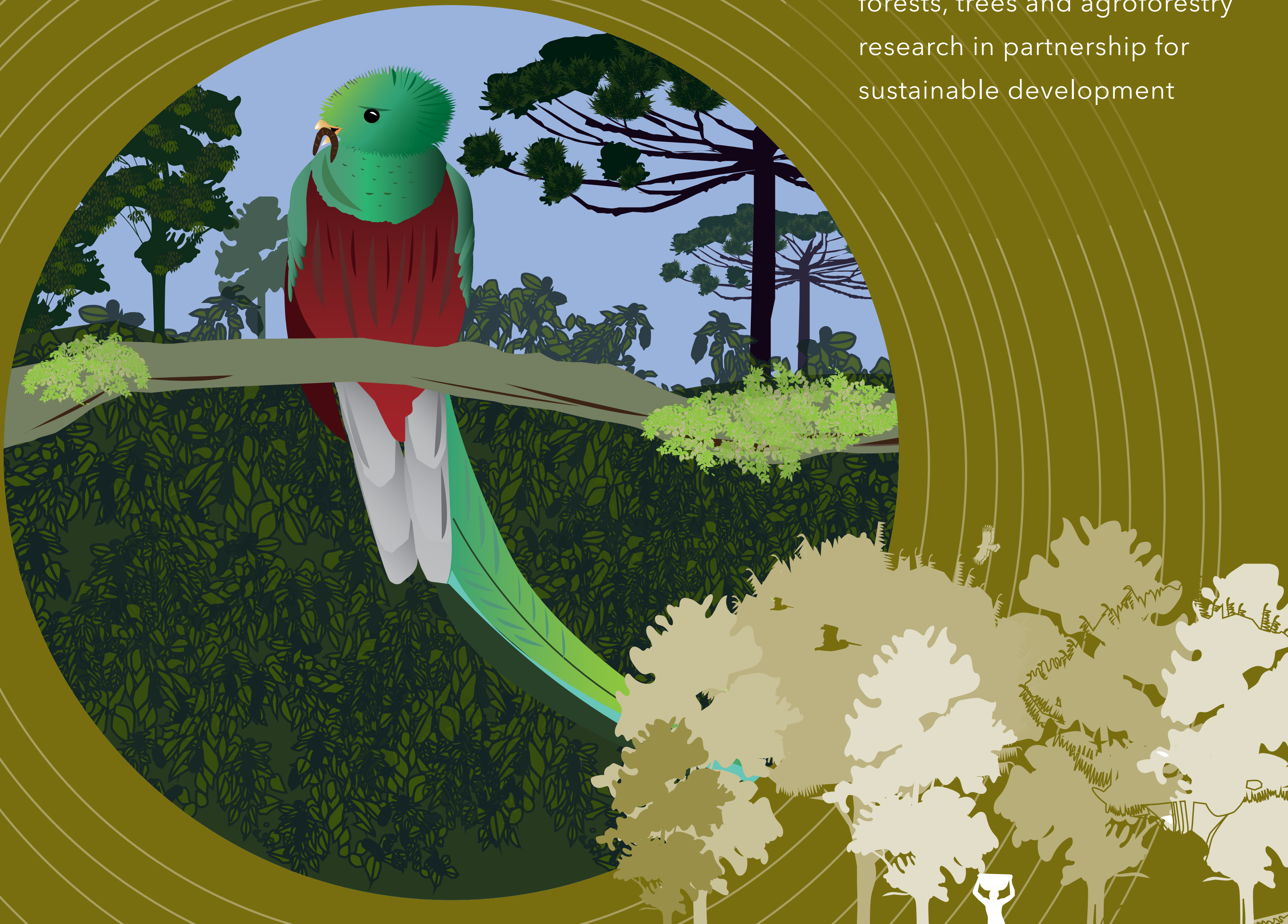
RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

FTA HIGHLIGHTS OF A DECADE
2011-2021

Conservation of Tree Biodiversity and Sustainable Forest Management

Ten years of forests, trees and agroforestry research in partnership for sustainable development



About the FTA Highlights series

This publication is part of a series that highlights the main findings, results and achievements of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA), from 2011 to 2021 (see full list of chapters on the last page).

FTA, the world's largest research for development partnership on forests, trees and agroforestry, started in 2011. FTA gathers partners that work across a range of projects and initiatives, organized around a set of operational priorities. Such research was funded by multiple sources: CGIAR funders through program-level funding, and funders of bilateral projects attached to the programme, undertaken by one or several of its partners. Overall this represented an effort of about 850 million USD over a decade.

The ambition of this series is, on each topic, to show the actual contributions of FTA to research and development challenges and solutions over a decade. It features the work undertaken as part of the FTA program, by the strategic partners of FTA (CIFOR-ICRAF, The Alliance of Bioversity and CIAT, CATIE, CIRAD, Tropenbos and INBAR) and/or with other international and national partners. Such work is presented indifferently in the text as work "from FTA" and/or from the particular partner/organization that led it. Most of the references cited are from the FTA program.

This series was elaborated under the leadership of the FTA Director, overall guidance of an Editorial Committee constituted by the Management Team of FTA, support from the FTA Senior Technical Advisor, and oversight of the FTA Independent Steering Committee whose independent members acted as peer-reviewers of all the volumes in the series.

FTA HIGHLIGHTS OF A DECADE 2011-2021
Conservation of Tree Biodiversity and Sustainable Forest Management

DOI:10.17528/cifor/008213
Vinceti B, Thomas E, Jalonen R, Guariguata MR, Snook L, Gaisberger H, Dawson IK, Jamnadass R and Kettle C. 2021. *Conservation of Tree Biodiversity and Sustainable Forest Management*. FTA Highlights of a Decade 2011–2021 series. Highlight No.3. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA).

CGIAR Research Program on Forests, Trees and Agroforestry
CIFOR Headquarters
Jalan CIFOR
Situ Gede, Sindang Barang
Bogor Barat 16115 Indonesia

T +62-251-8622-622
E cgiarforestsandtrees@cgiar.org

foreststreesagroforestry.org

We would like to thank all funding partners who supported this research through their contributions to the CGIAR Fund. For a full list of the 'CGIAR Fund' funding partners please see: http://www.cgiar.org/our-funders.

FTA HIGHLIGHTS OF A DECADE
2011–2021

Conservation of Tree Biodiversity and Sustainable Forest Management

Lead Author: Barbara Vinceti

Contributing Authors:
Evert Thomas, Riina Jalonen, Manuel R. Guariguata,
Laura Snook, Hannes Gaisberger, Ian K. Dawson,
Ramni Jamnadass and Chris Kettle

Editorial and publication team

Editorial Committee of the Highlights Series
Vincent Gitz (Chairperson of the Editorial Committee), Michael Allen Brady, René Boot, Marlène Elias, Ramni H. Jamnadass, Christopher Kettle, Yanxia Li, Christopher Martius, Alexandre Meybeck, Peter A. Minang, Fergus Sinclair, Plinio Sist and Eduardo Somarriba.

Independent Steering Committee of FTA
Anne-Marie Izac (Chairperson of the ISC), René Boot, Susan Braatz, Linda Collette, Vincent Gitz, Florencia Montagnini, Richard Stanislaus Muyungi, Robert Nasi and Stephan Weise.

FTA Director
Vincent Gitz

FTA Highlights Support Team
Technical and scientific editing: Alexandre Meybeck, FTA senior technical advisor
Coordination of publication process, editing and layout: Fabio Ricci, FTA communications coordinator
Coordination of the peer-review process: Monika Kiczkajlo, FTA program manager
Language editing and referencing: Patricia Halladay, consultant
Layout and design: Dharmi Bradley, consultant

Acknowledgements

The authors express special thanks to the CGIAR Trust Fund donors that have made it possible to generate the wealth of research findings presented here. They thank the large number of bilateral donors that have supported the work of hundreds of scientists over 10 years of collaborative activity within the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). They also express gratitude to the many research partners on the ground who have facilitated and contributed in various capacities — farmers, researchers, policymakers, practitioners, extensionists — to generating the massive amount of information and knowledge that supports forest conservation and sustainable management in different parts of the world.

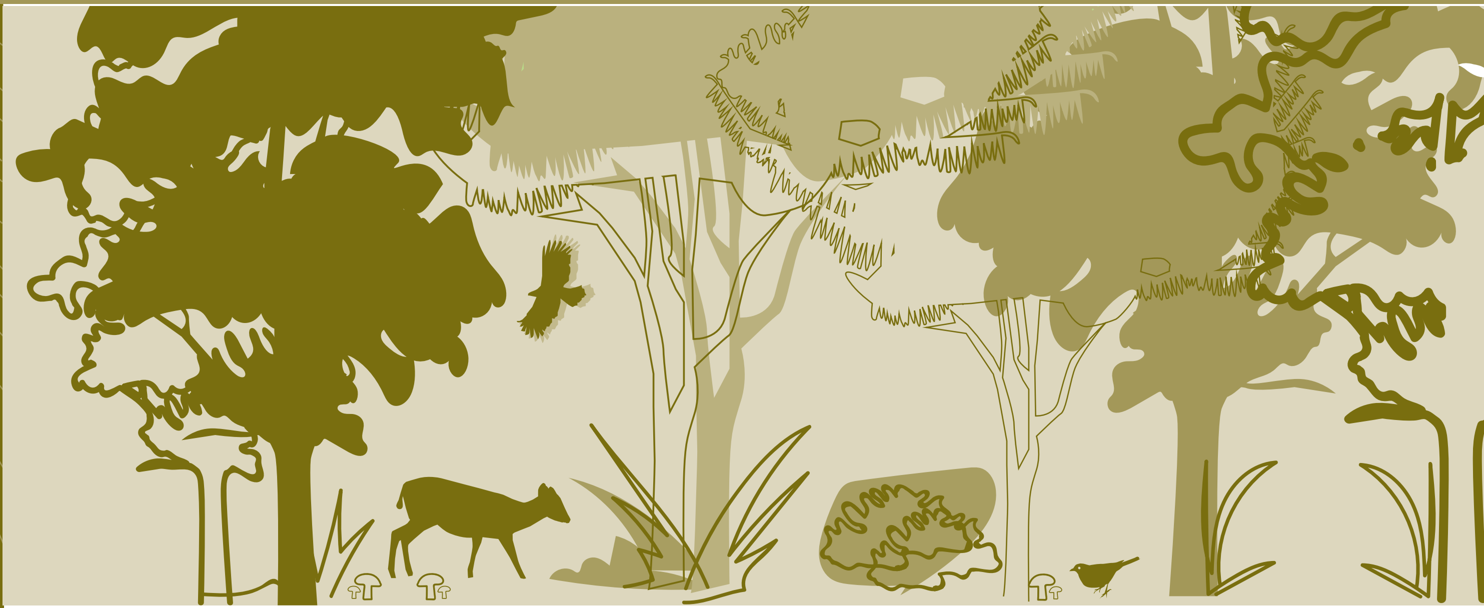
We gratefully acknowledge Linda Collette for her constructive review and feedback on an earlier version of the manuscript.

The final content remains the sole responsibility of the authors.

Table of contents

List of acronyms

APFORGEN	Asia Pacific Forest Genetic Resources Programme
CBD	Convention on Biological Diversity
COGENT	International Coconut Genetic Resources Network
FAO	Food and Agriculture Organization of the United Nations
FGRs	Forest genetic resources
FSC	Forest Stewardship Council
FTA	CGIAR Research Program on Forests, Trees and Agroforestry
GTTN	Global Timber Tracking Network
ICRAF	World Agroforestry
LAFORGEN	Latin American Forest Genetic Resources Network
NBSAP	National Biodiversity Strategy and Action Plan
NTFP	Non-timber forest product
SAFORGEN	Sub-Saharan Forest Genetic Resources Network
SDG	Sustainable development goal
TmFO	Tropical managed Forests Observatory
TonF	Trees on farms
UNFCCC	United Nations Framework Convention on Climate Change
UNCCD	United Nations Convention to Combat Desertification



Executive summary

Forests and trees are critical for the survival of life on earth. They conserve a tremendous biodiversity and fulfill essential ecosystem services such as climate regulation, cycling of nutrients and water. They contribute to food and nutrition security, are a major source of raw materials and offer countless livelihood opportunities. However, forests and trees are increasingly threatened by anthropogenic pressures such as overexploitation and land conversion, which are intensified by climate change. At the same time countless tree species and their forest genetic resources (FGR) with exceptional potential uses for supporting the global transition to low carbon food systems and the UN decade on Ecological Restoration are badly conserved and remain critically underutilized. For the last 10 years, the FTA program has set in place research activities that focused on understanding pressures on and threats to populations of socio-economically important tree species; formulating effective, efficient and equitable safeguards for tree genetic resources that are adapted to the local context and species characteristics; and promoting conservation and characterization of germplasm of high-value tree species from forests to farms. FTA has also conducted a range of ecosystem- and landscape-level research projects that explored how silvicultural and monitoring practices can support sustainable timber production while ensuring delivery of multiple ecosystem services, including biodiversity conservation, carbon storage, livelihood support and nutrition security from forest foods. Much of the program's later work focused on multiple-use forest management. This review of the program's most salient experiences — derived from a decade of collaborative research — presents a portfolio of the most promising solutions and the significant contributions

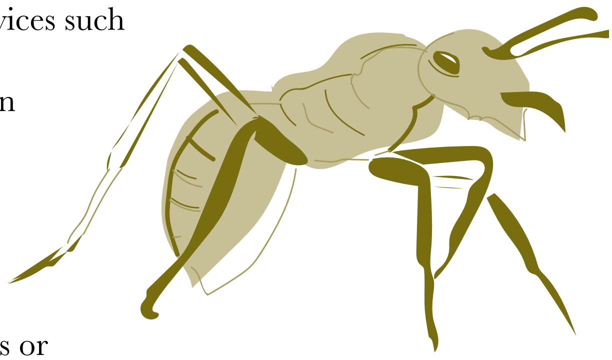
that FTA has provided to global conservation and sustainable use of tree biodiversity. These achievements also contribute to the international policy arena, particularly to the strategic objectives of various conventions (the Convention on Biological Diversity, United Nations Framework Convention on Climate Change, United Nations Convention to Combat Desertification), and to the efforts led by the Food and Agriculture Organization (FAO) to develop a global conservation strategy for forest genetic resources.

1. Introduction

This publication reviews the body of literature generated over the last decade by the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) on tree biodiversity and sustainable forest management. FTA is the world's largest research-for-development program aimed at enhancing the role of forests, trees and agroforestry for sustainable development and food security and for addressing issues related to climate change.

Forest biological diversity is a broad concept: it refers to all life forms that are found in forested areas and to their ecological functions. The focus of this highlight is on the biological diversity of trees (tree biodiversity), which is central to resilient and productive forests, agroforestry and other tree-based systems.

Forest biodiversity is critical to conserving forests and managing them sustainably for a wide set of reasons. Billions of people depend on trees for food, medicine, fuel, tools, fodder for livestock and shade. In addition, trees provide ecosystem services such as soil and water conservation, carbon sequestration, pollination, and mitigation of the effects of natural pest predators. Forest foods (e.g. wild fruits, nuts, vegetables, mushrooms) contribute to global food and nutrition security, supporting rural populations during the lean periods between harvests or



in case of extreme weather events. All these services, their resilience and their sustained provision over time depend on biodiversity. Furthermore, the diversity of key tree species in a forest ecosystem has a role in maintaining a diversity of associated organisms (e.g. insects and fungi).

Within forests and agroforestry systems, the individual components of biodiversity span various levels, from genes to ecosystems, and are critical to productivity and resilience. Resilience depends not only on the diversity of tree species but also on tree genetic diversity and on varied habitats. Genetic diversity ensures resistance to diseases, adaptation to climate change and other disturbances, and greater productivity.

Sustainable management of forest genetic resources contributes to maintaining genetic variation within tree populations for their survival, good growth and viability in the long term, enhancing their resistance to biotic (e.g. pests, predators) and abiotic (e.g. drought, salinity, wind) stressors and to the effects of global warming. Selecting individual trees with the most desirable characteristics for breeding programs enables them to adapt to changing conditions and to continue to support the goods and services that people need. Effective management of forest genetic resources can also increase social equity and the long-term sustainability of forests. Finally, genetic diversity is critical in forest restoration efforts to ensure that the trees planted today will lead to healthy forest ecosystems in the future.

Fruit trees across the landscape near Arslanbob, Kyrgyzstan.

Photo by Barbara Vinceti/ Alliance of Bioversity International and CIAT

FTA research focuses on a range of facets of forest biodiversity, including the characterization and conservation of forest genetic resources (FGRs), and their conservation through use,[1] by deploying intra-specific diversity in forest landscape restoration and multifunctional agricultural landscapes. In addition, research has addressed biodiversity management and other aspects of sustainable forest management — particularly the trade-offs between different forest management objectives, such as conservation and nutrition security — and identified solutions to reconcile multiple uses of forest resources.

Over-exploitation and degradation of forests, as well as land conversion, coupled with climate change, pose major threats to the conservation and sustainable use of forest diversity. FTA research focuses on understanding the extent of these pressures, their impacts on human well-being, the strategies to ensure sustainable management of forest resources in order to achieve multiple objectives, and on policies and strategies to reverse the trends of increasing pressures on forest resources. One critical aspect that remains highly undervalued is the effective use and safeguarding of FGRs, despite the importance of tree diversity and intra-specific diversity in the ecosystem services that are fundamental to reaching the sustainable development goals (SGDs). One reason for the general disregard of FGR is that it is often difficult to visualize genetic diversity, at least initially, due to the time that trees take to grow and mature and to the very large number of tree species. This makes individual studies possible only for selected species. In the limited number of cases where economic valuations of diversity have been undertaken, however, the importance of genetic variation is clear. Extending such work to a broader range of species and quantifying value more broadly than in just economic terms is, therefore, an important priority.

This publication has four objectives:

1. discuss innovative research outputs that have emerged from FTA research;
2. present in more details some illustrative case studies, with interesting methodological approaches and management solutions;
3. present examples of research outcomes;
4. identify critical directions for future research.

[1] Conservation through use means that valuing and using genetic resources contributes to their conservation.

2. Challenges and opportunities in conservation and sustainable management of forest biodiversity

2.1 Spatial patterns of genetic diversity

Conservation of forest genetic resources, in contrast to that of crop genetic resources, has been centred primarily around in situ approaches (e.g. in national parks and forest reserves). The design and location of these conservation areas are rarely driven by genetic principles, such as the need to maintain adequate effective population sizes[2] of some tree taxa. For most tree species of interest, the spatial distribution of genetic diversity is not known. FTA research has addressed this gap and focused on characterizing tree species genetic diversity and reproductive biology to assist both conservation actions (Lompo et al. 2018; Lompo et al. 2020; Pakull et al. 2016; Pakull et al. 2019) and sustainable management (Thomas et al. 2012; Thomas et al. 2015; Monthe et al. 2017; Balima et al. 2018; Duminil et al. 2015; Duminil et al. 2016; Chiriboga-Arroyo et al. 2020).

One novel approach has been to integrate different knowledge domains to separate the human and natural drivers of genetic differentiation. This was done for two model species: cacao (Thomas et al. 2012) and Brazil nut (Thomas et al. 2015), pointing at particular regions where diversity

[2] Effective population size is the number of individuals in a population that contribute offspring to the next generation. https://www.blackwellpublishing.com/ridley/a-z/Effective_population_size.asp.

originated and at areas where domestication has occurred. Thomas et al. (2012) combined molecular marker data and spatial analyses to study the domestication patterns of cacao in the Neotropics and derive guidance for conservation, in particular for the establishment of representative germplasm collections and the promotion of conservation in situ and on farms. It appears (ibid.) that more genetic data would be needed for many of the hyperdominant[3] tree species across the Amazon to resolve the complex picture associated with multiple origins of domestication. These data would support management of forest genetic resources and restoration of resilient forest landscapes across the Amazon (Thomas 2017).

A study on the African plum tree *Dacryodes edulis* (Burseraceae) revealed interesting linkages between the social dynamics linked to tree planting and patterns of genetic diversity (Rimlinger et al. 2021). This emblematic food tree species is found in the urban context of Yaoundé, Cameroon, where most trees are planted using seeds sourced from different parts of the country. This leads to a high concentration of genetic diversity in this species in Yaoundé, a diversity equivalent to that found across a whole region of production of the species.

Plum tree (*Prunus domestica*), Kyrgyzstan.

Photo by Barbara Vinceti/ Alliance of Bioversity International and CIAT

[3] This refers to a relatively small minority of species that have larger geographic ranges than other species, present higher maximum relative abundances in individual plots, and tend to be habitat specialists.

Based on a combination of molecular and phenotypic diversity data,[4] modeling of past climate suitability, and existing literature, a hypothesis about the domestication of peach palm (*Bactris gasipaes Kunth*) was developed (Galluzzi et al. 2015). This species has had a critical role in the livelihoods of communities in the Americas since pre-Columbian times, given its edible fruits and multipurpose wood. The hypothesis suggests that a single initial domestication event took place in southwest Amazonia, followed by dispersal by humans across western Amazonia and possibly into Central America, where secondary domestication events likely took place through hybridization with resident wild populations. These events, combined with differential human selection pressures, have likely led to the species' present-day diversity. These insights and tools are critical to understanding the domestication and dispersal patterns of priority tree species, managing their genetic resources, setting conservation priorities (Thomas et al. 2014a; Galluzzi et al. 2015; van Zonneveld et al. 2018a) and assisting restoration.

Molecular marker methods have advanced greatly over the last two decades. The costs to carry out analyses with molecular markers are continually decreasing, expanding the possibilities of performing such genetic studies on a larger number of species. Of particular interest is the possibility of linking molecular markers to key adaptive traits. At the same time, approaches to geospatial analysis have also evolved significantly (Fremout et al. 2020; Guarino et al. 2002; Miller 2005; van Etten and Hijmans 2010; Chan et al. 2011; van Zonneveld et al. 2014). The use of molecular markers in combination with new geospatial methods of geographic and environmental analysis has a lot to offer to assist decision-making and priority setting in conservation. This is especially true for tree species, because the maintenance of their genetic resources tends to depend on in situ conservation efforts. New methods to prioritize varieties, populations and geographic areas for in situ conservation, and to enable monitoring of genetic diversity over time and space, have emerged and are available to improve in situ germplasm management. GIS-based approaches enable researchers to obtain clear visual presentations of results through maps, facilitating the interpretation of findings. FTA research has contributed significantly to the development of these GIS-based approaches to conserve forest genetic resources in situ (van Zonneveld et al. 2014).

[4] Molecular diversity refers to the richness of molecules found in life; it occurs within one individual or between individuals of the same or different species, and is influenced in a major way by non-inheritable mechanisms. Phenotypic diversity refers to observable characteristics of an organism (e.g., morphology, developmental processes, biochemical and physiological properties, behaviour).

2.2 Understanding threats and mapping tree species vulnerability

The spatial distribution of threats to tree species of interest and the vulnerability of these species to various pressures is of critical importance when designing conservation strategies and mitigation measures. The FTA research program has concentrated on understanding threats to populations of socio-ecologically important tree species in order to help formulate effective, efficient and equitable genetic conservation strategies, and to support management and restoration. Several case studies were developed around single and multiple species, looking at species-specific vulnerabilities, and consolidating assessment approaches across many scales, in some cases adopting participatory methods that involved local experts in the validation of research outputs.

While most past efforts considered only exposure to threats, novel approaches were developed to integrate tree species characterization based on functional traits in order to assess species' sensitivity to particular threats. The research conducted on *Prunus africana* (Vinceti et al. 2013) is interesting for its geographic breadth, which includes almost the entire range of the species. The study identified conservation priorities based on an assessment of the species' vulnerability, combining threat maps with projections of agricultural expansion and climate change along with genetic data to determine which genetic resources were potentially most valuable and most at risk. An enhanced approach was implemented in Central Asia on *Juglans regia* L. (wild walnut) populations (Gaisberger et al. 2020) and on 16 food tree species populations in Burkina Faso, which included expert evaluation of distribution as well as the species sensitivity to multiple threats (Gaisberger et al. 2017). The same methodology was reported in The *State of the World's Forests 2020* (FAO and UNEP 2020). The Burkina Faso study was further refined by including a new trait-based scoring system that used both scientific literature and expert knowledge as sources of trait data; the improved approach was applied to tropical dry forest ecosystems in Latin America (Fremout et al. 2020), with scaling underway in Southeast Asia and central Africa. The methodology was also simplified to allow it to be implemented at a large scale. The information generated has had a critical role in setting conservation priorities (van Zonneveld et al. 2018a).

Working with partners on threat mapping in a regional workshop in Beijing, China.

Photo by Chinese Academy of Forestry

2.3 Understanding the relationships between forest biodiversity and ecosystem services

FTA scientists have contributed to important syntheses and reviews on the relationships between species richness and biodiversity and ecosystem services. A global assessment report reviewed evidence from hundreds of case studies, looking at relationships between biodiversity and carbon sequestration (Thompson et al. 2012), the impacts of deforestation and forest degradation on carbon, and the recovery of forest carbon and biodiversity following deforestation and forest degradation. Another review examined carbon sequestration and storage across a range of forest types and management approaches (Kapos et al. 2012).

Biodiversity was found to maintain critical ecosystem processes and secure the provision of many forest ecosystem services. However, highly modified environments that host small forest patches are not effective in maintaining these services. Carbon sequestration also varies considerably across different forest types and ages. In forests recovering from disturbance, biodiversity usually recovers much more slowly than carbon does (Thompson et al. 2012). Thompson et al. 2012 also indicate that spatial planning for biodiversity conservation objectives in tropical and sub-tropical forests needs to be more area-specific than for carbon management, given the uniqueness of some species assemblages. In addition, research findings focused on Brazil nut (Thomas et al. 2018; Thomas et al. 2021) revealed that both fine-scale structuring and environmental gradients across the distribution range of hyperdominant trees species — which contribute most to ecosystem services such as carbon sequestration and production of nuts — influence the quantity of ecosystem services delivered. Novel forest ecosystems were observed, but it is not clear whether they will be able to sustain the provision of ecosystem goods and services in the future (Thompson et al. 2012). Some important knowledge gaps remain:

- the relationships between plant species richness and functional diversity;
- the different rates of biomass accumulation in diverse forest systems;
- the relationship between species richness and ecosystem resistance to chronic disturbances;
- the impacts of losses in faunal diversity on forest ecosystem processes;
- the long-term influence of recurring disturbance and degradation events on the pace of recovery of forest ecosystems;
- the degradation/disturbance thresholds beyond which recovery is compromised.

Other research on the role of biodiversity in the provision of ecosystem services in forest and agroforest systems (Thompson et al. 2011) revealed the barriers to transferring knowledge from scientists to decision makers. It suggested that scientists should be more effective at informing policy, improving the focus of their research around policy-relevant questions, a nd providing relevant, timely and consistent information to decision makers and the public.

2.4 Assessing degradation of forest biodiversity

Forest degradation is widespread and is receiving considerable global attention in policy processes. However, there is no generally accepted definition or way to measure it, because degradation depends on perception, on the condition considered as baseline, and on its temporal and spatial scales. Various approaches have been designed with contribution from FTA scientists to track forest degradation (Thompson et al. 2013). They include an operational framework for defining and delineating degradation based on a minimum subset of seven indicators for five criteria. See Table 1.

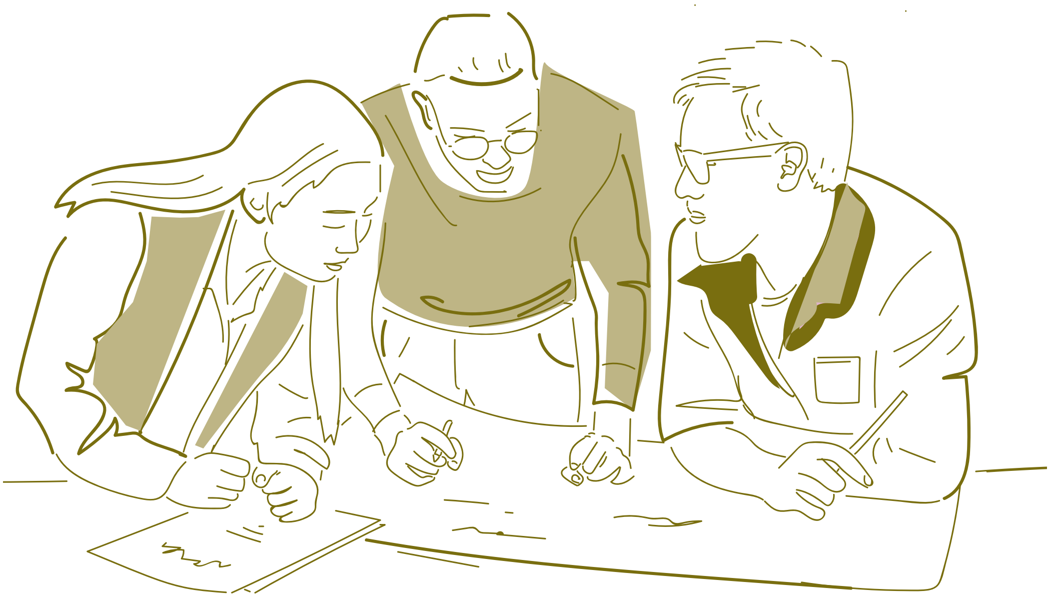
Table 1. A suggested framework of criteria and indicators for defining and delineating areas of degraded forest. A suggested minimum set of seven indicators is indicated by an asterisk (*).

Criterion	Indicator(s)	Variable(s)	General methods
Production	Growing stock* Nontimber forest products	m³/ha of wood Monetary value, number/yr	Satellite imagery, LiDAR, ground plots Country reporting, questionnaires by management unit
Biodiversity	Ecosystem state* Fragmentation* Species	Area of specific forest type Area fragmented Presence/absence, population density, relative abundance, indicator of abundance	Satellite imagery Satellite imagery, aerial photography Aerial or ground surveys
Unusual disturbances	Invasive species* Fire*	Population density, area affected Area affected	Satellite imagery, aerial photography, ground surveys Satellite imagery, aerial photography
Protective function	Soil erosion* Water volume or flow	Area affected Flow rate	Satellite imagery, aerial photography River or stream flow meters
Carbon storage	Stored carbon* High wood-density trees species	Biomass/ha Tree density, relative abundance	Satellite imagery, ground plots Ground plots, aerial photography

Source: Thompson et al. (2013).
Note: * = minimum of subset of indicators.

Participatory monitoring approaches were also reviewed by FTA scientists (Villaseñor et al. 2016). These present advantages compared to the environmental monitoring carried out by individuals with formal technical and scientific training, as they include elements of social learning and knowledge sharing, are more inclusive and tend to strengthen local institutions. Villaseñor et al. (2016) closely examined two main monitoring approaches: collaborative-learning and evidence-based; these differ in their theoretical background and their motivating factors. The objective was to determine if the type of participatory monitoring used has an influence on the way the findings are incorporated into decision making, and if the local power dynamics affect the way that monitoring results are taken into account. Based on the cases reviewed, Villaseñor et al. (2016) found that information produced through collaborative learning was used more often in decision making related to forest management than evidence-based information was.

Decentralization in decision making, in addition to participatory monitoring, also seemed to favour the incorporation of results from monitoring into management, which strengthened conservation.



2.5 Developing conservation strategies

FTA supported regional collaborative networking initiatives — the Asia Pacific Forest Genetic Resources Programme (APFORGEN), the Latin American Forest Genetic Resources Network (LAFORGEN), and the Sub-Saharan Forest Genetic Resources Network (SAFORGEN) — in various regions of the world to define their strategies. In particular, FTA supported APFORGEN, a network of 15 countries established to develop a regional strategy to implement the Food and Agriculture Organization's (FAO's) Global Plan of Action for Forest Genetic Resources (FAO 2014a). See Box 1. The regional strategy includes objectives to strengthen the conservation and sustainable use of threatened and regionally important tree species through collaborative studies, germplasm collections, provenance trials and regional networking. In addition, the strategy contributes to several of the priorities of FAO's Global Plan of Action. FAO's Asia-Pacific Forestry Commission endorsed the regional strategy at its 23rd session in 2017,[5] and encouraged countries to collaborate with APFORGEN in implementing it. In collaboration with FTA, APFORGEN countries have secured funding to implement the strategy.

[5] http://www.fao.org/3/i1701e/i1701e00.pdf.

Box 1. FTA contributions to FAO's State of the World reports

FTA research contributed to the formulation of the recommendations and priorities of the FAO's first Global Plan for Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources, adopted in 2013 (FAO 2014a). Relevant research findings that backed up the Global Plan of Action were synthesized and presented as thematic studies for FAO's *State of the World's Forest Genetic Resources* (FAO 2014b). These thematic studies were also converted into articles for a special issue of *Forest Ecology and Management*, which involved joint authorship across FTA and was edited by staff from Bioversity, ICRAF and FAO (Loo et al. 2014). *The State of the World's Forest Genetic Resources* provided a foundation for the global action plan. Some outputs of the action plan focused on policy constraints and knowledge, notably on the definition of degraded lands and on mechanisms for cooperation between timber concessionaires and communities.

FTA also contributed to *FAO's State of the World's Biodiversity for Food and Agriculture* (Bélanger and Pilling 2019), through, among other things, a thematic study on the roles of biodiversity in the sustainable intensification of food production (Dawson et al. 2019). The study assembled evidence from systematic sectoral reviews and meta-analyses in the scientific literature of how the positive interactions between biologically diverse organisms — including annual crops, animal pollinators, trees, micro-organisms, livestock and aquatic animals — already contribute to sustainable food production globally and how they could contribute further in the future. The study (ibid.) discussed how this could counter the current trajectory of global food production towards increased homogenization, with its accompanying loss of agrobiodiversity. Measures to support biodiversity-based food solutions that involve trees include the co-breeding of trees and crops for more positive interactions in farmland; the protection and new planting of animal pollinators' habitats; and the integration of tree legumes into farms. The study also reports a convergence between biodiversity's roles in supporting both environmental and dietary sustainability, in line with other recent globally oriented assessments. These include the latest global report on biodiversity and ecosystem services from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Díaz et al. 2019).

Farmer with Brazil nut (*Bertholletia excelsa*).

Photo by Rens Brower/ Wageningen University

Three of the FORGEN networks, with support in coordination provided by Bioversity and by FAO, identified regional priority tree species for conservation. These species are part of the global reporting efforts that FAO has been conducting, which is expanding to include conservation and sustainable management of FGRs. Modelling of species distribution and spatial location of threats was conducted for 100 tree species in Latin America (van Zonneveld et al. 2018a). In addition, tree species distribution modelling and threat vulnerability analyses are ongoing in Central Africa. In Asia, in collaboration with more than 40 organizations and experts, Bioversity has developed distribution and threat maps (Gaisberger et al. in press) for 65 socioeconomically important native tree species across South and Southeast Asia. The species were selected based on national priority lists and expert recommendations, and represent a diversity of uses, functional traits and conservation status.

All studied species are highly vulnerable to one or more threats on average in over half of their native distribution range. The findings (ibid.) revealed that climate change is a severe threat in an average of 10% of the species' ranges, but that species' vulnerability varies widely, with some species predicted to lose up to 40% of their current habitats, and others potentially gaining large areas. In addition, broad shifts in species compositions are expected to happen, due to a combination of land-use and climate-related threats. The maps were based on species distribution modeling using more than 10,000 quality-checked observations of species occurrences, 10 combinations of climate models and scenarios, and global datasets, including land cover, human population density, accessibility and fire incidence, among others.

Targeted conservation and restoration activities can be designed based on these maps, which are freely available along with related datasets on a global web portal.[6] This platform is progressively hosting all research outputs regarding mapping of priority tree species and identifying priority areas for conservation. To help equip farmers, scientists, and development institutions with useful information and tools to find the right tree for the right place for the right purpose, also taking into consideration expected climate changes and food/nutrition security, ICRAF researchers have combined years of in-depth knowledge and a vast collection of research with easily accessible technology to create a global tree information platform. The resources on the platform[7] have been developed since 1996 and include a wide range of interlinked databases, maps, R open-source software packages, guidelines and other decision-support tools to guide the planting — and survival — of trees in a range of environments.

Lack of viable seed sources constraints the recovery of many endangered tree species, including *Dalbergia cochinchinensis* (Siamese rosewood).

Photo by Riina Jalonen /Alliance of Bioversity International and CIAT

[6] www.tree-diversity.org.
[7] https://worldagroforestry.org/tree-knowledge.

FTA supported FAO in the development of a global conservation strategy for FGR: the FAO's *Global Plan of Action for Forest Genetic Resources* (FAO 2014a). FTA also led many of the studies in connection with this, particularly a special issue of *Forest Ecology and Management* (Loo et al. 2014).

Two major outputs were the global conservation strategies for cacao and coconut genetic resources (Bourdeix and Prades 2018). Regarding conservation and use of cacao genetic resources, the main achievements over the past 10 years were the establishment of a community of practice (CacaoNet) and a multi-stakeholder collaboration (Cocoa of Excellence). CacaoNet, a global strategy for cacao genetic resources, provides a clear framework for the conservation and use of cacao diversity.[8] It was developed through a consultation process that drew on the expertise of the global community. The Cocoa of Excellence initiative is based on the recognition on the ground of the value of cacao genetic resources.[9] The partnership brings together public and private stakeholders from the cocoa and chocolate industries, governments, farmers' associations, research institutions, leading sensory evaluation companies and sector-leading organizations to support excellence in cocoa and generate market opportunities. It provides incentives and tools for safeguarding diversity while benefitting the entire value chain, from the farming communities to the consumers. By conserving and celebrating cacao diversity, efforts by CacaoNet and Cocoa of Excellence aim to secure a more sustainable future for cocoa, and for the livelihoods of its growers. In addition, great progress was made with regard to safeguarding cocoa flavour diversity and improving farmers' livelihoods through the recognition and promotion of superior-quality cocoa origins[10] for the sustainability of the supply chain.

For cocoa, the main innovation in recent years has been the development of international standards for quality and flavour.[11] Countries are implementing these standards at the national level and an ambitious five-year program is under development with the International Cocoa Organization to build capacity in cocoa origin countries by connecting knowledge on quality with cocoa producers. At the moment, producers and chocolate makers are worlds apart. The community of practice is producing new publications and preparing a Global Compendium on Cacao Research.[12] For additional information on research work on cacao conducted within FTA, see FTA Highlight No.7 in this series (Somarriba et al. 2021), where agroforestry of cocoa production systems is addressed.

---

[8] https://www.cacaonet.org.
[9] http://www.cocoaofexcellence.org/info-and-resources.
[10] A Certificate of Origin is used extensively in international transactions. It identifies the country of manufacturing of a good or commodity.
[11] www.cocoaqualitystandards.org.
[12] https://www.cacaonet.org/research-compendium/registration.

The coconut palm (*Cocos nucifera* L.) has great cultural and socioeconomic importance for millions of people across Southeast Asia, the Asia-Pacific, Africa and Latin America. Conserving its genetic diversity and supporting sustainable use of its broad genetic base to breed improved varieties are critical to sustainably boosting productivity and livelihoods, and to addressing at the same time the critical challenges posed by climate change and pests and diseases. The International Coconut Genetic Resources Network (COGENT) promotes global collaboration for the effective conservation and use of coconut genetic resources; it was established in 1992 with 15 coconut-growing countries as members.[13] It has subsequently expanded to 39 member countries, representing more than 98% of global production. The network, involving a large number of stakeholders, developed a global strategy to conserve and harness coconut germplasm by cost-effectively optimizing the conservation and use of as much representative diversity as possible. An update of the strategy was finalized in 2018 and will provide the benchmark for effectively implementing the comprehensive conservation and research agenda proposed by the international coconut research community (Bourdeix and Prades 2018).

2.6 Biodiversity conservation through restoration

Forest and landscape restoration (FLR) initiatives can offer an important opportunity to sustain the conservation of native tree species and their genetic resources by bringing back diversity in the landscape. FLR initiatives can also place at the forefront efforts that take into account genetic diversity in the selection of tree planting material that is adapted to local conditions and restoration objectives, playing a crucial role in the successful re-establishment of vegetation when natural regeneration is insufficient. For more information about research work on FLR conducted within FTA, see FTA Highlight No.4 in this series (Guariguata et al. 2021). Adequate genetic diversity is the precondition for the successful restoration of forests with high adaptive capacity. However, most restoration, agroforestry and afforestation projects tend to neglect the importance of seed sourcing or species diversity in their planning. Jalonen et al. (2018a) showed how restoration projects worldwide typically use seed and seedlings of limited genetic diversity that do not capture the diversity found in remaining natural populations and, therefore, often do not contribute to its conservation. Moreover, one-third of the projects surveyed in the study (ibid.) reported that they often had to resort to using exotic species instead of native species because of a lack of native seed or seedlings. There is a need to improve tree species conservation and to effectively protect tree seed sources in situ in a range of seed zones, in order

[13] https://hdl.handle.net/10568/47280.

to establish seed conservation units for use by future generations. Identifying high-priority sources of tree genetic material still needs to be carried out in many tropical countries.

Building on a thematic study for FAO's *State of the World's Forest Genetic Resources* (Bozzano et al. 2014), Thomas et al. (2014b) provided recommendations for both restoration practice and related research to ensure adequate consideration of biodiversity, including using genetically diverse and site-adapted material, planning restoration efforts so that they contribute to landscape connectivity, and identifying existing constraints to and solutions for expanding the use of a wider variety of native species in restoration. As a result of this work, the 12th Conference of Parties to the Convention on Biological Diversity (CBD) adopted a decision to call for increased attention to native species and their genetic diversity in conservation and restoration (CBD 2019). In addition, a novel approach that integrates conservation priorities with restoration efforts was developed, based on distribution modeling and genetic data; it helps to identify seed sources to be conserved in each seed zone, to guide climate-smart seed sourcing (Fremout et al. 2021b). See Box 2. Its methods can easily be scaled up. Several papers and case studies contributed to building the conceptual framework for the approach (Aguirre-Morales et al. 2020; Bocanegra-González et al. 2018; Bocanegra-González et al. 2019). Other case studies from Argentina contributed to refine the conceptual basis of and offered applied examples of how to develop seed zones based on distribution modeling and genetic data (Azpilicueta et al. 2013; Soldati et al. 2013; Marchelli et al. 2017; Soliani et al. 2017).

Tree nursery in Medellin, Colombia, with seedlings to be established in a progeny trial.

Photo by Evert Thomas/Alliance of Bioversity International and CIAT

Box 2. Defining seed zones to guide climate-smart seed sourcing

Restoration efforts based on tree planting need to be supported by well targeted collection of reproductive material (most commonly seeds, but also seedlings, cuttings, etc.) from sources that are appropriate for the conditions of the restoration site and adapted to expected future conditions. The collection of planting should be based on a consideration of both species selection and individual tree populations with the desired characteristics. Usually, recommendations on which seed sources to use focus on locally sourced material, with an expectation that this material will be best adapted to the local conditions, and that this will also prevent the introduction of foreign genetic variation that may lead to maladaptation.

However, a new approach that is increasingly being considered relies on integrating local sources of planting material that is "climate-matched", i.e. adapted to the future climatic conditions of the planting site and source in areas where future climate conditions are already present. A constraining factor in adopting this approach may be that restoration practitioners usually do not have access to the necessary information to implement such climate-smart seed sourcing.

FTA designed this approach, which defines dynamic seed zones, in light of future climate changes, and tested it on 11 socioeconomically important tree species in the tropical dry forests of Colombia. Defining and using these seed zones aims to capture as much as possible of the observed genetic differentiation of a species, and it is dynamic under climate change, based on the clustering of environmental data and geographical coordinates. The seed zone maps were made available in a user-friendly online tool.[14]

Source: Fremout et al. (2021b)

[14] https://www.diversityforrestoration.org/.

Progeny trial of *Albizia saman* at the campus of the Alliance of Bioversity and CIAT in Cali, Colombia.

Photo by Lina Echeverria/Alliance of Bioversity International and CIAT

2.7 Citizen science and local knowledge supporting conservation

Local and indigenous people are repositories of important knowledge of the relationships between ecosystem functions and within species variation; establishing collaborations with them has been underlined as a critical step in documenting biodiversity dynamics at the intraspecific level (Des Roches et al. 2021). FTA research outputs show the value of working with local people as sources of large amounts of both qualitative and quantitative information. This can help answer scientific and management questions that would otherwise be too difficult to investigate, or that could be tackled only at a high cost. An example is a study conducted to assess the capacity of Brazil nut seed harvesters to accurately estimate the seed production of individual Brazil nut trees, and to validate their traditional ecological knowledge of the parameters that affect nut production (Thomas et al. 2017). Local harvesters' seed production estimates were found to be consistent with actual field measurements. This indicates that the local knowledge that guides Brazil nut extraction and keeps it within sustainability levels is robust, and that productivity estimates could be entrusted to harvesters, since taking actual measurements is very expensive and labour-intensive (ibid.). Two other research papers demonstrate the value of productivity data collected from local harvesters for testing complex hypotheses, including fine-scale processes that shape the provision of ecosystem services (Thomas et al. 2018; Thomas et al. 2021), such as the distance from individuals of the same species and density-dependence mechanisms that seem to regulate the spatial distribution of tree diversity in natural forests (Thomas et al. 2018).

A study conducted in rural communities of the tropical dry forests of northwestern Peru and southern Ecuador (Fremout et al. 2021a) revealed that the large majority of local perceptions of species' threat status and stress resistance coincided with scientific knowledge. These findings illustrate the large potential of local ecological knowledge to improve strategies for selection of tree species that need conservation or restoration.

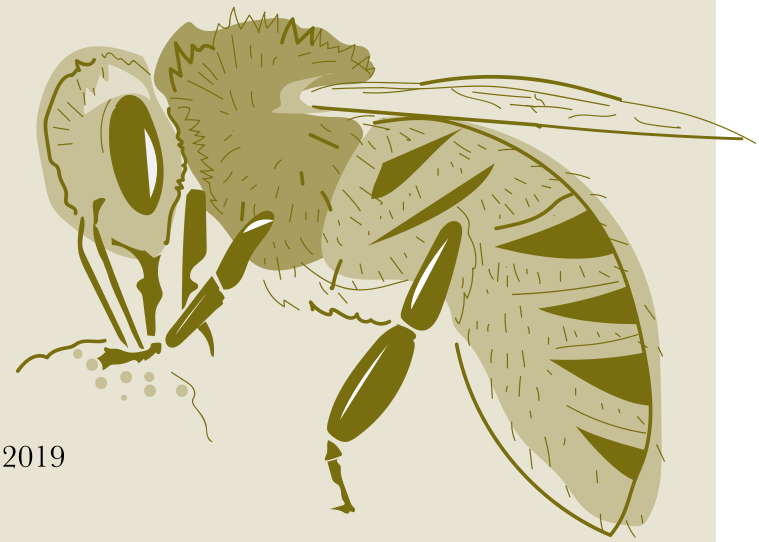
2.8 Managing forests and agroforests to conserve their genetic resources

In some circumstances, given past human impacts on forests and forest genetic resources, and current pressures on forests and trees, strategies that are put in place within production systems may be the only alternative to in situ conservation of forest genetic resources. Ex situ conservation is limited to a relatively small set of mainly commercial tree species due to a number of constraints, including resource limitations, seed storage problems and the need for periodic regeneration, and the limitations of ex situ populations as conservation gene pools.

A series of studies focused on conserving populations of trees to safeguard their genetic resources through sustainable forest management. An example from Mesoamerica relates to the role of community forestry in sustaining forest genetic resources (with a specific focus on *Swietenia macrophylla*/mahogany, known in Spanish as caoba) while simultaneously providing significant economic benefits to families (van Zonneveld et al. 2018b). Another example is from the Mozambique/Niassa project (Ribeiro et al. 2019), which focused on sustaining the forest genetic resources of the Miombo woodlands in the Niassa National Reserve. Research focused on two major threats: honey harvesting based on felling the trees; and uncontrolled logging (ibid.). Ribeiro et al. 2019 showed that both beehive making from tree bark and wild honey harvesting were widespread practices. These were destructive techniques for the tree species involved, and researchers proposed alternative non-destructive practices (see Box 3). The findings indicated that no alternative method to these recommended non-destructive practices had the equivalent potential to contribute to sustained honey production in the long term, since in diverse forests a population of trees may extend over thousands of hectares and few tropical trees can be conserved as seed.

Box 3. Gathering honey from wild and traditional hives in the Miombo woodlands of Niassa National Reserve, Mozambique

Honey hunters in Niassa National Reserve adopted less destructive honey harvesting practices as a result of an FTA project (Ribeiro et al. 2019). Research conducted by FTA revealed that honey production in the reserve was widespread and was based on destructive techniques for the tree species involved, leading to negative consequences in honey production. Many tree species were felled by honey hunters to obtain wild honey. This not only kills the bee colony and reduces the availability of cavities that wild bees can occupy, but also represents a threat to some tree species. The usefulness of non-destructive traditional practices was demonstrated by FTA and proposed for wide adoption. While stripping the bark of trees to create traditional hives also kills the source tree, if the most abundant tree species are used, this activity does not represent a threat in the short term. Traditional hives last a number of years; and producing honey in hives safeguards trees that might otherwise be felled to obtain the honey from wild hives. In addition, honey hunters were eager to learn techniques for climbing trees and removing honey from wild hives in a non-destructive way, which would allow them to harvest year after year from the same source tree.



Source: Ribeiro et al. 2019

A review by Dawson et al. (2013) gathered evidence on the mechanisms through which agroforests may be valuable for conserving tropical trees and highlighted the fact that conservation, given current global challenges and trends, will increasingly need to rely on initiatives of small-holder farmers to maintain diversity on farm. Also, it will be necessary to monitor aspects of concern, such as tree connectivity in agricultural landscapes and adequate access by farmers to diverse, high-quality planting material. Future research work should focus on best practices for in situ conservation and on conservation's relationships with ex situ pools of diversity.

While it is easy to quantify the benefits derived from particular tree species, the value of their genetic resources is often not properly tracked. Another review by Dawson et al. (2014) gave a picture of the benefits derived by several millions of people in the tropics from products and services provided by trees through the management of tree species diversity, and from the genetic variation within these species, in forests and farmland. A number of recommendations emerged from the review; they spanned harvesting of non-timber forest products (NTFPs) in natural, incipiently- and/or semi-domesticated forests and woodlands, smallholder agroforestry practices

Climbing a Colombian mahogany tree (*Cariniana pyriformis*) to collect grafting material in Yolombo, Colombia.

Photo by Evert Thomas/ Alliance of Bioversity International and CIAT and smallholder tree commodity crop production. These recommendations pointed to the need for a greater understanding of the genetic aspects of production for NTFP harvesting, greater attention to the genetic quality of planted NTFP species by smallholders, the accurate valuation of wild and semi-wild genetic resources for tree commodity crops, and attention to critical aspects of the value chain. Particularly critical in the shift from wild collection of NTFPs to agroforestry systems is an assessment of all the benefits that rural communities obtain from various tree production modalities, their trade-offs in terms of economic, environmental aspects, and equity in the market supply chain (Maas et al. 2020).

2.9 Community forests and conservation

Community ownership of forests has been increasing over recent decades and is proving to be a management option that can combine multiple purposes and benefits. Communities are often willing to manage forests with long time frames in mind and to support conservation: most people are interested in ensuring that their grandchildren have a viable resource to live off, rather than maximizing their short-term returns. FTA research in community forests in Petén, Guatemala, revealed that harvesting of timber and NTFPs was sufficient to lift people above the poverty line (Stoian et al. 2019).

A meta-analysis of the role of protected forests (40 case studies) and community-managed forests (33 case studies) in the maintenance of forest cover in the tropics revealed that community-managed forests had lower and less variable rates of annual deforestation than protected forests did (Porter-Bolland et al. 2012). An evaluation conducted in Petén, Guatemala, showed that community forestry could reconcile management with conservation of both forests and forest genetic resources, while simultaneously providing livelihood benefits to local people (Stoian et al. 2019). In another study, evidence was gathered indicating that the genetic diversity of mahogany was sustained in forests managed by communities (van Zonneveld et al. 2018b; see Box 4) and that community forestry had also contributed to the development of equitable social institutions and negotiating capacity on the part of local communities (Millner et al. 2020). In the same region, an interesting alternative community-based management model based on commercial sport hunting was researched (Baur et al. 2012). The findings revealed that the approach led to profitable and sustainable forest product diversification and was highly compatible with the goals of multiple-use management and forest conservation.

Box 4. Sustainable management of mahogany in community forests of the Maya Biosphere Reserve (Guatemala)

An FTA project in Guatemala provided evidence to support the contributions of community forestry in the Maya Biosphere Reserve to conservation of the forest and of mahogany in particular (a CITES-listed species). Mahogany (*Swietenia macrophylla* King) is the most valuable timber species in the multipurpose zone of the reserve and sustains the profitability of forest management of the concessionary communities in this area. The concessions are governed by a long-term contract (with a 25-year term); each year the wood from a different area of the concession is used, based on an annual operational plan. For each management unit, a management plan needs to be approved, based on an assessment of environmental impacts and with direct monitoring by various organizations. The FTA research assessed whether the genetic diversity of mahogany populations — and of the seeds and seedlings that will give rise to future generations — was affected by the uses under the current model of forest management applied by the communities. The results revealed that in the concessions managed by local communities enough mahogany trees remain after timber harvesting to ensure the capacity of seed germination and the genetic diversity of mahogany seedlings. The results also suggest that under current management, mahogany genetic resources are being maintained in forests managed for timber extraction. These results are helping the communities in their negotiations to renew the 25-year concession and to continue managing these forests for timber and non-timber products.

Source: van Zonneveld et al. 2018b

3. Governance and management

3.1 Co-management of natural resources with local/indigenous communities; gender aspects and gender-equitable management

Useful recommendations emerged from research focused on critical aspects in implementing novel co-management solutions that reconcile conservation objectives and use of forest resources by local communities (De Pourcq et al. 2017, 2019). These recommendations regard largely the inclusion of diverse gender-sensitive perspectives in the interactions between park authorities and local/indigenous people. Evidence from 10 protected areas showed that co-management can help avoid or mitigate conflicts between local/indigenous people and national authorities (De Pourcq et al. 2015). Further research (De Pourcq et al. 2017), through interviews conducted with a large number of stakeholders who live and work inside or nearby 15 protected areas in Colombia, brought to the surface the main causes of conflicts and their immediate consequences. It showed the full potential of the "impairment approach" to tackle conflict issues in the context of common pool resources. This approach links sources of conflicts with the resulting impairments or effects; these are defined by the perceptions of an actor and result from the behaviour of another actor. These findings allowed the formulation of precise interventions at multiple levels, which are necessary to move towards an effective resolution of the conflicts identified. The implementation of socially inclusive conservation strategies, which engage both women and men from various ethnic groups in design and implementation, appeared to be the main solution for conflict prevention and resolution in Colombia's national protected areas (De Pourcq et al. 2019).

Gender relations, norms, values and practices were also at the centre of FTA research, with the aim of understanding their influence on forest management structures and the development and uptake of innovation in diversified forest management approaches. Research also focused on understanding tenure patterns for a highly valuable tree species (*Parkia biglobosa* or néré) — see Pehou et al. (2020), on the differentiated access to this species for women and men across ethnic groups; on the gender-differentiated knowledge of agroecology and biodiversity (Elias and Fernandez 2014; Elias 2016), including intraspecific differences in trees (*Vitellaria paradoxa*, or shea; see Karambiri et al. 2017); on gender analyses of political-economic factors affecting community forest management in Central America (Millner et al. 2020); and on options for increasing the participation of women in inclusive management of native fruit trees in Malaysia and India (Faridah et al. 2017; Hegde et al. 2017) and in joint forest management in India (Elias et al. 2020). Building on participatory approaches, Jalonen et al. (2018b) identified community-based and gender-responsive solutions for sustainably managing non-timber forest species in two Indian states. Collection practices for individual species depended on market demand, tenure arrangements and collectors' capacities (which were influenced by gender), as well as species' traits that made existing sustainable practices unsuitable for some species. Male and female research participants in the communities provided detailed suggestions for fostering sustainable collection, including organizing collectors and collaborating with traders and other value chain actors.

Individuals of nerè (*Parkia biglobosa*) interspersed in farmers' fields, Burkina Faso.

Photo by Barbara Vinceti/Alliance of Bioversity

FTA research has contributed to more gender-responsive global policy processes, based on evidence that gender-equitable policies and initiatives can lead to an improved performance with regard to institutional and environmental aspects. For example, gender research influenced the design of policy documents that over the years informed the negotiation processes of the Convention on Biological Diversity (CBD) of the United Nations, including the development of a new strategy post-2020 that will be adopted for the next decades.[15] FTA launched a Gender Research Fellowship Programme to strengthen the capacities of young researchers in a range of geographic and socio-cultural contexts to carry out research on conservation and gender-equitable sustainable management, engaging local populations through participatory research in order to trigger transformational learning processes (Elias et al. 2017). The initiative was assessed a year after its completion (Thull et al. 2015). The evaluation revealed that the programme had successfully contributed to strengthening the capacity of the fellows involved, and to filling knowledge gaps about gender-differentiated knowledge, skills, access, management and use of tree and forest genetic resources. For more information about research work on gender conducted within FTA, please see FTA Highlight No.15 in this series (Elias et al. 2021).

3.2 Managing forests for multiple uses

FTA research on forest management for multiple uses focused on developing improved silvicultural and monitoring practices for multiple use management of forest ecosystems, and tools and methods to resolve conflicts about distribution of benefits and resource rights in the use of forest and tree resources. A special issue of *Forest Ecology and Management* focused on multiple use of tropical forests (Guariguata and Sist 2012). It contributed new knowledge on biophysical, institutional, regulatory and socio-economic aspects of forest use that affect the development and implementation of multiple use forest management in tropical regions. A set of case studies showed examples of diverse and novel management approaches to achieve a range of goals simultaneously: conservation and livelihoods, timber harvesting and nutrition, timber harvesting and biodiversity conservation. These case studies spanned management of forests by communities, timber concessions managed to sustain timber yields and access to food resources for local communities, and examples of co-management and participatory monitoring. The special issue was also translated into Spanish and disseminated as a book by CIFOR to enhance visibility and outreach.[16]

[15] https://www.foreststreesagroforestry.org/news-article/two-key-un-policy-processes-are-now-more-gender-responsive .
[16] https://www.cifor.org/publications/pdf_files/Books/BGuariguata1301.pdf.

The cases presented illustrate the complexity of the trade-offs involved in pursuing management for multiple purposes. This type of management requires a clear initial definition of the various goals and the engagement of all relevant stakeholders in a dialogue. One case study (Guariguata et al. 2012) discusses the fact that spatial planning, from stand to landscape level, requires particular attention, and that managers will need to acquire new skills through specific training and education to be able to implement the concept of multiple use forest management. See Box 5.

Box 5. Managing forests for multiple uses: timber logging and Brazil nut extraction

Two case studies in the special issue of *Forest Ecology and Management* (Guariguata and Sist 2012) addressed aspects related to tensions between management of timber and *Bertholletia excelsa* (Brazil nut) in Latin American communities (Cronkleton et al. 2012; Duchelle et al. 2012). Forests used traditionally for the extraction of non-timber forest products (NTFPs) have experienced increasing logging of timber, so that Brazil nuts and timber are harvested in the same stands. In Bolivia, management of each resource is typically carried out by different stakeholders; local families are responsible for Brazil nut gathering, while logging companies carry out the timber harvest, and finding a way to reconcile these uses has been difficult. Recommendations based on observations (Cronkleton et al. 2012) conclude that multiple-use forest management could be improved by strengthening community-level institutions. This could be achieved by confirming these institutions' authority over timber management operations and by building their capacity to oversee and monitor the extraction activities of loggers working on their land. A case study conducted in Western Amazonia (Duchelle et al. 2012) looked at the perceptions of representatives of different stakeholder groups — communities, industries (Brazil nut and timber), non-governmental organizations, and government agencies — on the integration of timber and Brazil nut management at multiple scales. This revealed distinct differences in perceptions among stakeholder groups, both within and among countries, in pursuing multiple-use forestry strategies. Negative perceptions were associated with policy barriers and high management costs. Important initial steps were taken to assess the compatibility of timber harvesting in forest stands with extraction of Brazil nut, a high-value NTFP. These steps included determining the level of logging intensity that could

Box 5. Managing forests for multiple uses: timber logging and Brazil nut extraction *continued...*

be compatible with nut production (Rockwell et al. 2015; see Box 6), and assessing the spatial distribution pattern and density of Brazil nut trees in disturbed logged forest stands (Rockwell et al. 2017). Elements of the research findings by Rockwell et al. (2015) were included in the official technical norms for management of non-timber forest product concessions in Peru in 2016, with important outcomes in terms of forest policy and offering a good example of how to design a research project to best link scientific findings with policy and influence action (Ramirez and Belcher 2020).

Research findings on the socioecological aspects of the extraction of Brazil nuts reveal that the species utilization represents a model system in terms of sustainability (Guariguata et al. 2017). However, recent evidence from the Madre de Dios Department in Peru (Willem et al. 2019), where Brazil nut concessions were launched in 2000, indicates that these concessions are subject to over-regulation, which is not accompanied by adequate intervention from state agencies, and that they are affected by inefficiencies in state monitoring and sanctions. In addition, law enforcement is inadequate and the value chain is characterized by power imbalance. Illegal timber harvesting and conflicts in customary versus regulatory governance demonstrate the lack of a framework that can truly enable multiple forest uses.

Beyond the model case of Brazil nut, opportunities for and constraints to implementing multiple forest use were further examined. A broad assessment of the potential for conflict in the use of multipurpose tree species was carried out across five countries sharing the Amazonian lowland forest: Bolivia, Colombia, Ecuador, Peru and Venezuela (Herrero-Jáuregui et al. 2013). It emphasized the economic dimension of conflicts and showed that half of the timber species assessed also have non-timber use, and that use of four multipurpose species leads to strong conflicts between timber and non-timber economic value. However, none of these uses had specific management options or legislation to promote sustainable use and mitigate potential conflicts.

Box 6. Compatibility of timber harvesting with collection of NTFPs

Work by FTA on non-timber forest product concessions in the Peruvian Amazon assisted the government to integrate the harvesting management of timber and Brazil nuts in order to optimize combined yields of both forest products. The compatibility of timber harvesting with the harvest of Brazil nuts, which supports thousands of rural families in Western Amazonia, was evaluated by combining GIS information and government databases as well as implementing a large-scale field study where the production of Brazil nut was assessed as a function of the volumes of timber being exploited in the concessions (Rockwell et al. 2015). The results from this work were included into the forestry technical norms issued by the Peruvian government to manage Brazil nut concessions, indicating how much timber could be harvested without compromising yields of Brazil nut; this reconciles livelihood benefits for the communities and produces incentives for forest conservation by local communities. In addition, the research conducted proved successful in showing how science can support policy (Ramirez and Belcher 2020), improving knowledge of Brazil nut ecology among concession owners and triggering a discussion on how to manage Brazil nut groves sustainably.

FTA scientists contributed to an analysis of opportunities for and challenges to sustainable forest management in the humid tropics (Africa, Southeast Asia, Tropical America), with a particular focus on multiple-use forest management and messages targeting forest managers (Sabogal et al. 2013). Evidence shows how invisible the trade of NTFPs is (Shanley et al. 2016). This creates the risk of its being neglected by policy makers, despite its importance, which goes beyond monetary value, embeds socio-cultural elements and plays a key role in adaptive livelihood strategies (ibid.). Multiple-use management practices that couple objectives such as ecosystem services and community needs with traditional forestry require cross-sectoral forest policies that reduce regulatory obstacles. This is especially needed for smallholders and for systems based on common property systems.

Degraded landscape with Brazil nut trees (*Bertholletia excelsa*) in Madre de Dios, Peru.

Photo by Evert Thomas/Alliance of Bioversity International and CIAT

3.3 Conflicts between timber harvesting in logging concessions and nutrition security

Research on diversified forest management was conducted in the Congo Basin, the second largest expanse of tropical forest in the world and the object of multiple uses by different stakeholders. Some of the uses are informal or illegal and are not accommodated within the framework of forest management administered by government. Widespread timber concessions granted to industries compete with agriculture, hunting, small-scale logging and, it has been suggested, with the gathering of non-timber forest products by local people who live in or near the forests (Tieguhong and Ndoye 2007; Guariguata et al. 2010). FTA research on forest uses by men and women in dozens of villages in Cameroon, Gabon and the Democratic Republic of Congo (Tieguhong et al. 2017) showed that local people depend on forest foods, including both plants and animals. Scientists analyzed the density and abundance of forest resources and found that extracting both industrial timber and forest foods from trees could be sustained from the same concession if users followed clear guidelines and negotiated agreements to reduce conflicts (Tieguhong et al. 2017; Maukonen et al. 2020). Expanding the number of resources managed and extracted from concessions would increase the benefits per hectare as well as the number of beneficiaries. A broader analysis of multiple-use forest management in the humid tropics identified agriculture, chainsaw logging and hunting as the main sources of conflicts between villagers and timber industries (Sabogal et al. 2013). Once these were identified, the researchers looked at ways to resolve the disputes and estimated the costs of the trade-offs required. This last step was crucial, as it gave stakeholders a clear idea of the costs and benefits associated with the implementation of a multiple-use scheme. It has become clear that multiple-use forest management needs effective financial incentives (ibid.). Going forward, the researchers (ibid.) suggest that concessions should not be dedicated solely to timber exploitation, but be part of a broader landscape for sustainable multiple resource-based development. Timber and non-timber products for different stakeholders can be obtained and sustained from the same concessions when all agree on appropriate practices and arrangements.

Large expanses of tropical forest in Central Africa are under legal concession arrangements with industrial timber producers. FTA research in the Congo Basin illustrated the importance of forest foods to the nutrition and livelihoods of people in Central Africa and explored the potential to manage concessions in a way that sustains both timber yields and access to food products from trees by local communities (Fungo et al. 2016; Maukonen et al. 2020; Muvatsi et al. 2021). These studies were carried out in the Democratic Republic of Congo, Gabon and Cameroon to evaluate the degree of potential conflict between timber production and harvesting forest foods (fruits and edible caterpillars) from tree species that are important for the timber trade. They led to several conclusions. Fungo et al. (2020) found that these food sources are very important to the nutrition of rural people who live in forest environments, most of whom suffer from hunger and malnutrition. Maukonen et al. (2020) show that most of the resources are collected within a relatively limited radius (circa 4 km) around villages. According to Muvatsi et al. (2021), many of the resources can be obtained from trees that have not yet reached minimum felling diameter, meaning they are not threatened by industrial timber harvesting; however, because these trees are smaller, they also produce less fruit and host fewer caterpillars than trees large enough to be legally harvested. In addition, many trees that have reached the minimum cutting diameter are not extracted in felling operations, either because they are inaccessible or because they are of poor form for timber production; these continue to produce fruits and caterpillars (ibid.). Industrial timber harvesting respects minimum cutting diameters because the export market they supply does not want undersize trees; however, local demand for wood and income means that it is often the villagers themselves (almost always men) who fell the trees, often those with much smaller diameters than the legal limit, that other villagers (often women) depend on as sources of food (Fungo et al. 2016). Several studies found that it would be feasible to manage these forests to produce both industrial timber and food (Noutcheu et al. 2016; Muvatsi et al. 2018; Tieguhong 2017; Taedoumg et al. 2018). See Box 7.

Walnuts and other dried fruits in a market in Kyrgyzstan.

Photo by Barbara Vinceti/Alliance of Bioversity International and CIAT

Box 7. Participatory mapping to solve conflicts between logging and NTFP extraction

Participatory mapping was carried out in selected villages in Cameroon located in close proximity to a forest concession. This approach was adopted to try and resolve conflicts generated by timber extraction activities carried out in concessions where local communities derive valuable non-timber forest products (NTFPs) from the same tree species targeted by loggers. Few quantitative studies have been conducted to determine the impact of logging on the ability of local populations to obtain NTFPs from the same forest sites. This FTA study (Maukonen et al. 2020) focused on three species that provide important food products to villagers and are also valuable timber trees that are targeted by logging operations. The tree species were *Baillonella toxisperma* (moabi), producing an edible fruit and seed oil; *Entandrophragma cylindricum* (sapelli), which hosts caterpillars and larvae commonly consumed in Central Africa and is at the same time the second most important timber species in terms of volume exported; and *Erythrophleum suaveolens* (tali), which hosts another edible caterpillar species and is also a valued timber species, largely exported from Cameroon. The research objective was to determine which individual trees were sources of food resources collected by local people, in order to evaluate whether and to what degree men and women living in villages near timber concessions obtained food products from trees in concessions that might be threatened by logging. The study was based on participatory resource mapping, which combined key informant interviews with GPS information and measurement of collection trees to which key informants guided the researchers. In order to account for different interests in resources between women and men, the teams were gender-differentiated. The findings revealed that in the targeted villages, most of the trees that provided important food resources to the local population were not located on concession lands. The study also recognized the need to respect minimum cutting diameters and legal requirements in agreement with local villagers, in order to safeguard access to food resources from timber trees, even where these are on timber concessions. Mapping and management guidelines are needed for multiple species in order to expand the benefits and the beneficiaries that can be derived from tropical forest management in Africa, and to sustain production of both timber and non-timber resources for multiple users.

Source: Maukonen et al. (2020)

With regard to nutritional security, FTA research has contributed to better understanding how indigenous food tree species (both wild and cultivated) contribute to improving diets through their supply of critical nutrients which are highly deficient in some contexts; this research has also generated evidence on species-specific variation in nutrient content in different edible parts, such as fruit, leaves, flowers, etc. For more information about research work on food security and nutrition conducted within FTA, see FTA Highlight No.5 in this series (Ickowitz et al. 2021).

3.4 Impacts of logging and plantations on forest biodiversity

In the last 50 years, tropical natural forests have been affected by intensive extraction of resources. Over half of all tropical forests have been subject to clearing or logging activities carried out to satisfy the increasing demand for tropical timber, so that degraded forests are now a conspicuous part of tropical landscapes. In addition, about half of the remaining forests (circa 400 million ha) is allocated to timber production, so understanding the dynamics of managed forests, including their role in the global carbon cycle, is critical (Blaser et al. 2011; Laurance et al. 2013). Most of the knowledge of tropical forests comes from research conducted in undisturbed sites. This means that long-term studies on the effects of silviculture on forest dynamics and ecology remain limited, despite the current greater extent of logged and disturbed tropical forests compared to so-called primary forests.

In order to monitor changes in logged forests and to assess the estimated potential of natural production of tropical forests, a network of 24 experimental sites has been set up. Distributed across three tropical regions, with a network of 536 permanent plots and about 1,200 ha of forest inventories, it is called the Tropical managed Forests Observatory (TmFO; see Sist et al. 2015). This network, supported by FTA scientists, has enabled the aggregated analyses of long-term data at regional and global scales in the Amazon Basin, Congo Basin and Southeast Asia, and has quantified the effects of selective logging on forest biodiversity and dynamics, carbon storage and tree species composition, framing a new approach to future tropical forest management (Rutishauser et al. 2015; Piponiot et al. 2019a; Piponiot et al. 2019b). TmFO is also contributing to other global initiatives, which are coupling remote sensing with field observations in tropical forests, to measure forest biomass and estimate biodiversity, feeding vast data repositories for ecological studies and global biomass assessments.

The research (Rutishauser et al. 2015), conducted across hundreds of plots, has also provided information on the recovery time for biodiversity and initial carbon stocks after logging, which is of great relevance in shaping policies that frame management practices. Initial results show that logging intensity has an overwhelming effect on the recovery capacity of Amazonian forests. Simulations (Piponiot et al. 2019a) also indicate that while tropical natural forests will continue to have a key role in providing environmental services (e.g. biodiversity protection and conservation, climate change mitigation, livelihood options), the timber supply from selectively logged forests will likely be insufficient to meet global demand, regardless of the duration of the cutting cycle and logging intensities. Therefore, significant efforts will need to be invested in forest restoration through plantations and intensive silvicultural practices (e.g. enrichment planting).

Edible products from *Adansonia digitata* (baobab) sold with vegetables at a market in Benin.

Photo by Barbara Vinceti/Alliance of Bioversity International and CIAT

Jalonen et al. (2014) reviewed the impacts of logging and habitat fragmentation on the genetic diversity of native Asian tree species, and assessed conservation measures in existing forest management guidelines. Dipterocarps are the dominant tree family in Southeast Asian rainforests; they act as important carbon sinks and have distinct dispersal patterns, with both pollen and seed dispersal typically limited to short distances. These traits, together with the high species diversity and low population densities of individual species, make dipterocarp species particularly vulnerable to genetic erosion[17] in the event of logging and habitat fragmentation. Existing studies reviewed by Jalonen et al. (2014) found that the reduction in genetic diversity through logging could not be adequately compensated for by gene flow from adjacent unlogged stands, and that inbreeding increased after logging in most studied cases. Inbreeding negatively affects the regeneration and vigour of progeny, with potentially long-term effects on the recovery of the logged stands. These results highlight the need to incorporate genetic conservation measures in harvesting practices. Jalonen et al. (2014) identified practical recommendations for forest managers on how to mitigate the negative impacts of logging on genetic diversity. Several recommendations from the study (ibid.) were adopted in the Malaysian Criteria and Indicators (MC&I) for Forest Management Certification (Natural Forests), which are applied across 4 million hectares of production forests in the country.

Regarding the effects on biodiversity from plantations in the tropics, a systematic review was conducted on biofuel crops (oil palm, soybean and jatropha), with a particular focus on the influence of plantations on species richness, abundance, community composition and ecosystem functions (Savilaakso et al. 2014). The results indicated that oil palm plantations have led to a decline in species richness compared with primary and secondary forests, and that forest conversion to oil palm plantations has led to a significant modification in the composition of species assemblages. Knowledge gaps remain with regard to how different production systems affect biodiversity and ecosystem function.

A key innovative approach to forest management to restore timber values emerged from research on regeneration of timber trees subject to infrequent large-scale disturbance in harvested forests in Mesoamerica (Snook et al. 2021). There, 80% of commercial timber tree species are intolerant of shade and do not regenerate in the small gaps produced by timber harvesting. The novel practice, which involved the use of patch clear-cuts and natural regeneration, was tested 11 years after it was implemented, at which time

[17] Genetic erosion is a natural or human-driven process that, over time, produces a loss of genetic diversity in populations of the same species, or a reduction of the genetic base of a species, or the loss of an entire species.

there was proof of success.[18] The proposed approach represents a major paradigm shift that acknowledges that many tropical forests do not regenerate through small gaps, which was considered to be widespread, but instead regenerate after infrequent large-scale disturbances such as hurricanes and fires. Different approaches, namely patch clear-cuts, which were tested and described in this research (Snook et al. 2021), are urgently needed.

Recommendations regarding management of natural regeneration were derived from research conducted on Brazil nut in the Madre de Dios region of Peru (Porcher et al. 2018). This tree (*Bertholletia excelsa*) has huge ecological and socioeconomic importance and is known for being a pioneer, gap-dependent species. Porcher et al. 2018 found that it regenerated more often in fallows than in mature forests. An increase of recruitment rates in fallows followed a number of fire events, with positive correlations observed for up to three fire events, largely due to an accumulation of resprouting individuals. These findings suggest using better fire management in fallows to ensure greater natural regeneration of Brazil nut.

Women cracking Brazil nut tree seeds (*Bertholletia excelsa*) to release the nuts in Puerto Maldonado, Madre de Dios, Peru.

Photo by Evert Thomas/ Alliance of Bioversity International and CIAT

[18] https://www.sciencedirect.com/science/article/abs/pii/S0378112721002942?via%3Dihub.

FTA research has also focused on the characterization of tree biodiversity in neotropical secondary and production forests, generating estimates of the recovery of biodiversity and biomass. A special issue of *Forest Ecology and Management*, edited by FTA scientists, focused on active restoration of timber production and other ecosystem services in secondary and degraded forests, in landscapes under strong human pressures (Ngo Bieng et al. 2021). The case studies presented illustrate assessments that link the timber potential of secondary forests with the provision of ecosystem services. The issue also presents cases that demonstrate how active restoration could help to mitigate forest biodiversity losses and other degradation processes in logged-over forests.

3.5 Governance and operational aspects of sustainable forest management (certification)

FTA research has developed innovative solutions to the design and implementation of institutional governance arrangements aimed at improving sustainable management of forests. One of the main areas of investigation has been the arrangements in consumer countries to improve governance capacities in producer countries; the ultimate goal of these measures was to reduce deforestation associated with the production of agricultural commodities (e.g. cacao, palm oil). For more information about work on sustainable value chains and finance conducted within FTA see FTA Highlight No.10 in this series (Brady et al. 2021). Another research area focused on the possibility of designing broad approaches to promote the uptake of sustainability standards and certification (Meijaard et al. 2014; Romero et al. 2017; Cerutti et al. 2017; Savilaakso and Guariguata 2017). The adoption of certification has been slow due to its costs and to institutional barriers, both of which have so far prevented the large upscaling of sustainability practices.

Furthermore, while governments in consumer countries are adopting measures to limit imports of unsustainable or illegal timber, regulations in the private sector have also emerged in producer and consumer countries, with the objective of promoting self-governance by private actors through codes of conduct, principles and guidelines, and wider commitments to sustainability.

A body of research has showed how the various combinations of public and private initiatives are contributing to more effective transitions to the sustainable supply of forest-related products in a range of geographic contexts, such as Cameroon (Cerutti et al. 2011; 2013), Congo Basin (Cerutti et al. 2014), Indonesia (Romero et al. 2015b) and Brazil (Romero et al. 2015a). These reports highlight constraints and opportunities that are specific to each country. This work is informing debates on the measures required to support sustainable supply in ways that reconcile the interests of producer and consumer countries, and of stakeholders along the value chain.

Assessing the impacts of certification by the Forest Stewardship Council (FSC) after more than 20 years of implementation — and correctly relating social, ecological and economic outcomes to forest management versus other factors — turned out to be very difficult to do in a stringent way, based on the information gathered through a range of different methods. To overcome this issue, a roadmap was developed based on rigorous methods to assess whether FSC certification is leading to the expected outcomes (Romero et al. 2017). An account of how the roadmap has been used is not available yet.

FTA work has also explored opportunities for and challenges to including forest ecosystem services in forest ecosystem certification (Meijaard et al. 2014). The challenges that emerged include the lack of markets for forest ecosystem services, the insufficient demand for bundled forest ecosystem services versus individual ones (e.g. pollination, flood buffering, as opposed to carbon sequestration alone), the difficulties in quantifying forest ecosystem

Morphological variation in fruits of *Dacryodes edulis* (African plum tree) collected from different individual trees.

Photo by Aurore Rimlinger/IRD

services, and the very high monitoring costs. Possible ways forward include simplifying certification criteria and developing new techniques to quantify how forest management practices influence service provision; for example, defining minimum thresholds under which sustainable forest ecosystem services can no longer be provided. A study to assess the feasibility of forest ecosystem services certification revealed a low willingness to pay for the certification of these services and limited technical capacity to manage them (Jaung et al. 2016). Attempts to incorporate forest ecosystem services in an existing forest certification scheme brought to light other constraining factors at the local scale; in particular, the lack of a specific vision and detailed information about future prospects for forest ecosystem certification turned out to be problematic when trying to attract market interest (Savilaakso and Guariguata 2017).

3.6 DNA-based verification methods to combat illegal logging

To support the implementation of sustainable forest management, methods to detect illegal logging and trade have been set in place. Various methods can be applied to track the origin of timber; they are based on analyses of wood anatomy, wood chemistry (stable isotopes, mass spectroscopy, near-infrared spectroscopy) and DNA samples extracted from timber. They vary in terms of advantages and limitations, and in the level of accuracy in detecting the species and origin of the material; using a combination of methods may be more effective (Dormontt et al. 2015; Lowe et al. 2016). In addition to wood anatomical methods, which are well-established, timber-tracking techniques are constantly evolving. One of the greatest limitations is the limited availability of reference data, which are necessary to verify the species and origin of a traded wood-based product. In the last decade, molecular genetic methods have been shown to hold great potential for use at a variety of levels to identify wood, from the identification of species to the verification of source region and concession, and to the tracking of individual logs or timber products (Lowe and Cross 2011; Lowe et al. 2016; Dormontt et al. 2015; Schmitz et al. 2020).

FTA has contributed to setting up the Global Timber Tracking Network (GTTN),[19] which promotes the implementation of innovative tools to identify tree species and determine the geographic origin of traded wood. FTA has also provided contributions in the formulation of an overview of various timber tracking methods and guidelines for sample collection (Schmitz et al. 2019; Schmitz et al. 2020). The guidelines for sampling aim to facilitate the

[19] https://globaltimbertrackingnetwork.org/.

harmonization of practices for collecting samples that are subject to various verification methods, especially if used in combination, to ensure that samples come from the same individual tree and from the same part of the tree. Critical to the implementation of verification measures to monitor and fight the trade of illegal wood is the development of reference databases for various timber tracking tools. GTTN is building a central database and a sample location facility. In future, when a reference database is in place for a given tree species and for more than one identification method, it will be sufficient to have at hand one sample of unidentified wood to determine its identity.

Genetic code extracted from wood can be used as a forensic tool to crack down on illegal logging.

Photo by Judy Loo/Bioversity International

4. Relevance of research outputs in the frame of global initiatives

Results from FTA research discussed here can inform the implementation of the post-2020 Global Biodiversity Framework (CBD 2021), which will set goals for biodiversity conservation and sustainable use for the next three decades, until 2050. The draft framework includes goals and targets to reduce the number of threatened species, maintain genetic diversity, improve conservation and sustainable management of ecosystems, and develop capacity building and scientific cooperation. The framework was scheduled for adoption at the 15th CBD Conference of Parties (COP) in October 2021.

As part of the process leading to the next COP, FTA organized an international scientific conference with the Kunming Institute of Botany, Chinese Academy of Science, and the Research Institute for Resource Insects, at the Chinese Academy of Forestry, in Kunming, China, on 22–24 June 2021. The theme was Forests, Trees and Agroforestry for Diverse Sustainable Landscapes.[20] The event presented the state of the evidence to support the implementation of the CBD, and to promote a better linkage between science and research with policy, development and implementation, around six main technical themes.

The final key recommendations were formulated for the attention of governments and all actors, public and private, the Rio platforms

[20] https://www.foreststreesagroforestry.org/wp-content/uploads/2021/07/FTA_Kunming_Conference-OutcomesRecs_vDEF.pdf.

and conventions — CBD, United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention to Combat Desertification (UNCCD) — trade-related bodies, and international organizations such as FAO. The recommendations resulted from the technical and plenary sessions of the conference and incorporated comments received from participants.

In May 2021 scientists from Bioversity attended the twenty-fourth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), which advises the CBD Parties on the implementation of the convention and development of the new global framework. Bioversity issued statements[21] at the meeting on the need to better incorporate forest biodiversity in the draft framework and its proposed indicators, and to set more explicit targets and indicators for genetic diversity. These comments were reflected in the report of SBSTTA co-chairs (SBSTTA 2021), which noted that forests should be better reflected across the goals and targets of the framework, including through additional targets where relevant.

In addition, the FAO's Global Plan of Action (FAO 2014a), derived from its *State of the World's Forest Genetic Resources*, is implementing a global monitoring system for FGRs that is directly supported by FTA work on tree biodiversity. Specifically, the spatially explicit threat analysis of tree species (Fremout 2020; Gaisberger et al. 2020) provides powerful new tools to support mapping and monitoring of FGRs. Furthermore, a thematic study accompanying FAO's *State of the World's Forest Genetic Resources* (Graudal et al. 2014) represents the first attempt to provide a thorough overview and synthesis of the appropriate indicators for defining intraspecific tree biodiversity state, existing pressures, benefits (the implications for society) and responses (the measures taken by society). These indicators would assist in the management of FGRs and have been proposed for immediate implementation by the global biodiversity community. This analysis had the objective to support new biodiversity-related indicators within the Convention on Biological Diversity post-2020.

For the post-2020 Global Biodiversity Framework, the critical role played by Trees on farms (TonF) in contributing to biodiversity conservation in agricultural landscapes through in situ conservation, in line with the objectives of Aichi Target 7, was presented by FTA scientists in a policy brief (Vidal et al. 2020). Despite the importance of TonF, they are not accounted for in National Biodiversity Strategies and Action Plans (NBSAPs), which are going to be key instruments for the implementation of the post-2020 Global Biodiversity Framework. A number of actions are proposed to include TonF

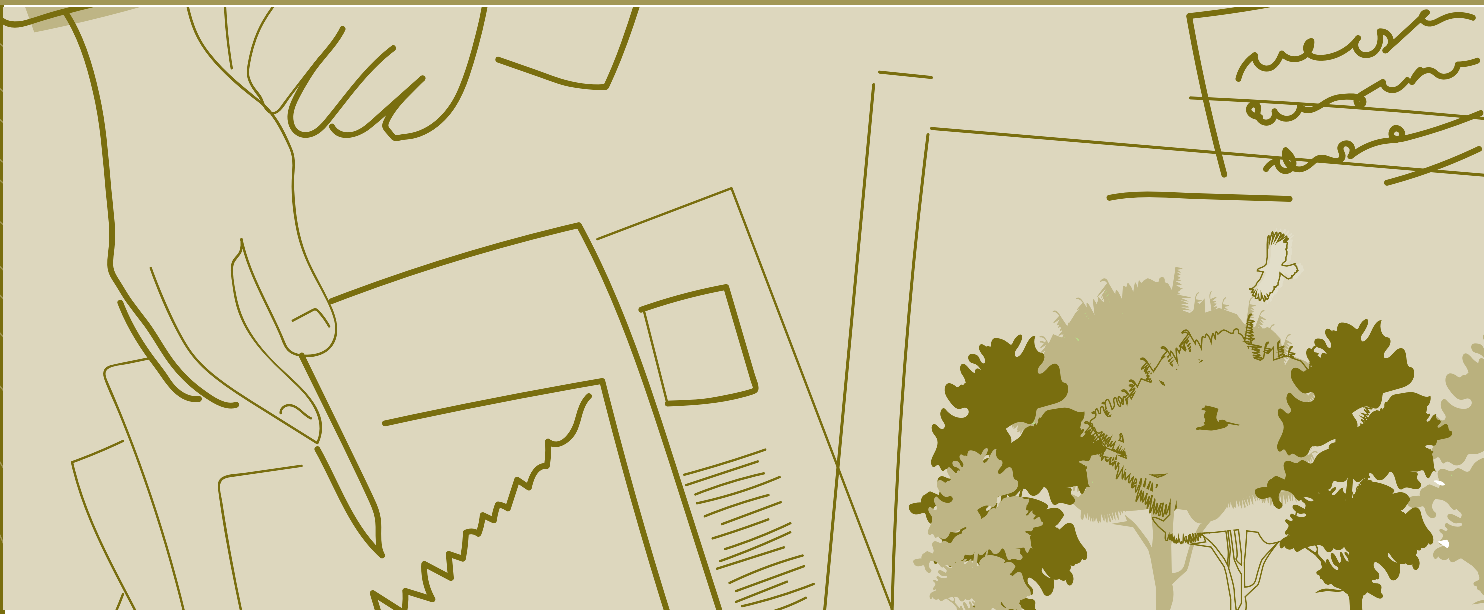
[21] https://www.cbd.int/doc/c/9472/6090/90511f710677dd22c112db03/sbstta-24-11-en.pdf.

under agricultural biodiversity strategies in NBSAPs. FTA research work has also contributed to improving regulations on seed systems and transfer zones; for more information about work on seeds and seed systems conducted within FTA, see FTA Highlight No.2 in this series (Graudal et al. 2021).

Finally, the research outputs generated by FTA are also relevant in relation to strategic objectives of the United Nations Convention to Combat Desertification and the United Nations Framework Convention on Climate Change.

Dacryodes edulis (African plum tree) in a homegarden in Cameroon.

Photo by Nardis Nkoudou Ze /University of Yaoundé



5. Future directions

5.1 Topics for future research that emerged from FTA work

FTA has contributed an enormous amount of knowledge to advance understanding of the threats to and the effective conservation strategies for forest tree biodiversity across the tropics. This has enabled significant steps forward in policies and regulations for the sustainable use and increased valuing of FGRs. Some topics have emerged as critical for future research and will be part of the agenda, not only of CGIAR scientists, but of the broader scientific community.

It will be important to achieve an improved understanding of the effects of species composition —which are different from those of species richness or of individual species — on forest productivity and other ecosystem functions. In particular, five issues are important: the relationships between plant species richness and functional diversity and biomass accumulation in diverse forest systems, especially for novel systems;[22] the relationships between species richness and ecosystem resistance and resilience; the repercussions of a loss of faunal diversity on processes in forest ecosystems; the long-term consequences of repeated disturbances on the recovery of forest ecosystems; and the degradation/disturbance thresholds that may constrain the capacity of forest ecosystems to recover their diversity, functions and provision of services.
It will be crucial to better understand the time scales and conditions required

[22] Novel systems are new combinations of species or ecosystem structures that are determined by new combinations of climatic and environmental factors, which often result from climatic changes.

to recover to pre-disturbance levels of biodiversity and carbon in secondary forests, which are of significant value to conservation of biodiversity and are important carbon stocks, but are currently poorly understood. Improved knowledge is also necessary regarding the effect of spatial scales in the provision of ecosystem services by individual tree species such as Brazil nut, for which ecosystem service provision is influenced by neighbouring effects on recruitment and seed production.

A better understanding of genetic variation in relation to adaptive traits remains a central research objective, especially concerning lesser-studied tree species, in order to guide their management in light of climate change. Another priority is a better assessment of diversity, and a comparison of current and future habitat niche modelling of extant wild and semi-wild stands of important tree commodity crops and other commercially valuable tree species.

Some very promising approaches, such as the use of species distribution models to set priorities in conservation and restoration, will require more investigation to support more systematic adoption in different contexts. In addition, future projections of species' responses to climate change, based on current and future species distribution models, need to incorporate plastic responses[23] and information on genetic differentiation as much as possible in order to improve their accuracy. Major objectives will be to identify gaps in conservation, to assess which forest genetic resources are not included within the existing networks of protected areas, and to define dynamic tree seed zones for seed collection in restoration initiatives in light of expected future climatic changes.

Operational management models that enable safeguard measures to be implemented for genetically diverse populations should be tested in a larger set of contexts, and should include the steps of a formal identification of genetic conservation sites and recognition of them by institutions; agreements with local communities on their involvement in protecting valuable tree populations; and involvement of local communities in tree seed sourcing through appropriate compensation mechanisms. In this way, incentives for conservation would stem from the use of forest diversity, valuing genetic resources in the context of restoration and embedding conservation of high-quality tree seed into economic assessments of costs and benefits of restoration. To support this, more case studies are needed.

In addition, research activities are required to test the adoption of multiple-use forest management models in a range of contexts. This will help

[23] Plasticity is the ability of a genotype to express different phenotypes depending on the environment in which it resides.

researchers understand the circumstances under which arrangements are most effective (e.g. community forests); where positive linkages can be achieved between cultivation and the conservation of forest and woodland populations that provide alternative sources for NTFPs; how production from trees under cultivation can sustain the conservation of wild sources of useful tree products; and the contexts where high tree diversity on farmland is compatible with production, since exotic tree species often outcompete and replace indigenous species. Finally, it will be necessary to explore domestication approaches that are most favourable to the maintenance of intraspecific diversity.

References

Aguirre-Morales CA, Thomas E, Cardozo CI, Gutiérrez J, Alcázar Caicedo C, Moscoso Higuita LG, Becerra LA and González MA. 2020. Genetic diversity of the rain tree (*Albizia saman*) in Colombian seasonally dry tropical forest for informing conservation and restoration interventions. *Ecology and Evolution* 10:1905–1916. https://doi.org/10.1002/ece3.6005.

APFORGEN (Asia-Pacific Forest Genetic Resources Programme). 2018. *Strategy 2018–2022: Implementing the global plan of action on forest genetic resources in Asia and the Pacific*. Asia-Pacific Forest Genetic Resources Programme. Beijing: Chinese Academy of Forestry; Serdang: Bioversity International. http://www.apforgen.org/fileadmin/user_upload/APFORGEN_strategy-_final_version_.pdf.

APFORGEN (Asia-Pacific Forest Genetic Resources Programme). 2014. Strategy for regional collaboration 2014–2016. Asia Pacific Forest Genetic Resources Programme. APAFRI and Bioversity International, Serdang, Malaysia. https://hdl.handle.net/10568/104519.

Azpilicueta MM, Gallo LA, van Zonneveld M, Thomas, E, Moreno C and Marchelli P. 2013. Management of *Nothofagus genetic* resources: Definition of genetic zones based on a combination of nuclear and chloroplast marker data. *Forest Ecology and Management* 302:414–424. https://doi.org/10.1016/j.foreco.2013.03.037.

Balima LH, Nacoulma BMI, Mensah Ekué MR, N'Guessan Kouamé F and Thiombiano A. 2018. Use patterns, use values and management of *Afzelia africana* Sm. in Burkina Faso: Implications for species domestication and sustainable conservation. *Journal of Ethnobiology and Ethnomedicine* 14. https://doi.org/10.1186/s13002-018-0221-z.

Baur EH, McNab RB, Williams LE Jr, Ramos VH, Radachowsky J and Guariguata MR. 2012. Multiple forest use through commercial sport hunting: Lessons from a community-based model from the Petén, Guatemala. *Forest Ecology and Management* 268:112–120. https://doi.org/10.1016/j.foreco.2011.06.005.

Bélanger J and Pilling D. eds. 2019. *The state of the world's biodiversity for food and agriculture*. Rome: FAO Commission on Genetic Resources for Food and Agriculture Assessments. http://www.fao.org/3/CA3129EN/ca3129en.pdf.

Blaser J, Sarre A, Poore D and Johnson S. 2011. *Status of tropical forest management 2011*. ITTO Technical Series No. 38. Yokohama: International Tropical Timber Organization. https://www.trae.dk/wp-content/uploads/2011/08/rapport.pdf.

Bocanegra-González KT, Thomas E, Guillemin ML, Alcázar Caicedo C, Moscoso Higuita LG, Gonzalez MA and de Carvalho D. 2019. Diversidad y estructura genética de cuatro especies arbóreas claves del Bosque Seco Tropical en Colombia. *Caldasia* 41:78–91. http://doi.org/10.15446/caldasia.v41n1.71327.

Bocanegra-González KT, Thomas E, Guillemin ML, de Carvalho D, Gutiérrez JP, Alcázar Caicedo C. Moscoso Higuita LG, Becerra LA and González MA. 2018. Genetic diversity of *Ceiba pentandra* in Colombian seasonally dry tropical forest: Implications for conservation and management. *Biological Conservation* 227:29–37. https://doi.org/10.1016/j.biocon.2018.08.021.

Bourdeix R and Prades A. comps. 2018. A global strategy for the conservation and use of coconut genetic resources, 2018–2028. Montpellier, France: Bioversity International. https://www.researchgate.net/publication/327416443_A_Global_Strategy_for_the_Conservation_and_Use_of_Coconut_Genetic_Resources_2018-2028.

Bozzano M, Jalonen R, Evert T, Boshier D, Gallo L, Cavers S, Bordacs S, Smith P and Loo J. 2014. *Genetic considerations in ecosystem restoration using native tree species*. A thematic study for the State of the World's Forest Genetic Resources report. Rome: FAO and Bioversity International. http://www.fao.org/3/a-i3938e.pdf.

Brady M, Louman B, Wardell DA, Gallagher E, Lescuyer G, Pacheco P, Piketty M-G and Shoneveld G. 2021. *Sustainable Value Chains and Finance*. FTA Highlights of a Decade 2011–2021 series. Highlight No.10. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008220.

CBD (Convention on Biological Diversity). 2021. *First detailed draft of the new post-2020 Global Biodiversity Framework*. https://www.cbd.int/article/draft-1-global-biodiversity-framework.

CBD (Convention on Biological Diversity). 2019. COP XII/19. *Ecosystem conservation and restoration*. https://www.cbd.int/kb recorddecision/13382?RecordType=decision&Event=COP-12.

Cerutti PO, Lescuyer G, Tacconi L, Eba'a Atyi R, Essiane E, Nasi R, Tabi Eckebil PP, Tsanga R. 2017. *Social impacts of the forest stewardship council certification in the Congo Basin*. Int For Rev. 2017;19: 50–63. https://doi.org/10.1505/146554817822295920.

Cerutti PO, Lescuyer G, Tsanga R, Kassa SN, Mapangou PR, Mendoula EE, Missamba-Lola AP, Nasi R, Eckebil PPT and Yembe RY. 2014. *Social impacts of the Forest Stewardship Council certification: An assessment in the Congo basin*. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/004487.

Cerutti PO, Tacconi L, Lescuyer G and Nasi R. 2013. Cameroon's hidden harvest: Commercial chainsaw logging, corruption, and livelihoods. *Society & Natural Resources* 26(5):539–553. https://doi.org/10.1080/08941920.2012.714846.

Cerutti PO, Tacconi L, Nasi R and Lescuyer G. 2011. Legal vs. certified timber: Preliminary impacts of forest certification in Cameroon. *Forest Policy and Economics* 13(3):184–190. https://doi.org/10.1016/j.forpol.2010.11.005.

Chan LM, Brown JL and Yoder AD. 2011. Integrating statistical genetic and geospatial methods brings new power to phylogeography. *Molecular Phylogenetics and Evolution* 59(2):523–537. https://doi.org/10.1016/j.ympev.2011.01.020.

Chiriboga-Arroyo F, Jansen M, Bardales Lozano R, Ismail SA, Thomas E, García M, Gomringer RC and Kettle CJ. 2020. Genetic threats to the forest giants of the Amazon: habitat degradation effects on the socio-economically important Brazil nut tree (*Bertholletia excelsa*). *Plants People Planet* 3(2):194–210. https://doi.org/10.1002/ppp3.10166.

Cronkleton P, Guariguata MR and Albornoz MA. 2012. Multiple use forestry planning: Timber and Brazil nut management in the community forests of northern Bolivia. *Forest Ecology and Management* 268:49–56. https://doi.org/10.1016/j.foreco.2011.04.035.

Dawson IK, Guariguata MR, Loo J, Weber JC, Lengkeek A, Bush D, Cornelius J, Guarino L, Kindt R, Orwa C, et al. 2013. What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? A review. *Biodiversity and Conservation* 22:301–324. https://link.springer.com/article/10.1007%2Fs10531-012-0429-5.

Dawson IK, Leakey R, Clement CR, Weber JC, Cornelius JP, Roshetko JM, Vinceti B, Kalinganire A, Tchoundjeu Z, Masters E and Jamnadass R. 2014. The management of tree genetic resources and the livelihoods of rural communities in the tropics: Non-timber forest products, smallholder agroforestry practices and tree commodity crops. *Forest Ecology and Management* 333:9–21. https://doi.org/10.1016/j.foreco.2014.01.021.

Dawson IK, Park SE, Attwood SJ, Jamnadass R, Powell W, Sunderland T and Carsan S. 2019. Contributions of biodiversity to the sustainable intensification of food production. *Global Food Security* 21:23–37. https://doi.org/10.1016/j.gfs.2019.07.002.

De Pourcq K, Thomas E, Arts B, Vranckx A, Sicard T and Van Damme P. 2017. Understanding conflict between local communities and conservation authorities in Colombia. *World Development* 93:125–135. https://doi.org/10.1016/j.worlddev.2016.12.026.

De Pourcq K, Thomas E, Arts B, Vranckx A, Sicard T and Van Damme P. 2015. Conflict in protected areas: Who says co-management does not work? *PLoS ONE* 10(12):e0144943. https://doi.org/10.1371/journal.pone.0144943.

De Pourcq K, Thomas E, Elias M and Van Damme P. 2019. Exploring park-people conflicts in Colombia through a social lens. *Environmental Conservation* 46:103–110. https://doi.org/10.1017/S0376892918000413.

Des Roches S, Pendleton LH, Shapiro B and Palkovacs EP. 2021. Conserving intraspecific variation for nature's contributions to people. *Nature Ecology & Evolution* 5:574–582. https://doi.org/10.1038/s41559-021-01403-5.

Díaz S, Settele J, Brondízio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, et al. eds. 2019. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn: IPBES Secretariat. https://doi.org/10.5281/zenodo.3553579.

Dormontt EE, Boner M, Braun B, Breulmann G, Degen B, Espinoza E, Gardner S, Guillery P, Hermanson JC, Koch G, et al. 2015. Forensic timber identification: It's time to integrate disciplines to combat illegal logging. *Biological Conservation* 191:790–798. https://doi.org/10.1016/j.biocon.2015.06.038.

Duchelle, AE, Guariguata MR, Less G, Albornoz MA, Chavez A and Melo T. 2012. Evaluating the opportunities and limitations to multiple use of Brazil nuts and timber in Western Amazonia. *Forest Ecology and Management* 268:39–48. https://doi.org/10.1016/j.foreco.2011.05.023.

Duminil J, Daïnou K, Kaviriri D, Gillet P, Loo J, Doucet J-L and Hardy OJ. 2015. Relationships between population density, fine-scale genetic structure, mating system and pollen dispersal in a timber tree from African rainforests. *Heredity* 116:295–303. https://doi.org/10.1038/hdy.2015.101.

Duminil J, Mendene Abessolo DT, Ndiade Bourobou D, Doucet J-L, Loo J and Hardy OJ. 2016. High selfing rate, limited pollen dispersal and inbreeding depression in the emblematic African rain forest tree *Baillonella toxisperma* – Management implications. *Forest Ecology and Management* 379:20–29. https://doi.org/10.1016/j.foreco.2016.08.003.

Elias M. 2016. Distinct, shared and complementary: Gendered agroecological knowledge in review. *CAB Reviews* 11(40):1–16. https://doi.org/10.1079/PAVSNNR201611040.
Elias M and Fernandez M. 2014. Genre, biodiversité et agriculture familiale. *POUR* 222:285–293. https://doi.org/10.3917/pour.222.0285.

Elias M, Grosse A and Campbell N. 2020. Unpacking 'gender' in joint forest management: Lessons from two Indian states. *Geoforum* 111:218–228. https://doi.org/10.1016/j.geoforum.2020.02.020.

Elias M, Jalonen R, Fernandez M and Grosse A. 2017. Gender-responsive participatory research for social learning and sustainable forest management. *Forests, Trees and Livelihoods* 26(1):1–12. https://doi.org/10.1080/14728028.2016.1247753.

Elias M, Paez Valencia AM, Ihalainen M and Monterroso I. 2021. *Advancing gender equality and social inclusion*. FTA Highlights of a Decade 2011–2021 series. Highlight No.15. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008225.

FAO (Food and Agriculture Organization). 2014a. *Global plan of action for the conservation, sustainable use and development of forest genetic resources*. http://www.fao.org/3/i3849e/i3849e.pdf.

FAO (Food and Agriculture Organization). 2014b. *The state of the world's forest genetic resources*. Rome: FAO. http://www.fao.org/3/a-i3825e.pdf.

FAO (Food and Agriculture Organization) and UNEP (United Nations Environment Programme). 2020. The state of the world's forests 2020. *Forests, biodiversity and people*. Rome: FAO and UNEP. https://doi.org/10.4060/ca8642en.

Faridah AM, Elias M, Lamers HA, Shariah U, Brooke P and Hafizul HM. 2017. Evaluating the usefulness and ease of use of participatory tools for forestry and livelihoods research in Sarawak, Malaysia. *Forests, Trees and Livelihoods* 26(1):29–46. https://doi.org/10.1080/14728028.2016.1246213.

Fremout T, Gutiérrez-Miranda CE, Briers S, Marcelo-Peña JL, Cueva-Ortiz E, Linares-Palomino R, La Torre-Cuadros MdlÁ, Chang-Ruíz JC, Villegas-Gómez TL, Acosta-Flota AH, et al. 2021a. The value of local ecological knowledge to guide tree species selection in tropical dry forest restoration. *Restoration Ecology* 29(4):e133347. https://doi.org/10.1111/rec.13347.

Fremout T, Thomas E, Bocanegra-González KT, Aguirre-Morales CA, Morillo-Paz, AT Atkinson R, Chris Kettle, González R, Alcázar Caicedo C, González MA, et al. 2021b. Dynamic seed zones to guide climate-smart seed sourcing for tropical dry forest restoration in Colombia. *Forest Ecology and Management* 490. https://doi.org/10.1016/j.foreco.2021.119127.

Fremout T, Thomas E, Gaisberger H, Van Meerbeek K, Muenchow J, Briers S, Gutierrez-Miranda CE, Marcelo-Peña JL, Kindt R, Atkinson R, et al. 2020. Mapping tree species vulnerability to multiple threats as a guide to conservation and restoration of tropical dry forests. *Global Change Biology* 26:3552–3568. https://doi.org/10.1111/gcb.15028.

Fungo R, Muyonga J, Kabahenda M, Kaaya A, Okia C, Donn P, Mathurin T, Tchingsabé O, Tiegehungo JC, Loo J and Snook L. 2016. Contribution of forest foods to dietary intake and their association with household food insecurity: A cross-sectional study in women from rural Cameroon. *Public Health Nutrition* 19:3185–3196. https://doi.org/10.1017/S1368980016001324.

Fungo R, Tieguhong JC, Iponga DM, Tchatat M, Kahindo JM, Muyongaa JH, Mikolo-Yobo C, Donn P, Tchingsabe O, Kaaya AN, et al. 2020. Can wild forest foods contribute to food security and dietary diversity of rural populations adjoining forest concessions? Insights from Gabon, DR Congo and Cameroon. *International Forestry Review* 22(S2). https://hdl.handle.net/10568/110381.

Gaisberger H, Kettle CJ, Vinceti B, Fremout T, Kemalasari D, Kanchanarak T, Thomas E, APFORGIS and Jalonen R. in press. Tropical and subtropical Asia's valued tree species under threat. *Conservation Biology*.

Gaisberger H, Legay S, Andre G, Loo J, Aaliev S, Bobokalonov F, Muhsimov N, Kettle CJ and Vinceti B. 2020. Diversity under threat: Connecting genetic diversity and threat mapping to set conservation priorities for *Juglans regia* L. populations in Central Asia. *Frontiers in Ecology and Evolution* 8:171. https://doi.org/10.3389/fevo.2020.00171.

Gaisberger H, Kindt R, Loo J, Schmidt M, Bognounou F, Da SS, Diallo O, Ganaba S, Gnoumou A, Lompo D, et al. 2017. Spatially explicit multi-threat assessment of food tree species in Burkina Faso: A fine-scale approach. *PLoS ONE* 12(9):e0184457. https://doi.org/10.1371/journal.pone.0184457.

Galluzzi G, Dufour D, Thomas E, van Zonneveld M, Escobar Salamanca AF, Giraldo Toro A, Rivera A, Salazar Duque H, Suárez Baron H, Gallego G et al. 2015. An integrated hypothesis on the domestication history of *Bactris gasipaes*. *PLoS ONE* 10(12):e0144644. https://doi.org/10.1371/journal.pone.0144644.

Graudal L, Aravanopoulos F, Bennadji Z, Changtragoon S, Fady B, Kjær ED, Loo J, Ramamonjisoa L and Vendramin GG. 2014. Global to local genetic diversity indicators of evolutionary potential in tree species within and outside forests. *Forest Ecology and Management* 333:35–51. https://doi.org/10.1016/j.foreco.2014.05.002.

Graudel L, Lillesø J-PB, Roshetko JM, Nyoka I, Tsobeng A, Kindt R, Dawson IK, Jalonen R, Thomas E, McMullin S, et al. 2021. *Tree Seed and Seedling Systems for Resilience and Productivity*. FTA Highlights of a Decade 2011–2021 series. Highlight No.2. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008212.

Guariguata MR and Sist P. eds. 2012. Multiple use management of tropical production forests: How can we move from concept to reality? Special Issue. *Forest Ecology and Management* 268:1–120. https://www.sciencedirect.com/journal/forest-ecology-and-management/vol/268.

Guariguata MR, Atmadja S, Baral H, Boissière M, Brady M, Chomba S, Cronkleton P, Djoudi H, Duchelle A, Duguma L, et al. 2021. *Forest and Landscape Restoration*. FTA Highlights of a Decade 2011–2021 series. Highlight No.4. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008214.

Guariguata MR, Cronkleton P, Duchelle AE and Zuidema PA. 2017. Revisiting the 'cornerstone of Amazonian conservation': A socioecological assessment of Brazil nut exploitation. *Biodiversity and Conservation* 26:2007–2027. https://doi.org/10.1007/s10531-017-1355-3.

Guariguata MR, García-Fernández C, Sheil D, Nasi R, Herrero-Jáuregui C, Cronckleton P and Ingram V. 2010. Compatibility of timber and non-timber forest product management in natural tropical forests: Perspectives, challenges, and opportunities. *Forest Ecology and Management* 259:237–245. https://doi.org/10.1016/j.foreco.2009.11.013.

Guariguata MR, Sist P and Nasi R. 2012. Multiple use management of tropical production forests: How can we move from concept to reality? *Forest Ecology and Management* 268:170–174. https://doi.org/10.1016/j.foreco.2011.09.032.
Guarino L, Jarvis A, Hijmans RJ and Maxted N. 2002. Geographic information systems (GIS) and the conservation and use of plant genetic resources. *In* Engels JMM, Ramanatha RV, Brown AHD and Jackson MT. eds. *Managing plant genetic diversity*. Rome: International Plant Genetic Resources Institute (IPGRI), 387–404.

Hegde N, Elias M, Lamers HA and Hegde M. 2017. Engaging local communities in social learning for inclusive management of native fruit trees in the Central Western Ghats, India. *Forests, Trees and Livelihoods* 26(1):65–83. https://doi.org/10.1080/14728028.2016.1257398.

Herrero-Jáuregui C, Guariguata MR, Cardenas D, Vilanova E, Robles M, Licona JC and Nalvarte W. 2013. Assessing the extent of "conflict of use" in multipurpose tropical forest trees: A regional view. *Journal of Environmental Management* 130:40–47. https://doi.org/10.1016/j.jenvman.2013.08.044.

Ickowitz A, McMullin S, Dawson I, Sunderland T, Powell B, Nurhasan M, Jamnadass R, Meybeck A, Gitz V, et al. 2021. *Food Security and Nutrition*. FTA Highlights of a Decade 2011–2021 series. Highlight No.5. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008215.

Jalonen R, Hong LT, Lee SL, Loo J and Snook L. 2014. Integrating genetic factors into management of tropical Asian production forests: A review of current knowledge. *Forest Ecology and Management* 315:191–201. https://doi.org/10.1016/j.foreco.2013.12.011.

Jalonen R, Valette M, Boshier, Duminil J and Thomas E. 2018a. Forest and landscape restoration severely constrained by a lack of attention to the quantity and quality of tree seed: Insights from a global survey. *Conservation Letters* 11(4):e12424. https://doi.org/10.1111/conl.12424.

Jalonen R, Lamers H and Elias M. 2018b. *Guidelines for equitable and sustainable non-timber forest product management*. Rome: Bioversity International. https://www.bioversityinternational.org/fileadmin/user_upload/Guidelines_Marlene_2018.pdf.

Jaung W, Putzel L, Bull G, Guariguata MR and Sumaila UR. 2016. Estimating demand for certification of forest ecosystem services: A choice experiment with Forest Stewardship Council certificate holders. *Ecosystem Services* 22:193–201. https://doi.org/10.1016/j.ecoser.2016.10.016.

Kapos V, Kurz WA, Gardner T, Ferreira J, Guariguata MR, Koh LP, Mansourian S, Parrotta JA, Sasaki N, Schmitt CB, et al. 2012. Impacts of forest and land management on biodiversity and carbon. *In* Parrotta J, Wildburger C and Mansourian S. eds. *Understanding relationships between biodiversity, carbon, forests and people: The key to achieving REDD+ objectives.* A Global Assessment Report. IUFRO World Series Volume 31. Vienna: IUFRO, 53–82. https://www.fs.fed.us/research/publications/misc/63334_2012%20Parrotta%20et%20al%20IUFRO%20ws31_full%20volume.pdf.

Karambiri M, Elias M, Vinceti B and Grosse A. 2017. Exploring local knowledge and preferences for shea (*Vitellaria paradoxa*) ethnovarieties in Southwest Burkina Faso through a gender and ethnic lens. *Forests, Trees and Livelihoods* 26(1):13–28. https://doi.org/10.1080/14728028.2016.1236708.

Laurance WF, Sayer J and Cassman KG. 2013. Agricultural expansion and its impacts on tropical nature. *Trends in Ecology and Evolution* 29(2):107–116. https://doi.org/10.1016/j.tree.2013.12.001.

Lompo D, Vinceti B, Konrad H, Gaisberger H and Geburek T. 2018. Phylogeography of African locust bean (*Parkia biglobosa*) reveals genetic divergence and spatially structured populations in West and Central Africa. *Journal of Heredity* 109(7):811–821. https://doi.org/10.1093/jhered/esy047.

Lompo D, Vinceti B, Konrad H, Duminil J and Geburek T. 2020. Fine-scale spatial genetic structure, mating, and gene dispersal patterns in *Parkia biglobosa* populations with different levels of habitat fragmentation. *Applications in Plant Sciences* 107(7):1041–1053. https://doi.org/10.1002/ajb2.1504.

Loo J, Souvannavong O and Dawson I. eds. 2014. Seeing the trees as well as the forest: The importance of managing forest genetic resources. *Forest Ecology and Management* 333:1–98. Special Issue. https://www.sciencedirect.com/journal/forest-ecology-and-management/vol/333.

Lowe AJ and Cross HB. 2011. The application of DNA methods to timber tracking and origin verification. *IAWA Journal* 32(2):251–262. https://doi.org/10.1163/22941932-90000055.

Lowe AJ, Dormontt EE, Bowie MJ, Degen B, Gardner S, Thomas D, Clarke C, Rimbawanto A, Wiedenhoeft A, Yin Y and Sasaki N. 2016. Opportunities for improved transparency in the timber trade through scientific verification. *BioScience* 66(11):990–998. https://doi.org/10.1093/BIOSCI/BIW129.

Maas B, Thomas E, Ocampo-Ariza C, Vansynghel J, Steffan-Dewenter I and Tscharntke T. 2020. Transforming tropical agroforestry towards high socio-ecological standards. *Trends in Ecology and Evolution* 35:1049–1052. https://doi.org/10.1016/j.tree.2020.09.002.

Marchelli P, Thomas E, Azpilicueta MM, van Zonneveld M and Gallo L. 2017. Integrating genetics and suitability modelling to bolster climate change adaptation planning in Patagonian Nothofagus forests. *Tree Genetics and Genomes* 13(6). https://doi.org/10.1007/s11295-017-1201-5.

Maukonen P, Donn P and Snook LK. 2020. Addressing potential conflict using participatory mapping: Collection of forest foods from timber trees around industrial concessions in Cameroon. *Frontiers in Forests and Global Change* 3(June). https://doi.org/10.3389/ffgc.2020.00072.

Meijaard E, Wunder S, Guariguata MR and Sheil D. 2014. What scope for certifying forest ecosystem services? *Ecosystem Services* 7:160–166. https://doi.org/10.1016/j.ecoser.2013.12.008.

Miller MP. 2005. Alleles in space (AIS): Computer software for the joint analysis of interindividual spatial and genetic information. *Journal of Heredity* 96(6):722–724. https://doi.org/10.1093/jhered/esi119.

Millner N, Peñagaricano I, Fernandez M and Snook LK. 2020. The politics of participation: Negotiating relationships through community forestry in the Maya Biosphere Reserve, Guatemala. *World Development* 127:104743. https://doi.org/10.1016/j.worlddev.2019.104743.

Monthe FK, Hardy OJ, Doucet J-L, Loo J and Duminil J. 2017. Extensive seed and pollen dispersal and assortative mating in the rain forest tree *Entandrophragma cylindricum* (Meliaceae) inferred from indirect and direct analyses. *Molecular Ecology* 26(19):5279–5291. https://onlinelibrary.wiley.com/doi/abs/10.1111/mec.14241.

Muvatsi P, Kahindo J-M and Snook LK. 2018. Can the production of wild forest foods be sustained in timber concessions? Logging and the availability of edible caterpillars hosted by sapelli (*Entandrophragma cylindricum*) and tali (*Erythrophleum suaveolens*) trees in the Democratic Republic of Congo. *Forest Ecology and Management* 410:56–65. https://doi.org/10.1016/j.foreco.2017.12.028.

Muvatsi P, Snook LK, Geoffrey Morgan G and Kahindo J-M. 2021. The yield of edible caterpillars *Imbrasia oyemensis* and *Cirina forda* from timber trees logged on concessions in the Democratic Republic of the Congo: A contribution to managing tropical forests for multiple resources. *Trees, Forests and People* 4:100079. https://doi.org/10.1016/j.tfp.2021.100079.

Ngo Bieng MA, Finegan B and Sist P. eds. 2021. Active restoration of timber production and other ecosystem services in secondary and degraded forests. *Forest Ecology and Management* 493. Special Issue. https://www.sciencedirect.com/journal/forest-ecology-and-management/special-issue/108B75LGGCX.

Noutcheu, R., Snook, L. K., Tchatat, M., Taedoumg, H., Tchingsabe, O., & Tieguhong, J. C. 2016. Do logging concessions decrease the availability to villagers of foods from timber trees? A quantitative analysis for Moabi (*Baillonella toxisperma*), Sapelli (*Entandrophragma cylindricum*) and Tali (*Erythrophleum suaveolens*) in Cameroon. *Forest Ecology and Management*, 381, 279–288. https://doi.org/10.1016/j.foreco.2016.09.039.

Noutcheu R, Snook LK, Tchatat M, Taedoumg H, Tchingsabe O and Tieguhong JC. 2016. Do logging concessions decrease the availability to villagers of foods from timber trees? A quantitative analysis for Moabi (*Baillonella toxisperma*), Sapelli (*Entandrophragma cylindricum*) and Tali (*Erythrophleum suaveolens*) in Cameroon. *Forest Ecology and Management* 381:279–288. https://doi.org/10.1016/j.foreco.2016.09.039.

Pakull B, Ekué MRM, Bouka Dipelet UG, Doumenge C, McKey DB, Loumeto JJ, Opuni-Frimpong E, Yorou SN, Nacoulma BMY, Guelly KA, et al. 2019. Genetic diversity and differentiation among the species of African mahogany (*Khaya spp.*) based on a large SNP array. *Conservation Genetics* 20(5):1035–1044. https://doi.org/10.1007/s10592-019-01191-3.

Pakull B, Mader M, Kersten B, Ekué MRM, Bouka Dipelet UG, Paulini M, Bouda ZH-N and Degen B. 2016. Development of nuclear, chloroplast and mitochondrial SNP markers for Khaya sp. *Conservation Genetics Resources* 8:283–297. https://doi.org/10.1007/s12686-016-0557-4.
Pehou C, Djoudi H, Vinceti B and Elias M. 2020. Intersecting and dynamic gender rights to néré, a food tree species in Burkina Faso. *Journal of Rural Studies* 76:230–239. https://doi.org/10.1016/j.jrurstud.2020.02.011.

Piponiot C, Rödig E, Putz F, Rutishauser E, Sist P, Ascarrunz N, Blanc L, Derroire G, Descroix L, Guedes M, et al. 2019a. Can timber provision from Amazonian production forests be sustainable? *Environmental Research Letters* 14:064014. https://doi.org/10.1088/1748-9326/AB195E.

Piponiot C, Rutishauser E, Derroire G, Putz F, Sist P, West TA, Descroix L, Guedes M, Coronado EH, Kanashiro M, et al. 2019b. Optimal strategies for ecosystem services provision in Amazonian production forests. *Environmental Research Letters* 14:124090. https://doi/org/10.1088/1748-9326/ab5eb1.

Porcher V, Thomas E, Corvera Gomringer R and Bardales Lozano R. 2018. Fire- and distance-dependent recruitment of the Brazil nut in the Peruvian Amazon. *Forest Ecology and Management* 427:52–59. https://doi.org/10.1016/J.FORECO.2018.05.052.

Porter-Bolland L, Ellis E, Guariguata MR, Ruiz-Mallén I, Negrete-Yankelevich S and Reyes García V. 2012. Community managed forests and forest protected areas: an assessment of their conservation effectiveness across the tropics. *Forest Ecology and Management* 268:6–17. https://doi.org/10.1016/j.foreco.2011.05.034.

Ramirez LF and Belcher BM. 2020. Crossing the science-policy interface: Lessons from a research project on Brazil nut management in Peru. *Forest Policy and Economics* 114:101789. https://doi.org/10.1016/j.forpol.2018.07.018.

Ribeiro NS, Snook LK, Nunes de Carvalho Vaz IC and Alves T. 2019. Gathering honey from wild and traditional hives in the Miombo woodlands of the Niassa National Reserve, Mozambique: What are the impacts on tree populations? *Global Ecology and Conservation* 17:e00552. https://doi.org/10.1016/j.gecco.2019.e00552.

Rimlinger A, Avana ML, Awono A, Chakocha A, Gakwavu A, Lemoine T, Marie L, Mboujda F, Vigouroux Y, Johnson V, et al. 2021. Trees and their seed networks: The social dynamics of urban fruit trees and implications for genetic diversity. *PLoS ONE* 16(3):e0243017. https://doi.org/10.1371/journal.pone.0243017.

Rockwell CA, Guariguata MR, Menton M, Arroyo Quispe E, Quaedvlieg J, Warren-Thomas E, Fernandez Silva H, Jurado Rojas EE, Kohagura Arrunátegui JA, Meza Vega LA, et al. 2015. Nut production in Bertholletia excelsa across a logged forest mosaic: Implications for multiple forest use. *PLoS ONE* 10 (8):e0135464. https://doi.org/10.1371/journal.pone.0135464.

Rockwell CA, Guariguata MR, Menton M, Arroyo Quispe E, Warren-Thomas EM, Silva HF, Rojas E, Arrunátegui J, Vega LA, et al. 2017. Spatial distribution of *Bertholletia excelsa* in selectively logged forests of the Peruvian Amazon. *Journal of Tropical Ecology* 33:114–127. https://doi.org/10.1017/S0266467416000614.

Romero C, Guariguata MR, Putz FE, Sills EO, Lima GR, Papp L, Voigtlaender M and Vidal E. eds. 2015a. *The Context of Natural Forest Management and FSC Certification in Brazil*. Occasional Paper No. 148. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/005911.

Romero C, Putz FE, Guariguata MR, Sills EO, Maryudi A and Ruslandi. 2015b. *The Context of Natural Forest Management and FSC Certification in Indonesia*. Occasional Paper No. 126. Bogor, Indonesia: CIFOR. https://www.cifor.org/publications/pdf_files/OccPapers/OP-126.pdf.

Romero C, Sills EO, Guariguata MR, Cerutti, PO, Lescuyer G and Putz FE. 2017. Evaluation of the impacts of FSC certification on natural forest management in the tropics: A rigorous approach to assessment of a complex conservation intervention. *International Forestry Review* 19(S2):36–49. https://doi.org/10.1505/146554817822295902.

Rutishauser E, Hérault B, Baraloto C, Blanc L, Descroix L, Sotta ED, Ferreira J, Kanashiro M, Mazzei L, d'Oliveira MVN, et al. 2015. Rapid tree carbon stock recovery in managed Amazonian forests. *Current Biology* 25(18):R787–R788. https://doi.org/10.1016/j.cub.2015.07.034.

Sabogal C, Guariguata MR, Broadhead J, Lescuyer G, Savilaakso S, Essoungou JN and Sist P. 2013. Multiple-use forest management in the humid tropics: Opportunities and challenges for sustainable forest management. FAO Forestry Paper No. 173. Rome: FAO. https://www.cifor.org/knowledge/publication/4254.

Savilaakso S and Guariguata MR. 2017. Challenges for developing Forest Stewardship Council certification for ecosystem services: How to enhance local adoption? *Ecosystem Services* 28:55–66. https://doi.org/10.1016/j.ecoser.2017.10.001.

Savilaakso S, Garcia C, Garcia-Ulloa J, Ghazoul J, Groom M, Guariguata MR, Laumonier Y, Nasi R, Petrokofsky G, Snaddon J and Zrust M. 2014. Systematic review of effects on biodiversity from oil palm production. *Environmental Evidence* 3:4. http://www.environmentalevidencejournal.org/content/3/1/4.

SBSTTA (Subsidiary Body on Scientific, Technical and Technological Advice). 2021. Scientific and technical advice on updated goals and targets, and related indicators and baselines, of the updated Zero Draft of the Post-2020 Global Biodiversity Framework. Co-chairs' text on item 3. Twenty-fourth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA). https://www.cbd.int/meetings/SBSTTA-24

Schmitz N. ed. 2020. *Overview of current practices in data analysis for wood identification: A guide for the different timber tracking methods.* Global Timber Tracking Network. https://doi.org/10.13140/RG.2.2.21518.79689.

Schmitz N, Blanc-Jolivet C, Boner M, Cervera MT, Chavesta M, Cronn R, Degen B, Deklerck V, Diaz-Sala C, Dormontt E, et al. 2019. *General sampling guide for timber tracking.* Global Timber Tracking Network, GTTN Secretariat, European Forest Institute and Thuenen Institute. https://www.fs.usda.gov/treesearch/pubs/58501.

Shanley P, Pierce A, Laird S, Lopez C and Guariguata MR. 2016. From lifelines to livelihoods: Non-timber forest products into the 21st century. *In* Pancel L and Köhl M. eds. *Tropical forestry handbook*. Berlin: Springer-Verlag, 2–50. https://doi.org/10.1007/978-3-642-41554-8_209-1.

Sist P, Rutishauser E, Peña-Claros M, Shenkin A, Hérault B, Blanc L, Baraloto C, Baya F, Benedet F, Da Silva KE, et al. 2015. The Tropical managed Forests Observatory: A research network addressing the future of tropical logged forests. *Applied Vegetation Science* 18(1):171–174. https://doi.org/10.1111/avsc.12125.

Snook LK, Capitanio R and Tadeo-Noble A. 2021. Restoring commercial timber species through silvicultural patch clear-cuts and natural regeneration in Mexico's Maya Forest: Composition and growth 11 years after three treatments. *Forest Ecology and Management* 493:119206. https://doi.org/10.1016/J.FORECO.2021.119206.

Soldati MC, Fornes L, van Zonneveld M, Thomas E and Zelener N. 2013. An assessment of the genetic diversity of *Cedrela balansae* (*Meliaceae*) in northwest Argentina by means of combined used of SSR and AFLP molecular markers. *Biochemical Systematics and Ecology* 47:45–55. https://doi.org/10.1016/j.bse.2012.10.011.

Soliani C, Umaña F, Mondino V, Thomas E, Pastorino M, Gallo L and Marchelli P. 2017. Zonas genéticas de Lenga y Ñire en Argentina y su aplicación en la conservación y manejo de los recursos forestales. Bariloche, Argentina: INTA Ediciones. http://hdl.handle.net/20.500.12123/2340.

Somarriba E, López-Sampson A, Sepúlveda N, García E and Sinclair F. 2021. *Trees on Farms to Improve Livelihoods and the Environment*. FTA Highlights of a Decade 2011–2021 series. Highlight No.7. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008217.

Stoian D, Rodas A, Butler M, Monterroso I and Hodgdon B. 2019. *Forest Concessions in Petén, Guatemala: A systematic analysis of the socioeconomic performance of community enterprises in the Maya Biosphere Reserve*. Bogor, Indonesia: CIFOR. https://hdl.handle.net/10568/112677.

Taedoumg H, Maukonen P, Yobo CM, Iponga DM, Noutcheu R, Tieguhong JC and Snook L. 2018. Safeguarding villagers' access to foods from timber trees: Insights for policy from an inhabited logging concession in Gabon. *Global Ecology and Conservation* 15:e00436. https://doi.org/10.1016/j.gecco.2018.e00436.

Thomas E. 2017. Do multiple origins of domestication matter for Amazon Forest? Response to Levis et al. 2017. Persistent effects of pre-Columbian plant domestication on Amazonian forest composition. *Science* 355:925–931. Washington, DC: AAAS. https://hdl.handle.net/10568/80794.

Thomas E, Alcazar Caicedo C, Loo J and Kindt R. 2014a. The distribution of the Brazil nut (*Bertholletia excelsa*) through time: From range contraction in glacial refugia to anthropogenic climate change. Boletín del Museo Paraense Emílio Goeldi. *Ciencias Naturales* 9:267–291. https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/The_distribution_of_the_Brazil_nut__Bertholletia_excelsa__through_time_1824.pdf.

Thomas E, Alcazar Caicedo C, McMichael CH, Corvera R and Loo J. 2015. Uncovering spatial patterns in the natural and human history of Brazil nut (*Bertholletia excelsa*) across the Amazon Basin. *Journal of Biogeography* 42:1367–1382. https://doi.org/10.1111/jbi.12540.

Thomas E, Atkinson R and Kettle C. 2018. Fine-scale processes shape ecosystem service provision by an Amazonian hyperdominant tree species. *Scientific Reports* 8:11690. https://doi.org/10.1038/s41598-018-29886-6.

Thomas E, Jalonen R, Loo L, Boshier D, Gallo L, Cavers S, Bordács S, Smith P and Bozzano M. 2014b. Genetic considerations in ecosystem restoration using native tree species. *Forest Ecology and Management* 333:66–75. https://doi.org/10.1016/j.foreco.2014.07.015.

Thomas E, Jansen M, Chiriboga-Arroyo F, Wadt LH, Corvera Gomringer R, Atkinson RJ, Bonser S, Velasquez-Ramirez MG and Ladd B. 2021. Habitat quality differentiation and consequences for ecosystem service provision of an Amazonian hyperdominant tree species. *Frontiers in Plant Science* 12:621064. https://doi.org/10.3389/fpls.2021.621064.

Thomas E, Valdivia J, Alcázar C, Quaedvlieg J, Wadt LHO and Corvera R. 2017. NTFP harvesters as citizen scientists: Validating traditional and crowdsourced knowledge on seed production of Brazil nut trees in the Peruvian Amazon. *PLoS ONE* 12(8):e0183743. https://doi.org/10.1371/journal.pone.0183743.

Thomas E, van Zonneveld M, Loo J, Hodgkin T, Galluzzi G and van Etten J. 2012. Present spatial diversity patterns of Theobroma cacao L. in the Neotropics reflect genetic differentiation in Pleistocene refugia followed by human-influenced dispersal. *PLoS ONE* 7(10):e47676. https://doi.org/10.1371/journal.pone.0047676.

Thompson I, Guariguata MR, Okabe K, Bahamondez C, Nasi R, Heymell V and Sabogal C. 2013. An operational framework for defining and monitoring forest degradation. *Ecology and Society* 18(2):20. https://doi.org/10.5751/ES-05443-180220.

Thompson ID, Ferreira J, Gardner T, Guariguata MR, Koh LP, Okabe K, Pan Y, Schmitt CB, Tylianakis J, Barlow J, et al. 2012. Forest biodiversity, carbon and other ecosystem services: relationships and impacts of deforestation and forest degradation. *In* Parrotta J, Wildburger C and Mansourian S. eds. *Understanding relationships between biodiversity, carbon, forests and people: The key to achieving REDD+ objectives.* A Global Assessment Report. IUFRO World Series Volume 31. Vienna: International Union of Forest Research Organizations (IUFRO), 21–52. https://www.fs.usda.gov/treesearch/pubs/47868.

Thompson ID, Okabe K, Tylianakis JM, Kumar P, Brockerhoff EG, Schellhorn NA, Parrotta JA and Nasi R. 2011. Forest biodiversity and the delivery of ecosystem goods and services: translating science into policy. *BioScience* 61(12):972–981. https://doi.org/10.1525/bio.2011.61.12.7.

Thull D, Elias M and Fernandez M. 2015. *Bioversity International's Gender Research Fellowship Programme: Results and ways forward*. Impact Assessment Brief No. 17. Rome: Bioversity International. https://www.bioversityinternational.org/e-library/publications/detail/bioversity-internationals-gender-research-fellowship-programme-results-and-ways-forward.

Tieguhong JC and Ndoye O. 2007. *The impact of timber harvesting in forest concessions on the availability of non-wood forest products in the Congo Basin*. FAO Forest Harvesting Case-Study 23. Rome: FAO. http://www.fao.org/3/a1105e/a1105e.pdf.

Tieguhong JC, Snook L, Taedoumg H, Maukonen P, Tchatat M, Loo J, Tchingsabe O, Noutcheu R, Ponga DM, Kahindo JM, et al. 2017. Beyond timber: Balancing demands for tree resources between concessionaires and villagers. *International Forestry Review* 19(S2):14. https://hdl.handle.net/10568/90667.

van Etten J and Hijmans RJ. 2010. A geospatial modelling approach integrating archaeobotany and genetics to trace the origin and dispersal of domesticated plants. *PLoS One* 5(8):e12060. https://doi.org/10.1371/journal.pone.0012060.

van Zonneveld M, Dawson, I, Thomas E, Scheldeman X, van Etten J, Loo J and Hormaza JI. 2014. Application of molecular markers in spatial analysis to optimize in situ conservation of plant genetic resources. *In* Tuberosa R, Graner A and Frison E. eds. *Genomics of plant genetic resources*. Springer Science+Business Media Dordrecht, 67–91. https://doi.org/10.1007/978-94-007-7572-5_4.

van Zonneveld, Thomas E, Castañeda-Álvarez NP, Van Damme V, Alcazar C, Loo J and Scheldeman X. 2018a. Tree genetic resources at risk in South America: A spatial threat assessment to prioritize populations for conservation. *Diversity and Distributions* 24(6):718–729. https://doi.org/10.1111/ddi.12724.

van Zonneveld M, Maselli S, Alarcón M, Méndez M, Madrid Cruz J, Loo J, Snook L and Duminil J. 2018b. Estudio de la diversidad genética de la caoba (*Swietenia macrophylla King*) en las concesiones forestales comunitarias de la zona de usos múltiples de la Reserva de la Biósfera Maya, Guatemala. Report by Bioversity International.

Vidal A, Kumar C, Zinngrebe Y, Dobie P and Gassner. 2020. *Trees on Farms as a nature-based solution for biodiversity conservation in agricultural landscapes: Policy considerations and proposed indicators focused on trees on farms for an enhanced new Aichi Biodiversity Target 7*. ICRAF Policy Brief No 47. Nairobi: World Agroforestry. https://doi.org/10.13140/RG.2.2.14852.07045.

Villaseñor E, Porter-Bolland L, Escobar F, Guariguata MR and Moreno-Casasola P. 2016. Characteristics of participatory monitoring projects and their relationship to decision-making in biological resource management: A review. *Biodiversity and Conservation* 25(11):2001–2019. https://doi.org/10.1007/s10531-016-1184-9.

Vinceti B, Loo J, Gaisberger H, van Zonneveld M, Schueler S, Konrad H, Kadu C and Geburek T. 2013. Conservation priorities for Prunus africana defined with the aid of spatial analysis of genetic data and climatic variables. *PLoS ONE* 8(3):e59987. https://doi.org/10.1371/journal.pone.0059987.

Willem H, Ingram VJ and Guariguata MR. 2019. Brazil nut concessions in the Peruvian Amazon: Success or failure? *International Forestry Review* 21:254–265. https://doi.org/10.1505/146554819826606540.

The FTA Highlights series

1. Introduction: Ten Years of Forests, Trees and Agroforestry Research in Partnership for Sustainable Development
2. Tree Seed and Seedling Systems for Resilience and Productivity
3. **Conservation of Tree Biodiversity and Sustainable Forest Management**
4. Forest and Landscape Restoration
5. Food Security and Nutrition
6. Wild Meat
7. Trees on Farms to Improve Livelihoods and the Environment
8. Biomass, Bioenergy and Biomaterials
9. Improving Rural Livelihoods through Supporting Local Innovation at Scale
10. Sustainable Value Chains, Finance and Investment in Forestry and Tree Commodities
11. REDD+: Combating Climate Change with Forest Science
12. Adaptation to Climate Change with Forests, Trees and Agroforestry
13. Multifunctional Landscapes for Sustainable Development
14. Governing Forests, Trees and Agroforestry for Delivering on the SDGs
15. Advancing Gender Equality and Social Inclusion
16. Capacity Development
17. Monitoring, Evaluation, Learning and Impact Assessment
18. The Way Forward

This list represents the order of the volumes in the series and not the time sequence of publication.

FTA HIGHLIGHTS OF A DECADE
2011–2021

Conservation of Tree Biodiversity and Sustainable Forest Management

Over the last decade, the CGIAR Program on Forests, Trees and Agroforestry (FTA) has undertaken innovative multidisciplinary research on tree biodiversity and sustainable forests, which are central to the maintenance of resilient and productive forests, agroforestry and other tree-based systems. This publication presents key FTA outputs developed from 2011 to 2021.

DOI: 10.17528/cifor/008213

This is No.3 of the FTA Highlights of a Decade series.
Published volumes are indicated below with their illustration. Other volumes forthcoming.


1

2


3


4

5

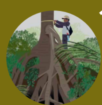

6

7

8

9

10


11

12

13

14


15

16

17

18

CGIAR
RESEARCH PROGRAM ON
Forests, Trees and Agroforestry