Brazilian sources on islands off the coast of continental West Africa from the 1820s onwards, before being transported to the mainland. Forastero types are now the most widely planted worldwide.

far from its origin (e.g. in Africa). The history of human transfer of oil palm, coffee, rubber and cacao germplasm is described in Box 8. Transfers initially occurred in large part during European colonial expansion in attempts to find new agricultural enterprises suitable for the colonies. Successful early cultivation in exotic locations was due in part to escape from pests and diseases that co-evolved with crops where they originated (Clement, 2004). However, founder material was often sub-optimal in performance because the crops were not well characterized when transfers were first made, sometimes hundreds of years ago (Mohan Jain and Priyadarshan, 2009).

With most production taking place outside the regions where the crops originated, tree commodity crops are similar to many annual staple crops where production has been widely dispersed (Harlan, 1975). However, tree commodity crops have generally been subject to fewer rounds of formal breeding than these highly manipulated annuals (Mohan Jain and Priyadarshan, 2009). Extant highly genetically variable landrace, semi-wild and wild resources of tree commodities (e.g. see Bekele *et al*., 2006 and Lachenaud and Oliver, 2005 for cacao; Montagnon and Pierre Bouharmont, 1996 for coffee; Cochard *et al*., 2009 for oil palm; Priyadarshan and Goncalves, 2003 for rubber) might, therefore, play a more important role in future crop development than is the case for annuals (Mohan Jain and Priyadarshan, 2009). Conserving these gene pools is, therefore, essential.

Coffee is an example of a tree commodity crop whose genetic resources are severely threatened. Due to the conversion of forest to agricultural land, there remains only around 2 000 km$^2$ of high quality Ethiopian montane forest containing the wild coffee progenitors of modern coffee varieties. The introduction of cultivated coffee germplasm that may hybridize with and genetically dilute wild stock is also threatening wild populations of Ethiopian coffee (Labouisse *et al*., 2008; Aerts *et al*., 2013). Threats to Ethiopian wild coffee are also presented by anthropogenic climate change: ecological niche modelling suggests a further loss of the wild coffee habitat in Ethiopia and a resultant high risk of natural stand extinctions by 2080 (Davis *et al*., 2012). Wild coffee seeds can't be stored long-term because the seed is recalcitrant, so conserving natural stands remains particularly important. The cryopreservation of seed and *ex situ* field gene banks are also possible conservation measures (Engelmann *et al*., 2007).

Placing an 'option value' on the genetic resources of wild coffee, cacao and rubber is not easy. There are many unknowns when carrying out valuation, such as how genetic variation is structured within wild populations, and what the future needs will be for accessing wild resources for particular breeding purposes. Breeding needs will depend on, among other factors, new disease outbreaks that are hard to forecast, the extent of local temperature and precipitation alterations caused by anthropogenic climate change (which may or may not be considerable, depending upon the success of current climate change mitigation actions) and changing consumer preferences. As described in Box 9, however, valuation has been attempted for wild coffee. The exercise provided a strong case for the need of the coffee industry to introduce additional measures to protect Ethiopian wild coffee stands (Hein and Gatzweiler, 2006). But, although the case for action is strong, how can and should coffee growers in countries such as Brazil and Indonesia, which produce more coffee than Ethiopia, support conserving wild coffee stands in East Africa? The dilemma for conservation presented by the geographic separation of origin and production centres applies to many other tree species in addition to tree commodity crops.

Box 9
**Costing the economic value of wild tree genetic resources to support future breeding: the case of coffee (taken from Hein and Gatzweiler, 2006; with further information from Reichhuber and Requate, 2007)**

The economic value of wild *C. arabica* stands contained in the highland forests of Ethiopia, which represent the genetic base of coffee production worldwide, was estimated from their potential use in coffee breeding programmes. Their potential as sources of resistance to three coffee pests and diseases – coffee berry disease, *Meloidogyne* nematodes and coffee rust – which are among the worst pests and diseases affecting coffee production worldwide, were considered. Valuation also considered breeding for low caffeine content (thereby avoiding the costs of decaffeination) and for increased yields. Based on a 30-year discounting period, net present values of wild coffee genetic resources of approximately USD 1.5 billion and 420 million were obtained at discount rates of 5 percent and 10 percent, respectively. Even the lower of these values provides a strong basis for urgent action to halt the ongoing rapid deforestation of the Ethiopian highlands.

Key uncertainties faced in estimating the option value of wild coffee for breeding included the length of time required to transfer valuable traits from wild plants into new cultivars, and the potential adoption rate by farmers of new cultivars. In the current case, a 15-year period for a successful breeding programme was assumed, and a 20 percent adoption rate applied for improved cultivar planting. Another uncertainty in valuing natural forest stands of coffee is the extent to which the important traits they contain have already been transferred to other parts of the world through establishing wild Ethiopian accessions in *ex situ* field gene banks in countries such as Brazil (i.e., to what extent are extant wild stands unique in conserving resources?).

## 4.3. Tree commodity crops, displacement and biodiversity loss

Although tree commodity crops provide smallholders with important revenues, this does not mean that they always play a positive role in supporting wider livelihoods; for example, their role in food and nutritional security is frequently questioned (FAO, 2012). The reasons for this questioning are manifold: one reason is that planting commodity crops often results in clearing natural forests that contain edible plants that are important foods to the very poorest people in rural communities who have no farmland. Another danger is that commodities are produced in monocultures that displace a range of foods from farmlands. Indigenous tree fruits may be one group of foods lost from farm landscapes in a trend to commodity monoculture, especially if these trees are only present anyway at low densities in farms (making them vulnerable to displacement and to productivity drops due to a lack of pollination, see above; Lengkeek *et al*., 2005). Widening oil palm cultivation is an example where a commodity crop causes both the loss of forest and of agrobiodiversity (Donald, 2004; Danielsen *et al*., 2009). Rubber agroforestry systems are compatible with habitat and biodiversity conservation (Wibawa *et al*., 2005; Beukema *et al*., 2007; Roshetko *et al*., 2007b), but they are, unfortunately, often a transient land use under pressure for conversion to less diverse agricultural systems (Ekadinata and Vincent, 2011).

It has sometimes been suggested that intensive monocultures are on balance better than mixed production systems because they raise yields and hence reduce the amount of farmland needed for production, thus limiting the need to clear natural habitats for more agriculture. The issues are clearly complex and need to be understood in the context of trends in global and local food systems, including raising livestock and aquaculture as well as annual and perennial crop-based production (Khoury et al., 2014). There are, however, few quantitative data that support the view that 'land sparing' is more effective than 'land sharing' as a conservation approach (Balmford *et al*., 2012; Tscharntke *et al*., 2012). Buying food from the income received from a single commodity crop rather than cultivating food directly can also lead to food insecurity for farm households when commodity receipts are one-off, delayed and/or unpredictable in value, as observed for cocoa production in West Africa (Edward Millard, personal communication). Mixed agroforestry regimes integrating commodities into diverse production systems with food trees, staple crops, vegetables and/or edible fungi, etc. that increase or at least do not decrease commodity yields and profitability (Clough *et al*., 2011), and promote resilience, can help to avoid these negative effects.

Chapter 5

# Final considerations and recommendations

To improve rural peoples' lives through NTFP harvesting it is necessary to better understand how to manage the resource and how to ensure equitable relationships between the different participants in supply chains to consumers (Marshall *et al*., 2006). Interventions to benefit local communities include: technical support in harvesting and processing; business support for establishing social enterprises; providing market data; and advocating policies that support diversified livelihood strategies. Specialized market niches for products and processes (organic, eco-labelled, fair-traded, etc.) can capture different consumer preferences, can help protect against market substitution and can contribute to social equity. However, the costs of certification can place trade beyond the reach of many small producers and traders. The ecological implications and genetic aspects of NTFP harvesting, with regard to productivity, sustainability, etc., have received limited attention and require further research (Ticktin, 2004).

To improve rural communities' returns from tree products, value chain analysis is one important approach. This characterizes the processes by which products are brought from production to consumption (Kaplinsky and Morris, 2002; Jensen, 2009). Through understanding how value is created and identifying constraints and opportunities to participation, value chain analysis can be used to help integrate rural communities into tree product markets (e.g. Facheux *et al*., 2007; Wambugu *et al*., 2011). A common mistake to be avoided is to begin by producing more of a tree commodity or product with the idea that a market will emerge on its own to absorb it; this often leads to surpluses that act as disincentives to investment. Another mistake is to focus on single commodities, as markets are changeable; diversification is needed to help ensure stable revenues (Russell and Franzel, 2004).

Human-driven climate change and forest displacement by agriculture (FAO, 2010; Peres *et al*., 2010) mean that the tree products and services will in future increasingly be sourced from farms. With increased smallholder tree planting being encouraged to support livelihoods and conservation, it is necessary to better understand the consequences of cultivation and market development for alleviating poverty, malnutrition and hunger (Leakey, 2010), and for the conservation status of over-exploited forest resources (Dawson *et al*., 2013). Although a shift from forest harvesting to farm cultivation of NTFPs and timber can have desirable outcomes for smallholders, it can disadvantage the poorest in communities who do not have land for planting and, therefore, can only collect products from the wild (Page, 2003). Such effects need to be better understood.

Key constraints to be addressed to improve tropical smallholders' livelihoods from tree planting are described in Box 10. Improvements are required in policies, in markets, and in developing and delivering appropriate high-quality planting material and farm management methods. As women tend to be involved in NTFP- and AFTP-based activities when there is less money at stake, producer associations for women need to be formed and strengthened (Shackleton *et al*., 2011b) to improve their situation. It is also important to improve women's access to information by training more women extension staff and holding separate meetings for women farmers, although care must be taken in such interventions to ensure

Box 10

**Key constraints to be addressed to improve smallholders' livelihoods from tree planting (taken from Roshetko *et al.*, 2007c; Jamnadass *et al.*, 2011; Lillesø *et al.*, 2011; Place *et al.*, 2012)**

**Policy constraints**

Policy plays an important role in successful agroforestry. There are three key areas in which constraints need to be overcome to distribute benefits more widely. First, farmers need land and tree tenure: where these are absent or contested, farmer involvement in tree planting and management is often limited, but when they are assured, greater interest in agroforestry is stimulated. Second, policies that support farmers' access to seeds, seedlings and clones of a wide range of tree species suitable for their various planting requirements are crucial. Current germplasm provision policies often slow adoption by discriminating against small-scale entrepreneurial seed and seedling suppliers. Current laws to control germplasm flows internationally have also unintentionally slowed smallholder access to appropriate planting material. Third, the current policy environment often does not recognize agroforestry options as attractive investments. For example, governments often subsidize artificial fertilizers to enhance staple crop yields, which discourages using green fertilizers that can increase staple production more cost effectively and sustainably.

**Constraints in delivering tree products to markets**

For many tree products, markets are poorly structured. This results in low and unstable returns to farmers and high prices for buyers, limiting consumption. The problems producers frequently cite include: the absence of collective bargaining systems; poor transport infrastructure; and the involvement of multiple intermediaries in supply chains, all of which act to reduce farm-gate prices. Smallholders and other small- and medium-scale enterprises often lack the information and equipment they need to properly store, grade, preserve, transport, etc., tree products. For perishable goods such as fruit, the result is high wastage and a failure to reach quality grades. Prevailing low returns mean farmers struggle to afford inputs to improve sub-optimal farm management practices. Traders also face many problems such as poor roads and corrupt officials.

**Underinvestment in research**

There has been underinvestment in developing new tree lines, cultivars, clones, etc. that have high yields and provide quality products under smallholders' production conditions. Until recently, for example, science mostly ignored the great potential for improving indigenous fruit trees, and there are still too few scientists working out how to cultivate them. For many indigenous food trees, only limited information is available on nutritional value, which can be expected to vary significantly even within species. Although the benefits of agroforestry systems for responding to climate change are recognized, the great diversity of agroforestry landscapes and the sometimes long life cycles of trees and production systems mean that the most effective combinations of trees, staple crops, vegetables, animals, etc., and how to manage these together in particular environments, are often unknown.

men do not become resistant to the involvement of women (Kiptot and Franzel, 2012).

Tree commodity crops play an important role in supporting rural livelihoods, but a better understanding is required of the complicating factors in converting land to monoculture production systems, and of the impacts that single-source incomes have on food and nutritional security. Commodity varieties that are highly productive in mixed farming systems are needed and breeding efforts should be prioritized accordingly (Mohan Jain and Priyadarshan, 2009). International purchasers of commodities are actively encouraging diverse production systems through standards, certification and other means, but they are only appropriate for some commodities (Millard, 2011).

In summary, we recommend that particular attention be given to the following points to better support rural peoples' tree-based livelihoods in the future:

- Develop germplasm delivery mechanisms that better support smallholders' access to a wide range of high-quality tree planting material. This will involve supporting small-scale, local entrepreneurial tree seed, seedling and clone suppliers with business and technical training, and will involve supplying them with appropriate 'starter' germplasm. Lessons from the past 40 years demonstrate that national governmental agencies and non-governmental organizations that have traditionally been involved in tree germplasm delivery need to reorient their roles; instead of trying to take on the job of delivery directly, they should support local entrepreneurial suppliers to do so (Graudal and Lillesø, 2007).
- Increase research capacity to promote domesticating new tree crops in smallholders' farms. This requires understanding what approaches to date for tree domestication have been most effective in improving incomes, food and nutritional security, health, etc. for smallholders, based on a more extensive quantification of impacts of past and present initiatives. The utility of the participatory domestication approach outside Central Africa, where it has to date been practiced most widely, should be evaluated carefully. Scaling up this approach could be the start of a second wave of plant domestications targeted to low- and middle-income tropical nations (Leakey, 2012a, b). Greater research capacity is also required to understand how to promote the resilience of agroforestry production systems in the face of climate change.
- Undertake value chain analysis and supply chain development, including of post-harvest processing, storage and packaging methods, with particular emphasis on domestic markets for tree products, considering especially rapidly growing urban markets. This will involve developing producer-trader-processor links that expand farmer opportunities, promote transparency and reduce inefficiency.
- To better quantify the current importance of NTFPs and AFTPs for local communities, national statistical services should seek, with the assistance of FAO, to partition but cross-standardize the collection of data from on-farm and in-forest, and small-scale and large-scale, product sources. The need for uniform, consistent data collection methods has been a common refrain over the last decades, but implementing such approaches remains a challenge (e.g. compare Byron and Arnold, 1997 with FAO, 2010). The development of a more appropriate typology for estimating the extent and importance of trees-outside-forests will assist future characterization (de Foresta *et al*., 2013).
- Undertake costings of the option values of wild stands of major tree crops. This is crucial for providing an evidence-based justification for *in situ* conservation of tree genetic resources. Such valuations will indicate which tree populations and areas of a forest are of most conservation concern. Because the economic value of tree commodity crops is high and since there is a high measure of international interdependence in their production, appropriate mechanisms by which 'producer' countries and their growers can properly support maintaining genetic resources in 'centre of origin' nations are required.
- Determine the circumstances where commercializing the harvesting of tree products from natural forests and expanding smallholder cultivation can help to conserve tree species and genetic

resources, both in the wild and in farmland. This will support more sustainable livelihoods for rural people. Case studies for research on this topic could involve species such as allanblackia (Box 7). The topic is the subject of ongoing research efforts involving CIFOR, Bioversity International and ICRAF (Manuel Guariguata, CIFOR, personal communication).

- Define more effective measures to support and protect the innovations of poor farmers and local communities in low-income countries when, for example, they develop new tree cultivars through local domestications. Strategies are needed for managing the distribution of planting material of new tree crops such as allanblackia that may become the new commodities of the future. In such cases, should germplasm distribution be restricted to the country of origin, to the continent of origin, or be allowed worldwide (as applied in past centuries for cocoa, coffee, oil palm, tea, etc.)? And how will most smallholder producers benefit? Governments require support in making such decisions.

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# Appendix

**Examples of indigenous food trees, identified through priority-setting exercises, to be promoted in different parts of sub-Saharan Africa (adapted from Jamnadass et al., 2011; with further information from Place et al., 2011)**

**Baobab** *Adansonia digitata*, a tree with a large swollen trunk that can have a diameter of up to 10 m, is a long-lived species (sometimes more than 2 000 years) located in the arid and semi-arid savannah in sub-Saharan Africa. The edible white, powdery pulp found in the fruit is rich in vitamins C and B2 and is used to make a refreshing drink. Young leaves, also rich in vitamin C, are in high demand in West Africa for making soup. A recent estimate suggested baobab may have a value across Africa of more than USD 250 million annually. Baobab has been given safe status for use in foods in the European Union and the United States of America.

**Ber** *Ziziphus mauritiana*, a spiny evergreen shrub or small tree that can grow to 15 m, is native to drylands in Africa and Asia. The fruit is eaten fresh or dried and can be made into a floury meal, butter, or a cheese-like paste that is used as a condiment. The fruit is a good source of carotene, vitamins A and C, and oils. Macerating the fruit in water produces a refreshing drink. The use of ber in India can be traced back to 1 000 BC. Improved, large-fruited cultivars are available there and elsewhere in Asia.

**Bitter cola** *Garcinia kola*, native to the moist lowland tropical forests of Central and West Africa, is a medium-sized evergreen tree. The bitter kernels are highly valued in Central Africa and chewed as a stimulant. Kernels are also used for treating coughs, bronchitis and liver disorders, while split stems and twigs are used as chewing sticks. A recent inventory revealed that the species, which is currently harvested mainly from the wild, is close to commercial extinction in Ghana.

**Bush mango** *Irvingia gabonensis* and *I. wombolu*, collectively known as bush mango or dika nut, are economically important long-lived fruit trees native to moist lowland tropical forests in Central and West Africa. The fruit mesocarp of *I. gabonensis*, sweet bush mango, is eaten as a fresh fruit snack. Ground kernels of both species are used to thicken and flavour soups, although those of *I. wombolu*, bitter bush mango, are the most valued and fetch high prices in cross-border trade, which contributes significantly to local economies. One estimate suggested that the demand for kernels in southern Nigeria is approximately 80 000 metric tons per year, worth approximately USD 40 million.

**Desert date** *Balanites aegyptiaca*, a spiny shrub or tree that grows to 10 m, is a species with wide ecological distribution across Africa. The fleshy pulp of the fruit is eaten fresh or dried, and oil from the kernel is used for cooking and in cosmetics. The fruit is processed into drinks in West Africa and is used as a soup ingredient in East Africa. Young leaves and tender shoots are used as a vegetable, which are boiled, pounded and fried.

**Kola nut** *Cola nitida*, an under-storey evergreen tree that generally grows to 9 to 12 m tall, is native to lowland tropical forests in Central and West Africa. Nuts, which contain caffeine, kolatine and theobromine, are chewed as a stimulant. At first, the nuts taste bitter when chewed but they leave a sweet taste in the mouth later. Chewing the nut before drinking water helps to render the water sweeter. The nut is widely used in social ceremonies.

**Marula** *Sclerocarya birrea* is a long-lived tree with an extensive distribution across the dryland savannah habitats of the sub-Sahara. The fruit pulp of *S. birrea* subspecies *caffra*, widely distributed in southern Africa, is used to produce jam, juice, beer and, in South Africa, the internationally-available liqueur

Amarula Cream, while the oily kernels are consumed raw, roasted and in sauces. In addition to current use, archaeological evidence indicates that humans harvested the fruit as far back as 10 000 years ago.

**Njansang** *Ricinodendron heudelotii*, a fast-growing tree that grows up to 50 m in height, is found primarily in Central and West Africa, often in secondary forests. A spicy sauce made from the kernels is widely used in stews, and the high oil content of the seeds makes them suitable for use in the soap industry. In Cameroon, it is valued for its medicinal properties and is used to treat constipation, dysentery, eye infections, female sterility and as a poison antidote. Export of the kernels from Cameroon to neighbouring countries was estimated at more than USD 1 million over 20 years ago.

**Safou** *Dacryodes edulis* is a medium-sized evergreen tree found in the humid tropical zone of Central and West Africa. It has been cultivated by farmers in southern Nigeria and Cameroon for many years and is considered semi-domesticated in many areas, based on planters' selective seed sampling. Rich in vitamins and amino acids, the fruit has an oily texture like avocado and is eaten boiled or roasted. Fruit from improved trees are much more commercially valuable than fruit from unimproved trees.

**Star apple** *Chrysophyllum albidum*, a long-lived tree that grows to 35 m, is a canopy species of lowland mixed rainforest that is distributed from West Africa to western Kenya. The fleshy and juicy fruits are widely eaten and can be fermented and distilled to produce wine and spirits.

Tamarind *Tamarindus indica*, a tree that grows to 30 m in height, is extensively distributed in the tropics. It is believed to have its origin in Africa, where it is found across dryland savannah regions. The species was cultivated in Egypt as early as 400 BC. The fruit pulp is used to prepare juice and jam, and is an ingredient in curries, chutneys and sauces. The ripe fruits of the sweet types are eaten fresh as a snack.

**Wild loquat** *Uapaca kirkiana*, a small- to medium-sized evergreen or semi-deciduous tree, is found in the miombo woodlands of southern Africa. The fruit is highly regarded and is eaten fresh. It is also used to prepare jams and beverages. Harvesting the fruit from wild populations is an important coping strategy during times of extreme hunger. A study in Zimbabwe more than 15 years ago showed that households in several regions made between USD 10 and 40 annually per household from selling the fruit.

For further information, see www.worldagroforestry.org/output/agroforestree-database.

Products and services derived from trees in forests, on farmland and within other landscapes provide benefits to hundreds of millions of people in the tropics. However, these products and benefits from the trees and their genetic resources have not been well quantified. This is the case, in part, because trade of the products often takes place outside formal markets and because there are a multiplicity of species, product sources and ways in which trees are used. Furthermore, the value of genetic diversity within tree species is often not properly considered.

From a genetic perspective, tree resources exist at different levels of domestication of populations and species. Some tree species, especially those producing fruit valued for human consumption, began to be domesticated within forest environments several millennia ago, and the process of their domestication remains ongoing today. Others, such as many timber tree species harvested from natural forests and trees that provide medicines, remain largely undomesticated.

This study, prepared within the ambit of *The State of the World's Forest Genetic Resources*, reviews what is known about the value of trees for tropical rural communities. It focuses on non-timber products harvested from trees in natural and managed forests and woodlands, the various products and services obtained from trees planted or retained in agroforestry systems, and the commercial products of tree commodity crops. The role of intra-specific genetic variation in determining the value of trees in supporting livelihoods is discussed in each of the three contexts. The study also identifies specific points that should be given particular attention in the future to better support tree-based livelihoods of rural communities in the tropics.

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