RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

FTA HIGHLIGHTS OF A DECADE
2011-2021

Adaptation to Climate Change with Forests, Trees and Agroforestry

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.

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FTA HIGHLIGHTS OF A DECADE
2011-2021

Adaptation to Climate Change with Forests, Trees and Agroforestry

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The final content remains the sole responsibility of the authors.

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List of acronyms

amsl	Above mean sea level
CPF	Collaborative Partnership on Forests
CWR	Crop wild relatives
EbA	Ecosystem-based adaptation
NAMA	Nationally Appropriate Mitigation Action
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
REDD+	Reducing Emissions from Deforestation and forest Degradation
SLR	Sea level rise
UNFCCC	United Nations Framework Convention on Climate Change
WEF	Water-energy-food

Executive summary

Forest, trees and agroforestry are crucial for adaptation to climate change in two ways that make the sector unique. First, forests and trees are already affected by climate change, and their resilience to climate impacts is a prerequisite for forest and ecosystem health and the provision of ecosystem services, including carbon sequestration. Second, forests, trees and agroforestry resources are vital to the livelihoods of forest dependent-people and the adaptation of other sectors, and to rural to urban communities overall, starting with agricultural systems and farming households, from local to continental scale, given the effects of trees and forests on local climate, the water cycle, and the provision of resources, products and ecosystem services, which are vital for many people. This highlight synthesizes the science and the engagement work done by the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) on the adaptation of forests, trees and agroforestry, and on their contribution to the adaptation of people and landscapes. FTA work includes the assessment of the impacts of climate change on forests, trees, and on the people and sectors that depend on them. It also increases the understanding of the roles of forests and trees as providers of ecosystem services, how these roles might be affected by climate change, and how forests and trees contribute to building the resilience of people and landscapes. FTA initiatives also include work on tree genetic resources and how they can be made available to smallholders, and on practices for adaptation and on ecosystem-based adaptation (EbA). This highlight also describes the contribution of FTA to national policies and to global narratives on climate action, including joint mitigation and adaptation approaches and nature-based solutions.

1. Introduction

Trees and forests are a vital part of any global effort to address climate change. Forests have often been mainly considered from a mitigation angle, through reforestation, afforestation and conservation, and through Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiatives. However, forests and trees are already affected by climate change, threatening their capacity to adapt to and mitigate further climate change and to support the adaptation of farming systems, other economic activities and ultimately, of the people who depend on these activities. Therefore, in order for people to continue to benefit from ecosystem services from forests, including the contribution of these services to mitigation, adaptation strategies must also reduce the negative impacts of climate change on forests themselves. These two aspects of adaptation can be summarized as "adaptation for forests" and "forests for adaptation" (Locatelli et al. 2010).

Climate change adaptation and mitigation have comprised one of the five components[1] of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA) since it was created in 2011, with clear links with the other

[1] In the first phase: Component 1: Smallholder production systems and markets; Component 2: Management and conservation of forest and tree resources; Component 3: Landscape management for environmental services, biodiversity conservation and livelihoods; Component 4: Climate change adaptation and mitigation; Component 5: Impacts of trade and investment on forests and people.
In the second phase: Flagship 1 Tree genetic resources to bridge production gaps and promote resilience; Flagship 2 Enhancing how trees and forests contribute to smallholder livelihoods; Flagship 3 Sustainable global value chains and investments for supporting forest conservation and equitable development; Flagship 4 Landscape dynamics, productivity and resilience; Flagship 5 Forests and climate change: Climate change mitigation and adaptation opportunities in forests, trees and agroforestry.

Mangrove canopy photo taken during a CIFOR study on above-ground and below-ground biomass in mangrove ecosystems in Kubu Raya, West Kalimantan, Indonesia.

Photo by Sigit Deni Sasmito/CIFOR

components (CIFOR 2013, 2016). The programme was ahead of the global reflection on climate change action that 10 years ago, especially regarding forests, was still very focused on mitigation. FTA gave equal importance to adaptation, focusing on the links between ecosystems and population vulnerability, and, as a result, on ecosystem-based adaptation (EbA). The proposal for the first phase of FTA (2011–16) noted the need to both mainstream adaptation into forest and tree management, and to mainstream forests and trees into wider adaptation strategies. FTA, since its inception, has also promoted the need to jointly consider mitigation and adaptation, as well as their relationships to other sustainable development objectives. These principles have guided FTA's research, its support to actors and policymaking, and its contributions to global debates.

FTA research encompasses ecosystems (i.e. the impacts of climate change on forests and trees), social systems (i.e. the vulnerability of local communities to climate change and political or economic change) and their relationships. Emphasis is placed on the interactions between ecological and social systems in order to understand how changes in ecosystems (e.g. due to climate change, land-use change or degradation) may affect people's vulnerability, and how the consequences of climate change on people may in turn affect ecosystems (e.g. through unsustainable use of forest products for coping with climate-related stress). Analyzing the dynamics of socioecological systems is crucial to the development of effective adaptation strategies that increase the resilience of both ecosystems and social systems.

This highlight synthesizes the work done by FTA on the adaptation of forests, trees and agroforestry to climate change and on their contribution to the adaptation of people and landscapes, covering the numerous areas of research that ground adaptation actions. Section 2 synthesizes FTA research related to impacts of climate change on forests, agroforestry and trees, and the people and communities that depend on them. Section 3 focuses on FTA research on the role of forests and trees for adaptation to climate change. Section 4 gathers FTA research findings and results on adaptation practices, while Section 5 focuses on FTA's work on some main elements of an enabling environment for adaptation and on how these elements can be combined in national, sectoral or landscape policies, plans and measures. Section 6 shows how FTA is using its research findings and projects' results to contribute to global narratives and inform climate change negotiations and policy making towards an integrated agenda. Section 7 draws some conclusions and proposals for moving forward.

2. Impacts of climate change

This section covers the work of FTA partners related to observed impacts of climate change on forests and trees, projected impacts from potential future climate on species of interest and on their geographical distribution; and impacts on forest-dependent communities, as studied by vulnerability assessments.

2.1 Impacts of climate change on trees and forest ecosystems

Several FTA studies looked at historic data for specific locations to determine the relationships between the evolution of the climate and that of forests, and to study what changes have occurred in the last decades, covering different types of forests and agroforestry systems in several regions.

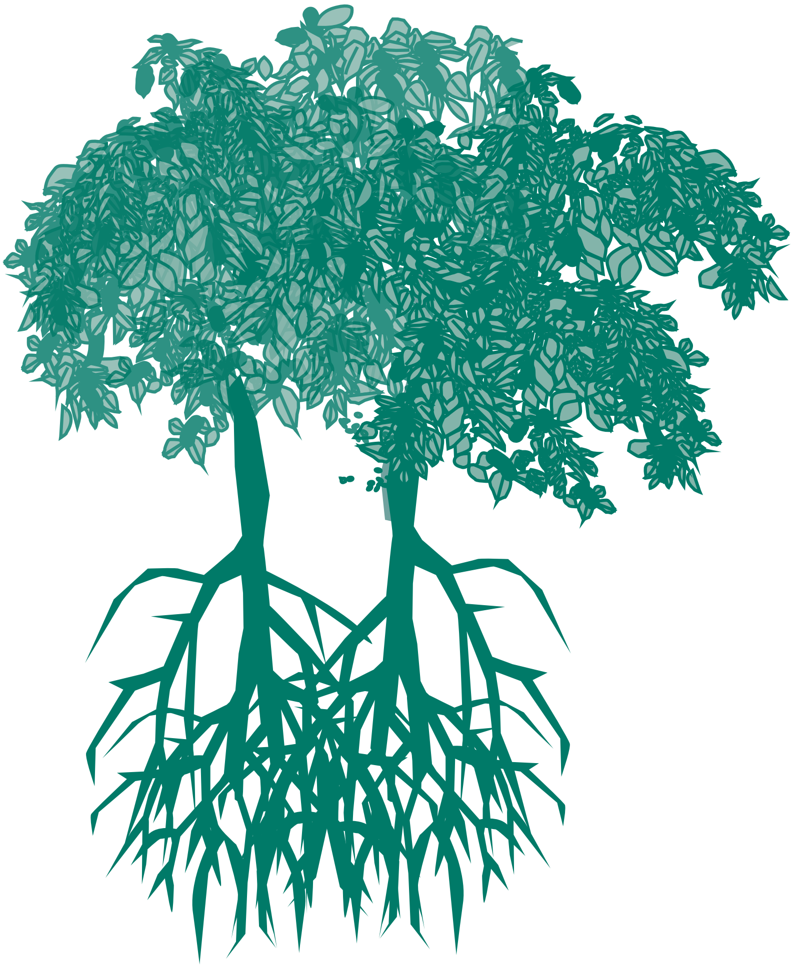
FTA scientists reviewed the literature on the impacts of drought in West Africa (Gautier et al. 2016). They reported that remote sensing had shown that annual amount of rainfall was positively correlated with the production of above-ground phytomass. They also noted that species richness decreased in the second half of the 20th century and that during the droughts of the 1970s and 1980s both tree density and plant cover decreased significantly. Non-climatic factors could also explain these trends. There was a consensus on the negative consequences of drought for the regeneration of tree species, but the general impacts of drought on the forest as a whole were still controversial.

Several FTA studies were conducted on threats to mangrove areas, including accelerated sea level rise (SLR) and increase in storm frequency and strength, Local fishermen understand the importance of mangroves by using ponds of brackish water for fish breeding at Pulau Dua Natural Reserve.

Photo by Aulia Erlangga/CIFOR

and the impacts of these changes on agriculture and coastal development. A study by Ward et al. (2016) reviewed the regional impacts of climate change on mangrove ecosystems. It found that sea level rise (SLR) was likely to influence mangroves in all regions, although local impacts were likely to vary. Changes in the frequency and intensity of storms were likely to have a greater impact in North and Central America, Asia, Australia and East Africa than in West Africa and South America. That review (ibid.) also noted the numerous gaps in geographical knowledge of climate change impacts, with some regions particularly understudied (e.g. Africa and the Middle East). Sasmito et al. (2016) found that many basin and fringe mangroves could cope with a low SLR scenario up to the year 2100, but in a high SLR scenario, estimated that the surface accretion rate could keep pace only up to 2055 in fringe mangroves and up to 2070 in basin mangroves. Mangrove ecosystems may be vulnerable to contemporary SLR in small island locations such as the Caribbean, East Africa and parts of the Indo-Pacific that are dominated by fringe mangroves and where surface elevation change cannot keep pace with even a low SLR scenario.

The evaluation of modifications in coastal communities driven by climate change is an important area for FTA and its partners. For example, Munji et al. (2013) investigated coastal changes in six communities in southwest Cameroon over the period 1965 to 2008. They reported changes, either through inland retreat or seaward shifts. Settlement submergence, house damage, and landscape deformation were the key impacts of flooding. They found that seasonal flooding improved access into the mangrove forests and hence promoted their exploitation for non-timber forest products (NTFPs), fuel wood and mangrove poles. They noted that the area of mangrove forests lost over the period has implications for the forest resource base, ecosystem stability, and livelihoods (Munji et al. 2014).



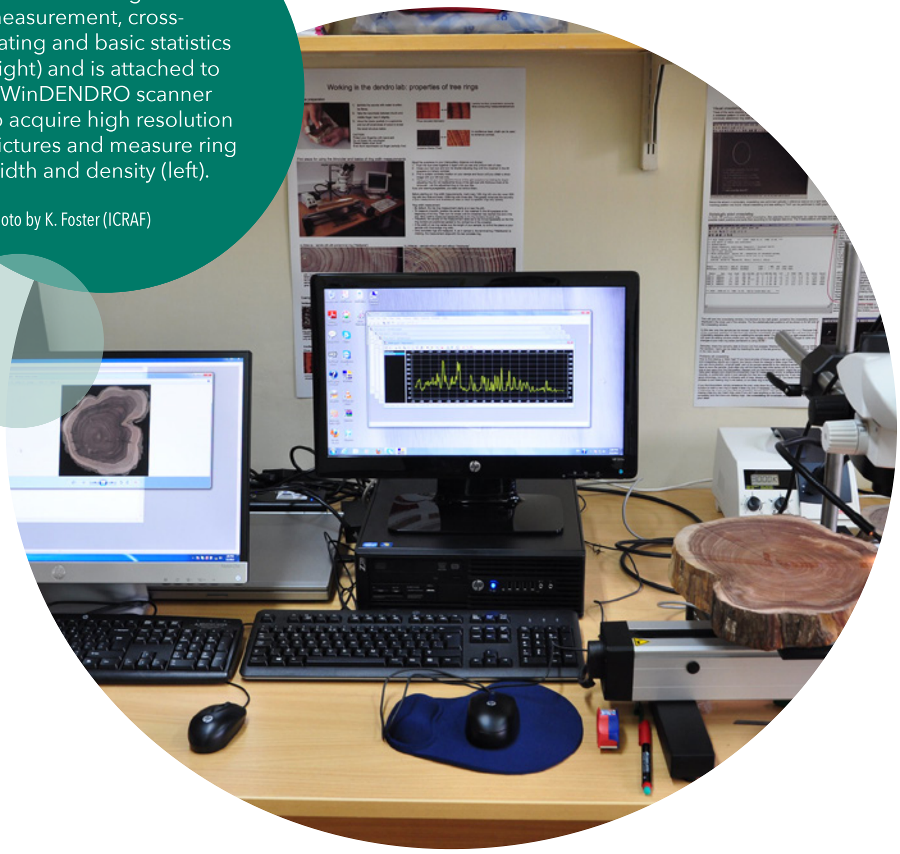
A brand-new dendrochronology laboratory facility at the World Agroforestry Centre's Nairobi headquarters will allow scientists and partners to carry out exciting new research in Africa. This Lintab TM is used to measure tree rings with high precision.

Photo by K. Foster (ICRAF)

The development of techniques for studying the relationships between trees and forest change and climate change is also fundamental to the work of FTA. Dendrochronology, which uses tree rings as a tool of retrospective bioindication, allows users to obtain information on the growth rates of trees, past climate conditions, and the dynamics and carbon sequestration rates of natural forest stands (Gebrekirstos et al. 2014). The carbon isotope composition of riparian trees can be used to reconstruct climate variability and assess ecological responses to climate change, as shown for the Volta Region of Ghana (Boakye et al. 2019). The periodicity of tree growth ring formation in seasonally flooded peatlands in Borneo, Indonesia, was studied by Worbes et al. (2017). They were able to show for the first time for Borneo peatlands that the existence of annual growth rings related to seasonal climate conditions. They could also demonstrate the formation of growth rings for trees planted in a non-flooded site. They concluded that the tree species that form annual rings, such as *Horsfieldia crassifolia*, can act as an indicator species, which allows the use of tree rings to estimate wood growth and

This Lintab TM uses TSAP software for ring width measurement, cross-dating and basic statistics (right) and is attached to a WinDENDRO scanner to acquire high resolution pictures and measure ring width and density (left).

Photo by K. Foster (ICRAF)



carbon sequestration rates. However, species react with different sensitivities to the modulation of flooded and dry periods. Some, like *Dyospros evena*, form rings during intervals of more than one year. This species specificity must be considered when using tree ring analysis for environmental and climate assessments.

FTA partners also carried out studies on specific tree products, such as Brazil nut (*Bertholletia excelsa*), which is one of the most important non-timber producing tree species in the Amazon forests. Thomas et al. (2014) studied how the distribution of the species has changed over time and would continue to do so in light of climate change.

FTA partners have contributed to studying the potential impacts of future climate change in a range of ecosystems and human production systems, using mathematical models that calculate the effects of different climate parameters on specific systems.

The changes in ecosystem hydrological services under future climate scenarios, and the impacts on per capita water availability for the main watersheds of Mesoamerica, were assessed by Imbach et al. (2015). They found a general decreasing trend in per capita water availability, with resource availability limitations mostly in the northern part of Central America, and in basins with a high population density (i.e. capital cities). The study updated previous water balance scenarios developed for the region- and watershed-scale indicators of potential stress in resource availability due to climate change.

To evaluate the possible consequences of climate change for local forest ecosystems, Hiltner et al. (2016) used a simulation model to identify the influence of precipitation variability on forest growth dynamics in a dry tropical montane forest in southeast Ethiopia. They found that both biomass and species richness increased with increased mean annual precipitation, with the effects stabilizing over time. Their results emphasize the impacts of the duration and frequency of water limitation on forest structure and growth.

2.2 Projected changes in area suitability and distribution of tree species

Fremout et al. (2020) quantified and compared the effects of future climate change and four current threats (fire, habitat conversion, overgrazing and overexploitation) on the 50 most common tree species of the tropical dry forests of northwestern Peru and southern Ecuador. They found that these species faced considerable threats, with an average of 46% of species' distribution ranges displaying high or very high vulnerability to at least one of the threats. They also provided an online, user-friendly tool to visualize both the vulnerability maps and the maps that indicated priority restoration and conservation actions.

Several studies modelled the potential impacts of climate change on tree species of interest in a specific area or specific production system.[2] Studies often used a combination of spatial approaches and expert knowledge and resulted in suitability maps.

This was the case in the species-specific spatially explicit approach of Gaisberger et al. (2017), which predicted threats to 16 important food tree species in Burkina Faso. They studied six key threats: overexploitation, overgrazing, fire, cotton production, mining and climate change. They

[2] Some of these studies were conducted using the BiodiversityR package that was expanded within FTA (Kindt 2018).

found that all 16 species faced serious threats, and predicted that climate change would be the most prevalent threat in the long term. Their study also proposed that tree populations that grow naturally in areas designated as highly threatened due to climate change should be used as seed sources for ex situ conservation and for planting in areas where suitable habitats are predicted.

The work in Central America by de Sousa et al. (2017) produced current and future suitability maps for 54 tree species that are commonly used for shade in agroforestry systems in the region. These included fruit trees, timber trees and species used to improve soil conditions. They modelled changes in suitability by 2050 under two different scenarios: one with a mean increase in temperature of 1.4°C; and another with a mean increase in temperature of 2.0°C. Their results showed that there would be a decrease in suitability area for 30 species, with losses of more than 30% of the current land area for important species and an increase in suitability for 11 species.

Areas suitable for coffee and cocoa production are going to shift, with consequences for current areas of production. De Sousa et al. (2019) assessed the impacts of climate change in Mesoamerica on habitat suitability for coffee, cocoa and 100 of the most common tree species associated with these crops in plantations. They showed that between 55% and 62% of current areas for coffee production would no longer be suitable by 2050. Cocoa production will probably lose between 13% and 17% of its current distribution range, especially in some lowland areas of 0–300 m above mean sea level (amsl), but cocoa could potentially replace 85% of the vulnerable coffee areas under climate change in moist regions at elevations below 400 m amsl and 53% at elevations between 400 m and 700 m amsl.

Similar efforts were carried out by Ranjitkar et al. (2016a) in Nepal, where they analyzed the current and future suitability of coffee and banana crops for various agroecological zones. They reported that by 2050 climatic conditions would improve for banana cultivation, but worsen for coffee.

In China's Yunnan Province, Ranjitkar et al. (2016b) projected future changes in distribution for 10 agroforestry tree species of commercial, ethnobotanical and restoration value. Their results showed potential areas of expansion for selected tree species. They suggested that west and southwest Yunnan could be important locations for tea and alder-based agroforestry, with the southern parts of Yunnan important for tea and hog plum (*Spondias mombin)*, and that the northern parts of Yunnan could support walnut-based agroforestry options.

Thomas et al. (2014) studied how the distribution of the Brazil nut (*Bertholletia excelsa*) could change in light of climate change. Future climate projections predict a positive future for Brazil nut in the Amazon region. Thomas et al. (2014) also included a number of recommendations to improve the species' conservation, use and management, both within and outside its current distribution area.

Brazil nut harvester Serapio Condori Daza, at work in Felicitas Ramirez Surco's concession, Madre de Dios, Peru.

Photo by Marco Simola/CIFOR

2.3 Increased fire risks

Climate change, especially where it leads to less precipitation or longer dry periods, is increasing the risks of fire, both in frequency and intensity (IPCC 2014a). FTA's work builds on the rich research of CIFOR on fire-related issues since 1993. Research on fire is particularly extensive in Indonesia, where CIFOR has its headquarters, including through various collaborations with the Indonesian authorities. It also extends to all tropical and equatorial regions, and, with support from the Government of Japan, even to boreal forests. Understanding and addressing the drivers of fire calls for interdisciplinary research across the natural and social sciences (Carmenta et al. 2011).

An important body of FTA research has analyzed the consequences of fires in terms of greenhouse gas emissions (Huijnen et al. 2016; Krisnawati et al. 2015; Gaveau et al. 2014) and air pollution (Marlier et al. 2015). Research on weather conditions and the resulting droughts that are favourable to fires is key to predicting levels of risks (Taufik et al. 2017; Hayasaka 2019; Jadmiko et al. 2017). Even in non-drought conditions higher temperatures play a role (Fernandes et al. 2017). These findings can inform tools for assessing the impacts of climate variability and change on wildfire regimes (Herawati et al. 2015). Weather conditions aggravate the risk of fires spreading and increase the extent of burned areas, but the direct cause of fire is generally linked to human activity, with the highest risk being when drought conditions and human causes are combined (Sloan et al. 2017).

Research on understanding and addressing these human causes has been particularly thorough in Indonesia. Addressing fire risks requires understanding the actors involved and the political economy of fire and its relationships to local interests (Purnomo et al. 2017, 2019). Such work is supported by analysis of perceptions and discourses and how they influence policymaking (Carmenta et al. 2017a, 2017b). Such improved understanding supports the design of public policies for strengthening and scaling up community-based fire prevention and initiatives of private corporations through good governance of palm oil value chains in Indonesia (Purnomo et al. 2018a, b). Through participatory action research, CIFOR researches, facilitates and mainstreams technical options for land improvement and agricultural development without using fire (CIFOR 2019a). These findings have contributed to a shift in Indonesian policies towards programmatic prevention measures to reduce fire risk and fire danger; assessment of their effectiveness and efficiency is ongoing (CIFOR 2019b).

An Unmanned Aerial Vehicle (UAV) flies over burning peat, Palangka Raya, Central Kalimantan.

Photo by Aulia Erlangga/CIFOR

There is also a significant body of FTA work on the human drivers of fire and fire management in the Amazon. Land-cover change interacts with drought severity to change fire regimes in Western Amazonia (Gutiérrez-Vélez 2014). Carmenta et al. (2016) showed that land reserve status had no discernible impact on fire density; fires were less prevalent in sustainable use reserves, but this was because of sparser human settlements and remoteness, rather than because of their status. A study in the eastern Amazon showed that shifting cultivation practices rarely implement the fire management measures required by legislation (Carmenta et al. 2013). On the other hand, management to address the impacts of landowner absenteeism, such as bolstering community fire control efforts in high-risk areas, could help minimize the size of fires when they do occur (Schwartz et al. 2015). Lessons learned from the experience of Indonesia in peatlands can support decision making in other countries; for instance, for Peruvian peatlands (Lilleskov et al. 2019).

The increase of fires emphasizes the critical importance of considering fire in REDD+ programmes (Barlow et al. 2012). The importance of including fire prevention and management as part of adaptation actions in order to preserve the mitigation potential of forests has led the Thematic Working Group (TWG) on Agriculture, Food Security and Land Use under the NDC

Partnership (NDC-P),[3] a country-led, peer-to-peer network for countries and international organizations, to make it a topic of work. An e-dialogue was facilitated by Mongolia and FTA, with the results presented in a side event of UNFCCC COP25 in Madrid.

The work of FTA researchers has also shown the importance of fire as a regulating factor in vegetation distribution patterns. A study has modelled current and future fire regimes in Ethiopia and their influence on natural vegetation (van Breugel et al. 2016). Results show a clear congruence between the distribution patterns of fire and major vegetation types. The study concludes that modifications of fire regimes need to be considered in order to predict the possible effects of climate change.

[3] https://ndcpartnership.org/.

3. Trees and forests for adaptation to climate change

The work of FTA on the contribution of forests and trees to ecosystem services and their relationships with social systems has also helped build a deeper understanding of forests and adaptation and how trees and forests will be even more important in a context of increased climate variability, to buffer shocks and increase livelihood resilience. Trees as providers of environmental services in multifunctional landscapes are vulnerable to climate change (Jamnadass et al. 2011). The contribution of forests and trees to resilience is related to the importance of biodiversity, at all scales, from gene pools to ecosystems. For more information about work on tree seeds and seedling systems conducted within FTA, see Highlight No. 2 in this series (Graudal et al. 2021). For more information about work on conservation of tree biodiversity and sustainable forest management conducted within FTA, see Highlight No. 3 in this series (Vinceti et al. 2021).

3.1 Ecosystem services for adaptation

The ecosystem products and services provided by forests and trees contribute to local climate regulation in agricultural areas (by supporting water provision and providing shade); regulate temperature in urban areas; protect coastal areas from storms and sea level rise; protect watersheds; and contribute to climate regulation at the regional and continental scale and support the resilience of farming systems and households (van Noordwijk et al. 2011;

Locatelli 2016). They can also contribute to people coping with stress and adapting to changes.

The social-ecological mechanisms and contextual factors that affect how a landscape and its ecosystem services contribute to human well-being were analyzed further by Fedele et al. (2017). They proposed a framework that expanded the ecosystem service cascade to focus more on socioeconomic interactions. They applied this framework to two case studies from Indonesia where local people use forests for timber and other products that help them overcome shortages in food and income during drought and floods. Ecosystem service cascades represent impact chains that can be used to develop a range of indicators to evaluate the impact of land-use changes on human well-being.

These approaches involve the application of integrated ecological, economic and social principles to the transition of smallholder farming systems towards greater resilience (Sinclair et al. 2019). Local agroecological knowledge needs to be mobilized for climate change adaptation, as shown in a study of tree-based options in northern Morocco (Kmoch et al. 2018). The capacity of ecosystems to support social adaptation has been recognized through emerging concepts of ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction and adaptation services, which are considered nature-based solutions (Lavorel et al. 2020). These concepts share the central theme that ecosystems — typically, when in good condition — can sustain people's efforts to adapt to environmental change by regulating risks from climate change and natural hazards, and by providing options for sustaining material and non-material benefits.

Nature's contributions to human well-being within social-ecological systems have been widely studied using multiple conceptual frameworks, yet there is a growing need to better articulate how both human and nature interactions contribute to quality of life. Bruley et al. (2021) propose the use of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework through a participatory approach that combines quality-of-life dimensions with an analysis of nature's contributions to people (NCP) coproduction; this provides an integrated view of social-ecological functioning.

3.2 The role of forests and trees in the water cycle

Trees and forests play a key role in Earth's water and carbon cycles and, therefore, in the regulation of climate. Forests and trees are linked to rainfall and water availability; they help move water locally and globally; they can cool temperatures locally and globally; and they regulate water supply. The interactions between forests and water and energy cycles provide the foundations for carbon storage, cooling terrestrial surfaces and distributing water resources (Ellison et al. 2017). The role of forests in the water cycle exerts itself at all scales, from the field to local and even regional and continental levels. This contribution to terrestrial water flows and water basins is well known, but a very important effect (through atmospheric fluxes of water) is taken into account much less frequently. FTA is promoting better recognition and integration of these roles in practices and policies.

Agroforestry is part of nature-based water management (van Noordwijk et al. 2019), and forest and landscape restoration has an important influence on water; both are of particular interest and importance to addressing climate change. For more information about work on forest and landscape restoration conducted within FTA, see Highlight No. 4 in this series (Guariguata et al. 2021). At a regional scale in the Andes, FTA reviewed the literature concerning the impacts of forestation on water supply and on hydrological regulation and mitigation of erosion and landslides. The study found that 20 years of tree plantation was sufficient to recover infiltration rates and sediment yield that were close to the levels of native forests, but did not recover organic matter levels (Bonnesoeur et al. 2019).

FTA researchers contributed to the Global Forest Expert Panels initiative of the Collaborative Partnership on Forests (CPF), Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities (Creed and van Noordwijk 2018). This resulted in an in-depth assessment of the current knowledge of the science of water and tree interactions at various levels; the current situation as a basis for a systems response to ongoing change; the determinants of change in the forest-water relationship, and global drivers of change; the effects of changing climate and quantity, quality and pattern of tree cover in forests on the way in which water becomes available for human use and ecosystem integrity; and projections regarding the relationship of forests and water in a changing world.

3.3 Vulnerability assessments of forests and forest-dependent communities

Assessing the vulnerability of forests and forest-dependent people enables practitioners to identify the risks posed by climate change and to develop adaptation options targeted to the most vulnerable areas and people. The vulnerability of a system is a function of its exposure to change, its sensitivity to such change, and its capacity to adapt to it. Vulnerability has many dimensions (environmental, economic, social, political and geographic) that interact in specific locations and contexts (Meybeck et al. 2019).

Building on FTA's work on ecosystems, social systems and their relationships, FTA researchers have actively participated in the development of methodologies and approaches to carry out vulnerability assessments at various levels.

Several FTA studies have sought to understand the drivers and heterogeneity of vulnerability. Certain populations and sectors are likely to be harder hit, particularly where systems based on natural resources support livelihoods (Paumgarten et al. 2020a). Widayati et al. (2021) assessed local perceptions of climate stressors, adaptation and vulnerability using focus group discussions in Ketapang, West Kalimantan, Indonesia. The main climatic stressors perceived by participants were extreme and unpredictable seasons, fires, and saltwater intrusion, all of which affect ecosystem services and agricultural production. The study (ibid.) notes the importance of considering existing local adaptation strategies and the opportunities for alternative actions within each local context when designing strategies to reduce vulnerability. In addition, vulnerability is perceived to be due to a bundle of simultaneous threats and to the incomplete responses to those threats, and cannot therefore be seen only as climate vulnerability. The study also shows that vulnerability assessments done at different scales and therefore involving different stakeholders produce both similar and complementary results. The latter for example related to the issue of water availability; the local perception is that climate change will mainly cause irregular water distribution throughout the year, but at the district level there is a concern that climate change and oil palm cultivation together will cause shortages of drinking water for nearby cities.

The climate analog approach identifies locations where the current climate is similar to projected conditions at a particular site of interest. The approach is often considered a valuable tool for projecting climate change impacts and planning for adaptation, especially for complex systems that cannot be modeled reliably. FTA researchers (Bos et al. 2015) have considered how the approach can be used in vulnerability assessments of agricultural systems. They conclude that it is meaningful only if climate is a dominant driver of the differences between the baseline and analog sites (ibid.). The climate analog approach requires more study to evaluate its suitability for adaptation planning and vulnerability assessment (Luedeling et al. 2013).

Another contribution of FTA has been in the development of decision support tools such as the Capacity-Strengthening Approach to Vulnerability Assessment (CaSAVA) and the Community-based Risk Screening Tool – Adaptation and Livelihoods (CRiSTAL). CaSAVA synthesizes local and scientific knowledge to identify existing livelihood assets (human, social, financial, physical and natural capital) and deficits at multiple landscape scales (Dewi et al. 2013). CRiSTAL Forests, a specialized version of CRiSTAL, aims to provide a logical, user-friendly process to help people better understand the links between climate-related risks, ecosystem services and livelihoods (IISD 2013). These tools have been applied in a range of contexts. Using a participatory approach across levels and genders, Djoudi et al. (2013) explored the vulnerability of livestock- and forest-based livelihoods to climate variability at the former Lake Faguibine, northern Mali, where drastic ecological, political and social changes have occurred. Their results showed that the distribution of vulnerability within livelihoods and groups shifted

Brazil nut fruits ready to be hacked open to extract the nuts.

Photo by Marco Simola/CIFOR

when the ecosystem evolved from a lake to a forest. New vulnerability drivers emerged, related to resource availability and access and power relations. In addition, political interests and psychological barriers hindered the local transition to an equitable and sustainable use of forest products and services.

Bele et al. (2013) worked with two forest communities, Lekié and Yokadouma, in Cameroon, exploring their vulnerability to climate change and their adaptation needs. They concluded that adverse effects were already being felt and exerting considerable stress. Drought, changing seasons, erratic rain patterns, heavy rainfall and strong winds were among the main climate-related disturbances perceived by people. Important social, ecological and economic processes over the past decades seemed to have shaped vulnerability, and some coping and adaptive strategies used before were now outdated. Also in Cameroon, a study of the vulnerability of villages in the Sangha Trinational landscape by Devisscher et al. (2013) created the basis for evaluating future vulnerability and identifying possible adaptation strategies that could be synergistic with mitigation efforts in the Congo region. The participatory assessment showed the dynamic nature of vulnerability, with important social, ecological and economic changes occurring over time, and where competition for productive land and forest resources has degraded forests around the villages and increased the fragility of local livelihoods. Villagers recognized a number of threats that affected their livelihoods, including intense drought, changing seasons and strong winds. Children and the elderly seemed to be the most vulnerable social groups in the villages.

Building on this work FTA collaborated with FAO to prepare a framework methodology that provides practical technical guidance for the assessment of vulnerability of forest and forest-dependent people in the context of climate change (Meybeck et al. 2019). The methodology describes the elements that should be considered for different time horizons, and outlines a structured approach for conducting vulnerability assessments, using various tools and methods. It pays particular attention to the relationships between the diverse causes of vulnerability and to the potential contributions of forests and trees to reducting the vulnerability of populations.

3.4 Vulnerability, adaptation and gender

Gender inequalities, common across most countries in the world, limit women's access to and control of resources, which can hinder their capacity to adapt to climate change. FTA research has investigated the causes and effects of gender inequalities in communities that depend on forests and agroforestry, in order to inform gender-sensitive decisions on adaptation in the sector.

In forest- and tree-based landscapes, the different cultural, domestic and economic roles that women and men play influence the sets of knowledge they develop (Bee and Sijapati Basnett 2016). In turn, this knowledge affects their varying adaptive capacities and their strategies to face a changing natural resource base (Djoudi and Brockhaus 2011).

Using a livelihood vulnerability index, Su et al. (2019) examined how gender affects climate vulnerability in five prefectures in Yunnan Province, southwest China. Their analysis revealed gender-specific differences in consumption patterns, lifestyles, access to and control of resources, decision-making, and power relations. These differences were in turn linked to levels of vulnerability to climate change. Vulnerability to climate change in female-headed households was most strongly linked to education, health and access to water. They also found that women were largely disenfranchised from local decision-making processes.

An FTA study of the heterogeneity of climate-related risks among rural households in two agroecological zones in South Africa identified distinct patterns of climate-related risks associated with households' experience of climate hazards, their degree of exposure and vulnerability, and the associated impacts (Paumgarten et al. 2020a). The study reported that the age and gender of the household head affected risks, indicating that responses to climate risks need to account for sociodemographic characteristics. It also provided lessons for the development of local climate change adaptation responses.

FTA research on mitigation/adaptation linkages in Burkina Faso (Djoudi and Brockhaus 2011) compared household adaptive capacities under various forest- and tree-based mitigation strategies. The findings showed that women's adaptive capacities, especially in terms of options for livelihood diversification and secure access rights, were significantly higher in parklands based on indigenous trees (*Vitellaria and Parkia*) and small-scale restored lands than in monoculture tree plantations. Northern Mali increasingly faces frequent and unpredictable droughts and other climatic variabilities. Research in the region (Djoudi and Brockhaus 2011; Brockhaus et al. 2013; Djoudi et al. 2013) has traced

the effects of these variabilities and the range of adaptation strategies being employed by local communities. One of the key findings is that the strategies adopted by women and men are being determined by gender norms and by ethnic and class relations (Djoudi et al. 2016).

3.5 Contribution of forests to increasing livelihood resilience

Forest and trees can play a major role at the global level in reducing climate change. For more information about work on REDD+ combating climate change with forest science conducted within FTA, see Highlight No. 11 in this series (Martius and Duchelle 2021). Forest and trees can also reduce human vulnerability by affecting the three components of vulnerability: exposure, sensitivity and adaptive capacity. For example, forests, trees and agroforestry contribute in multiple forms to food security and nutrition (Gitz et al. 2021), a role that — if appropriately leveraged and preserved — can increase the resilience of households to climate change. Forests contribute to increasing the resilience of forest-dependent people and local communities by providing additional sources of food and extra income from forest products and by providing ecosystem services, which can reduce some of the effects of climate change. For more information about work on food security and nutrition conducted within FTA, see Highlight No. 5 in this series (Ickowitz et al. 2021).

FTA research has shown the role of wild foods in sustaining rural livelihoods by providing food (and nutritional) security, either regularly or on an ad hoc basis (Paumgarten et al. 2018, 2020b), when exploring the nature and prevalence of unanticipated shocks, including natural hazards, experienced by households in two villages in Venda, South Africa. For more information about work on wild meat conducted within FTA, see Highlight No. 6 in this series (Nasi et al. 2021).

Fedele et al. (2016) studied two smallholder-dominated rural landscapes in Indonesia that were affected by floods, drought and disease outbreaks. Their results suggested that forests and trees are important in supporting community resilience and decreasing vulnerabilities to climate-related stresses and climate disasters in various ways, depending on the type of ecosystem service and the phase of the climate hazard (pre-disaster or recovery).

Fodder trees are an important feed source for livestock in a wide range of farming systems and can contribute to increasing the resilience of communities who depend on these systems. A review of the role of fodder trees and shrubs in Africa was carried out by Franzel et al. (2014). They concluded that in addition to contributing to improved meat and milk yields, most fodder trees are multipurpose, also providing products such as firewood and services such as control of soil erosion. Fodder trees can help farmers adapt to climate change since they are generally more resistant to drought than grass species are and they maintain high protein levels in livestock diet during the dry season. By improving livestock productivity, they also contribute to reducing the methane emissions per unit of output.

According to the findings of Koffi et al. (2017), landscape structure and crop and tree composition were important for rural households' food security and for people's ability to cope with crop food shortages in southwest Burkina Faso. Households with empty granaries developed differentiated adaptive strategies according to the composition of their specific landscape (woodlands, cropping areas, parkland matrix). Koffi et al. (2017) also noted that in parkland areas, the households that rely most on tree products could be constrained in their adaptive capacities if their rights to collect food are not recognized.

4. Adaptation practices, from field to landscape

FTA's main findings on some practices of interest for adaptation range from the field to the landscape level, and from diversification and agroforestry to ecosystem-based adaptation (EbA) and restoration. It is important to consider that, due to the wide range of climatic contexts, ecological systems and affected sectors, there is no universal recipe for designing and implementing adaptation. Unless development interventions consider existing local coping mechanisms and the sustainability of actions in the context of climate change, they can be ineffective or can even disrupt local adaptation efforts and waste opportunities for sustainable long-term development (Brockhaus et al. 2013).

4.1 Agroforestry for adaptation in the field and beyond

Farmers and farming communities in various countries are adopting measures that increase agricultural diversity in order to cope with climate change and its impacts. These climate-smart agriculture measures include cultivation of a larger number of species and overall farm diversification; introduction of better adapted crops and varieties and livestock animals and breeds; and integration of trees and shrubs into production systems (López-Noriega et al. 2017). For example, Brockhaus et al. (2013) found that at the former Lake Faguibine in northern Mali (where the ecosystem evolved from a lake to a forest), most local strategies to cope with drastic ecological, social and economic changes were based on diversification of income sources of households, including through partial and/or temporary migration within the livestock production system or complementary to it, with differences according to gender, age and ethnicity. By altering the microclimate, agroforestry practices can protect systems from shifting temperatures and precipitation variation, and from strong winds associated with storms (van Noordwijk et al. 2014; Sinclair et al. 2017). Agroforestry also supports the provision of ecosystem services that contribute to increasing systems' resilience to climate change (van Noordwijk 2019). In places where agroforestry is practised, there is greater habitat diversity to support organisms such as native pollinators and beneficial insects (Schoeneberger et al. 2012). Other co-benefits of agroforestry include enhanced nutrient cycling, integrated pest management, and increased resistance of trees to diseases, which additionally protect farm production. Agroforestry also has high potential to fulfil commitments set out in Nationally Determined Contributions (NDCs) and to reduce greenhouse gas emissions from agriculture (Duguma et al. 2017).

One of the many study sites chosen to obtain widely representative coverage of different geographical regions, forest types, forest tenure regimes, levels of poverty, infrastructure and market access, and population density. Cleared land, recently replanted in the Latin America region.

Photo by Amy E Duchelle/CIFOR

A recent article revisited early agroforestry research on agro climate, tree phenology and microclimate modifications induced by trees, and assessed the progress made and the remaining gaps (van Noordwijk et al. 2021). The review concluded that agroforestry can contribute to climate change adaptation in four ways: (1) reversal of negative trends in diverse tree cover as a generic portfolio risk management strategy; (2) targeted, strategic shifts in resource capture (e.g. light, water) to adjust to changing conditions (e.g. lower or more variable rainfall, higher temperatures); (3) vegetation-based influences on rainfall patterns; and/or (4) adaptive, tactical management of tree-crop interactions based on weather forecasts for the (next) growing season (van Noordwijk et al. 2021, 17).

Agroforestry is also a type of intensification and diversification strategy — by integrating tree products that may be consumed or sold, such as fruit, nuts, timber, firewood and fodder, and through which trees can sustainably intensify smallholder farming systems through interactions with other components (Sinclair et al. 2017). McMullin et al. (2021) looked at which interventions are most successful for diversifying farming systems with orphan crops, including orphan tree crops. Both production-oriented (e.g. seed supply) and consumption-oriented (e.g. nutrition education) interventions have been shown to be important, but coordinated testing of both types of intervention together was rare, representing a current gap in knowledge. Thorlakson and Neufeldt (2012) studied how agroforestry can help subsistence farmers reduce their vulnerability to climate change in western Kenya. They found that agroforestry improves households' general standard of living through enhancement of productivity, increase in off-farm incomes, and providing coping strategies to help households during exposure to climate-related hazards. Agroforestry also provides substantial labour savings to women by reducing the time spent on fuelwood collection.

In East Africa, where most parts of the region would be expected to become drier in the next decades, Dawson et al. (2014) discussed issues relevant to agroforestry interventions to support livestock keeping, which included the planting of mostly exotic fodder trees. They concluded that wider cultivation and improved management of fodder trees provide adaptation and mitigation opportunities in the region, but that these opportunities are generally not well quantified. There are clear opportunities for increasing productivity and resilience through diversification, genetic improvement, improved farm-input delivery and better modelling of future scenarios.

A key role of trees in agroforestry is to provide shade to underlying or intercropped plants, but such shading needs to be optimal (and must consider

Kouanda Issiaka, 65 years old, is watering his mango plantation for extra income for his family, Boromo, Burkina Faso.

Photo by Ollivier Girard/CIFOR

location and time of day). The role of trees in livestock farming systems for multiple objectives, such as fodder and shade, is further discussed in Highlight No.7 in this series (Somarriba et al. 2021). The FTA innovation ShadeMotion (Somarriba et al. 2020, 2021), interactive web-based software, was designed to quickly explore various tree-planting configurations and combinations of species to help farmers and extension staff decide on the best agroforestry designs for specific contexts. It has proven to be a handy tool for teaching agroforestry at all levels, from farmer field schools to universities. It can also support the design of measures and systems to adapt to climate change through planting shade trees. Changes in the environment due to the adoption of agroforestry practices for adapting to climate change may also influence human health. In sub-Saharan Africa, Rosenstock et al. (2019) concluded that agroforestry is likely to improve a diverse range of pressing health concerns by increasing food and nutrition security through improved water management, nutrient cycling, biodiversity and economic stability.

FTA's research on agroforestry and agroecology shows that complex and diverse systems that include trees are more resilient to climate variability and change. For instance, the persistence of agriculture systems in the Sahel and the Mediterranean drylands is largely grounded in the buffering function of trees, including soil protection (Bayala et al. 2019). FTA was commissioned to write a background paper for the Global Commission on Adaptation (GCA) on the contribution of agroecological approaches to building climate resilient agriculture (Sinclair et al. 2019). This resulted in agroecological practices becoming an explicit feature of the overall GCA report.

4.2 Adaptation of tree crop plantations

FTA researchers have conducted extensive and diverse research on climate change impacts and on potential adaptation measures for coffee and cacao. For instance, FTA explored the impacts of climate change on the coffee value chain in northeast Peru and the potential strategies of actors (Robiglio et al. 2017). The study estimated that between 13% and 40% of the area where coffee is currently cultivated will not continue to be suitable and that alternatives to coffee cultivation will need to be developed in these areas. The study also estimated that respectively 85% of producers will need to implement incremental adaptation measures and 45% will need to implement systemic adaptation measures (ibid.).

De Sousa et al. (2019) considered potential adaptation measures for coffee and cocoa in Mesoamerica. They show that changing the composition of tree species in agroforestry systems may be the best approach to adapting most of the coffee and cocoa production areas, and that cocoa could potentially become an alternative in most of the coffee-vulnerable areas. An illustrated manual for cocoa farmers was developed by CATIE to help farmers optimize their shade canopy given their specific context and production system through a five-step diagnosis method (Somarriba-Chavez et al. 2011; Somarriba 2018). The Shade Tree Advice tool is based on the collection of local knowledge. It was developed for the coffee and cocoa systems of Uganda and Ghana to inform and facilitate choices of shade trees according to local conditions and farmer preferences, with the aim of maximizing the provision of ecosystem services. It is now being extended to other farming systems and geographical areas (van der Wolf et al. 2019).

FTA work on the adaptation of natural rubber builds on its work on rubber agroforestry systems (Penot et al. 2017) and on the sustainability of rubber systems (Kenney-Lazar et al. 2018; Gitz et al. 2020). In 2020 FTA — with the International Rubber Study Group, the International Rubber Research and Development Board, and the French Agricultural Research Centre for International Development — organized a digital workshop on natural rubber systems and climate change (Pinizzotto et al. 2021a). The purpose of the workshop was to review the available knowledge in order to identify knowledge gaps and develop recommendations for action. The workshop showed some of the main impacts of climate change. In some regions longer dry seasons and more variable precipitation threaten the survival of young plants. Abnormal rains can also disrupt rubber tapping. The distribution of pests and diseases is also changing, with more severe impacts. All these changes could drive a shift in climatically favourable areas. Three types of adaptation measures can be mobilized: management practices (such as partial irrigation of young plants or use of rain guards, and monitoring and early intervention on pests); breeding; and medium-term planning of plantation renewals, for the subsequent rotation. FTA and its partners are now bringing these findings to the attention of decision makers, with two papers on adaptation and on mitigation for the XV World Forestry Congress in Seoul; and a policy brief calling for better integration of the rubber sector in the implementation of climate change-related policies and actions (Pinizzotto et al. 2021b).

Rubber tapping can be severely affected by longer dry seasons or abnormal precipitation.

Photo by Icaro Cooke Vieira/CIFOR

A farmer picks red coffee cherries in the plantation in Tri Budi Syukur village, West Lampung regency, Lampung province, Indonesia.

Photo by Ulet Ifansasti/CIFOR

4.3 Adaptation in the landscape: towards ecosystem-based adaptation (EbA)

It is at the landscape level that the various contributions of forests and trees to the resilience of ecosystems, human settlements and livelihoods to disasters and to climate change can best be assessed and improved. Drawing on a large range of case studies, predominantly from the dry, humid and subhumid tropics across the world, the ICRAF book *Climate-Smart Landscapes: Multifunctionality In Practice* provides directly applicable knowledge while also noting the key issues that require further work (Minang et al. 2015).

Forest and land restoration is covered in Highlight 4 in this series (Guariguata et al. 2021). In general, land and forest restoration, as part of the restoration of ecosystem services and ecosystem resilience, is essential to climate change adaptation and to reducing the vulnerability of forest-dependent communities (Pramova et al. 2012b). At the same time, planning for restoration needs to take future climate into account (Pramova et al. 2019). In this context, the suitability studies mentioned above are particularly important, given that trees' lifetimes can span decades or even centuries. Forest- and tree-based restoration interventions require knowledge of the suitability and origin of seed sources and planting material. In light of accelerating climate change, it may be prudent to supplement local seed provenances with climate-matched provenances, where seeds originate from sites whose current climate conditions are similar to those anticipated in the future at the planting site. Restoration practitioners usually do not have access to the necessary information to implement such climate-smart seed sourcing.

Fremout et al. (2021) combined genetic data with spatial environmental data for 11 socioeconomically important tree species of the tropical dry forests of Colombia to inform the delineation of dynamic seed zones[4] for the restoration of this highly threatened ecosystem. They proposed a set of 36 provisional seed zones that are applicable across species and dynamic under climate change, based on the clustering of environmental data and geographical coordinates.

Ecosystem-based adaptation (EbA) is being promoted by FTA as a key approach for conserving ecosystem services and reducing vulnerability. EbA encompasses adaptation strategies that explicitly value the roles of ecosystems (and ecosystem services) in adaptation to climate change across sectors and scales (Pramova et al. 2012, 2020). Therefore, forests and trees are central components of EbA.

In a study to evaluate the contributions of EbA practices to the water-energy-food (WEF) nexus balance, Muthee et al. (2021) designed practical pathways and identified barriers to achieving this balance. They analyzed data collected from 50 community forests spread across three regions in The Gambia. They established 14 priority EbA practices and categorized them into four major groups (forest and tree development, climate-smart farming, nature-based solutions, and water resource development) based on their application similarities. Duguma et al. (2020) looked at EbA practices based on community preferences, gender choices, values and incentives, and potential enablers and barriers, and also reviewed policy and institutional frameworks. They studied the importance of the perceived benefits of various EbA practices. The project restored 1,861 ha of degraded land: 1,400 ha of protected areas, 400 ha of agroforestry farmlands and 61 ha of degraded school lands. It was part of a broader intervention, with data collection in additional communities, capacity building, and curriculum development support provided to the University of the Gambia. It also helped to build strong political will and societal ownership, as shown by the adoption of the tree cover resolution of Banjul, with the participation of three ministers and 100 delegates.

[4] A seed zone is an area within which plant materials can be transferred with little risk of being poorly adapted to their new location.

New national planning initiatives, such as national adaptation plans (NAPs), offer opportunities for integrated approaches. As an example, Fiji's NAP recommends prioritizing ecosystem-based adaptation; for instance, to reduce shoreline erosion or provide storm protection.

5. Enabling adaptation

The contribution of forests and trees to both adaptation and mitigation is linked to, and depends on, policies in numerous sectors: in the forest sector of course, but also in land planning, water management, energy, transport, urban and peri-urban development and agriculture.

5.1 Genetic resources: conservation, characterization and breeding for adaptation-relevant traits

An important research area of FTA deals with tree genetic resources. Evaluating, conserving, testing and using genetic diversity is vital for ensuring the future production of goods and environmental services from trees, especially under climate change (Alfaro et al. 2014). For more information about work on tree seeds and seedling systems conducted within FTA, see Highlight No. 2 in this series (Graudal et al. 2021).

FTA scientists have analyzed the state of knowledge of the impacts of climate change on tree genetic resources and the implications for actions in a smallholder setting (Dawson et al. 2011). The study proposed facilitating translocation of environmentally-matched germplasm across appropriate geographic scales; increasing the effective population sizes of tree stands through

the promotion of pollinators and other farm management interventions; and using of a wider range of "plastic" species and populations for planting. The barriers identified by the study at the time (ibid.), and that remain current, include limitations in the international exchange of tree seeds and seedlings, and the absence of well-functioning delivery systems.

New and orphan crops are novel or traditional crops that — although important to consumers and farmers — are neglected by mainstream research and businesses because they are not well known or are perceived as underperforming. FTA research has explored which traits and features of tree orphan crops need to be improved genetically to support their integration into farming systems, in order to diversify and to increase resilience in the context of climate change. The key traits were found to be those that allow effective integration into existing production system niches, those related to the increased processability of tree products, and those related to labour costs (Dawson et al. 2018, 2019).

Studying the diversity and distribution of crop wild relatives (CWRs) could contribute to developing conservation strategies for future climate conditions. Gonzalez-Orozco et al. (2020) aimed to improve the collection of cacao CWRs in Colombia, where threats to cacao cultivation include diseases, extreme climate variability and change, and deforestation. They mapped biogeographic patterns of species diversity and endemism, and mapped cacao CWR climate suitability. They also attempted to understand the spatial biodiversity of cacao CWR at the national and regional levels. They proposed germplasm collection and habitat protection strategies for cacao CWRs in Colombia.

As the current rate of climate change is typically more rapid than natural tree migration rates, tree seed sourcing should encompass methods of human-assisted geneflow and assisted migration. The AlleleShift R package (Kindt 2021), developed under FTA, predicts how climate change would modify the frequencies of alleles that are associated with adaptive traits, such as to conditions of drought or extreme temperatures. AlleleShift R, used in tandem with outcomes of species suitability modelling as described above (ibid.), can inform the design of tree seed sourcing programmes by selecting specimens that are better adapted or more suitable to future climates, making sure that source populations have the required genomic composition.

A sustainable supply of diverse high-quality tree germplasm (seeds, cuttings and other propagules) is fundamental to the success of tree-based systems (Lillesø et al. 2011; Lillesø et al. 2018). Providing the means for this supply will be fundamental for adapting ecosystems to climate change. In 2011 Dawson et al. explored how tree seed systems needed to change to address climate change concerns (Dawson et al. 2011). They indicated that at a macro scale better networking was required between national tree seed centres to disperse seed to appropriate planting environments. This effort would then link up with more local networked suppliers. They estimated that the rate of change in some regions would be so large that this macro intervention was likely to be needed (Dawson et al. 2011). Those recommendations are still valid to date, as are those of Nyoka et al. (2014), who reviewed tree seed and seedling supply systems in sub-Saharan Africa, Asia and Latin America. They found that across these regions some systems did not efficiently meet farmers' demands and environmental expectations in terms of productivity and species and genetic diversity. Quality control systems for germplasm were rare, and appreciation of the value of tree germplasm of high genetic quality was low. To enhance the use of high-quality germplasm, there is a need to demonstrate the value of using it and to raise awareness of germplasm quality among farmers and policymakers. For those wanting to know more, the work of FTA on seed and seedling systems is further developed in Highlight 2 in this series (Graudal et al. 2021).

Prosper Sawadogo is a 63-year-old farmer. His knowledge of agricultural production has allowed him to feed his family for the whole year. He has completed several training sessions with the environmental technical services, Birou village, Burkina Faso.

Photo by Ollivier Girard/CIFOR

5.2 Institutional frameworks

FTA has contributed to the understanding of the institutional settings that enable adaptation, in various contexts and at various scales. The relationship between governance and adaptive capacity at the local scale was explored in the work of Brockhaus et al. (2012). Using a comparative analysis of case studies undertaken earlier in Burkina Faso and Mali, they characterized and assessed the effects of a set of factors and indicators related to two core variables: institutional flexibility; and understanding and perceptions (both individual and organizational). They found that perceptions of climate change and of potential adaptation are influenced to a high degree by specific narratives and discourses; for instance, on mobility versus sedentarization or on the potential of technology fixes. This limits the capacity to explore potential solutions and can impede action. Revealing the ideological character of discourses can help enable adaptive capacity, as it reduces the influence of the actors who employ these discourses for their own interests. Most interviewees across all levels also reported horizontal and vertical coordination of adaptation activities as a key challenge.

Locatelli et al. (2020) looked at information flows and collaborations among 76 key actors in climate change policy in Peru. They identified actors who could connect adaptation and mitigation subdomains. Their results showed a concentration of influence in national government actors, particularly in the mitigation subdomain, and the isolation of actor groups that matter for policy implementation, such as the private sector and subnational actors. They also noted the predominance of mitigation over adaptation and the existence of actors who are well positioned to broker relationships between the subdomains.

The concept of an integrated landscape approach to land-use management has received growing interest in the last decade in the scientific literature as a way to reconcile multiple — and often competing — objectives: nature conservation, food production, poverty alleviation, climate change mitigation, sustainable management of natural resources, and sustainable development. FTA researchers have been particularly active in this area (Sayer et al. 2013; Reed et al. 2016; Minang et al. 2015). From a forest and forestry perspective, a landscape approach enables a better understanding of the relationship between forests and other land uses within the landscape. Landscape-scale analysis enhances understanding of the contributions of forests and trees to the broader landscape via ecosystem goods and services (HLPE 2017). Such analysis can help identify the various drivers of tree-cover changes, which have been described along a forest transition curve (CIFOR

An aerial view of southwest Mau Forest in Kenya.

Photo by Patrick Sheperd/CIFOR

2013), and can help recognize the implications of maintaining, restoring or depleting forest cover. A landscape approach thus stimulates a more holistic consideration of forests and forestry as integral components of the sustainable development of a specific area. FTA adopts a broad perspective, characterizing landscape approaches in the following way: "As it relates to agriculture, forestry and other land uses, and to the livelihoods they sustain, the landscape approach transcends traditional management and governance boundaries, seeking to provide tools and concepts to identify, understand and address a complex set of environmental, social and political challenges, and to enable evidence-based and inclusive prioritization, decision-making and implementation" (FTA n.d., 1). Climate change creates additional constraints to landscape approaches, both directly (through reduced production potential) and indirectly (through additional demands for bioenergy and carbon sequestration and to support the adaptation of human settlements, activities and livelihoods). At the same time climate change strategies and plans can create new opportunities to develop and sustain landscape approaches that fully integrate forests and trees. There is increasing recognition of the need to consider landscapes as a level of implementation for climate mitigation policies (Bernard et al. 2013), with examples of jurisdictional approaches to REDD+ in particular (Boyd et al. 2018). Many national adaptation plans either explicitly integrate subnational planning or integrate the possibility of having actions that are subnational (Meybeck et al. 2020).

The capacity and willingness of actors to invest in adaptation depend on multiple factors, many of which in turn depend on legal and institutional national frameworks. Ownership, tenure and access rights affect incentives for the long-term and sustainable management of forests and trees and the resources and ecosystem services they provide. Of particular importance are the duration, stability and protection of tenure and use rights against encroachment by other actors, as well as good governance. For more information about work on governing forests, agroforestry and trees for delivering on the SDGs conducted within FTA, see Highlight No. 14 in this series (Minang et al. 2021a). A survey of forest managers almost a decade ago showed that even though they perceived natural and planted forests as being at risk from climate change effects, they were reluctant to invest in adaptation, given the other major drivers of forest loss and degradation (Guariguata et al. 2012).

Agroforestry is itself an adaptation strategy (Sinclair et al. 2017), but adoption of agroforestry often encounters multiple administrative barriers. In 2014, India, with technical support from FTA and national research organizations, was the first country in the world to adopt a national agroforestry policy; this removed several bottlenecks from the policies of agriculture, forestry, water and environment, and promoted an integrated land-use system. With the support of the Climate Technology Centre and Network, together with the World Agroforestry Centre (ICRAF), and in line with its Nationally Determined Contribution (NDC), Nepal developed its agroforestry policy, published in 2019. The Association of Southeast Asian Nations (ASEAN) has developed agroforestry guidelines, and several countries in Asia, Africa and the Caribbean are working on their policies/strategies.

National adaptation strategies and plans, because they are economy wide, provide considerable opportunities to establish the enabling environment for the adaptation of forests and trees and to strengthen their contribution to the adaptation of other sectors. FTA is supporting countries in these efforts. Pramova et al. (2012a) assessed the extent to which ecosystem services had been considered in National Adaptation Programmes of Action (NAPAs), established in 2001 for least developed countries to address their most urgent needs. The importance of ecosystem services was acknowledged in more than 50% of the NAPAs, with forests and trees cited most often. Approximately 22% of the proposed projects in the NAPAs included activities related to ecosystem services. The study (ibid.) concludes by encouraging users to adopt a broader perspective towards ecosystem-based adaptation.

All developing countries are now preparing a National Adaptation Plan (NAP). The NAP process was established under the United Nations Framework Convention on Climate Change (UNFCCC) for developing countries to identify medium- and long-term adaptation needs and address those needs. The process offers new opportunities to better integrate forests, trees and agroforestry in national adaptation policies and measures. FTA, with FAO, has prepared the co-publication Addressing Forestry and Agroforestry in National Adaptation Plans: Supplementary guidelines (Meybeck et al. 2020), which provides technical guidance on integrating forests, agroforestry and trees in the formulation and implementation of NAPs. It is grounded in an analysis of previously published NAPs. Given that the process is generally conducted by sectors that reflect the organization in line ministries, the publication provides recommendations on interacting with other sectors. The publication is available in English,[5] French[6] and Spanish[7] and soon will be available in Arabic. It has been actively promoted during climate change events, and served as the basis for capacity building as part of a training session organized by the Asian Forest Cooperation Organization.

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[5] https://doi.org/10.4060/cb1203en.

[6] Intégration de la foresterie et de l’agroforesterie dans les plans d’adaptation nationaux - Directives complémentaires. https://doi.org/10.4060/cb1203fr.

[7] Cómo abordar la silvicultura y la agroforestería en los Planes Nacionales de Adaptación: Directrices complementarias. https://doi.org/10.4060/cb1203es.

6. Contribution to global narratives

FTA is using its research findings in various regions to contribute to global narratives and inform climate change negotiations and policymaking. It has contributed to major policy-relevant scientific reports, including IPCC and IUFRO reports as well as those of the Climate Adaptation Commission.

It is noteworthy that FTA was recognized for having brought a gender perspective to global policy processes related to climate change; FTA was invited to provide capacity building on gender issues for UNFCCC. Following the organization by FTA, with the Center for People and Forests (RECOFTC), of a side event on gender and climate finance at COP25, FTA was invited to provide capacity building on gender mainstreaming to the Governors' Climate & Forests Task Force.[8] FTA's research on gender and climate finance in Indonesia (Atmadja et al. 2020; Liswanti et al. 2020) was also shared at the Asia Pacific Ministerial Conference on the Beijing+25 Review (2019).[9]

6.1 Synergies and trade-offs between adaptation and mitigation

Since its inception, FTA has provided, through its climate adaptation and mitigation programme, evidence of the potential of forests, agroforestry and

[8] https://forestsnews.cifor.org/68417/mobilizing-to-address-gender-in-forests-and-climate-change-actions?fnl=en. The task force secretariat is located in Boulder, Colorado.
[9] https://www.cifor.org/publications/pdf_files/AReports/CRP/ARCRP2019.pdf.

trees to contribute to both adaptation and mitigation, and has analyzed their synergies and trade-offs. Trade-offs may exist when mitigation actions are not conducive to adaptation, either of the forests themselves (which is likely to undermine the sustainability of mitigation/carbon sequestration), or of livelihoods; for instance, if mitigation/carbon sequestration negatively affects land uses or land rights. FTA's work is increasingly informing global debates. Structured, sequenced, iterative adaptation implementation pathways should enable people to appropriately decide on and manage trade-offs and synergies with mitigation.

Lavorel et al. (2020) have proposed an analytical framework that teases apart trade-offs and co-benefits according to different human-derived capital along three steps of co-production. A review by Locatelli et al. (2015) explored the opportunities and trade-offs when managing landscapes for both climate change mitigation and adaptation. They noted various conceptualizations of the links between adaptation and mitigation. In an effort to assess how adaptation and mitigation were carried out in the land management sector, Duguma et al. (2014a) suggested that more emphasis be laid on complementarity — mitigation projects that provide adaptation co-benefits and vice versa — rather than on synergy. Going beyond complementarity, synergy should emphasize functionally sustainable landscape systems in which adaptation and mitigation are optimized as part of multiple functions. Duguma et al. (2014a) argued that seeking co-benefits (complementarity) was a necessary but insufficient step towards addressing synergies.

Using their synergy score analysis, Pavageau et al. (2013), compared enabling conditions for synergies between adaptation and mitigation among countries. They found that a significant number of developing countries (51%) exhibited positive actions towards synergy. Among developing countries, middle-income countries had strong synergy potentials compared to low- and high-income countries. National committees and bodies addressing climate change and joint programmes at the national and subnational levels were prevalent indicators, while unified climate policies and submission of a Nationally Appropriate Mitigation Action (NAMA), REDD+ Readiness Preparation Proposal and NAPA were the least prevalent in developing countries.

Another study that assessed the enabling conditions for synergies at the national level in developing countries found that despite the relative infancy of the synergy concept, about half of the countries studied exhibited good synergy potential, 80% of which were middle-income developing countries. Emerging economies possessed strong synergy potential, which might be associated with better capacity being available and/or potential for shaping their global images due to their growing emissions (Duguma et al. 2014b). This analytical framework was applied by Ngum et al. (2019) to look at efforts made by the Government of Cameroon and other stakeholders to promote synergies between climate change mitigation and adaptation. The authors concluded that policies, laws, strategies and institutional arrangements relevant to promoting an integrated approach to climate change were insufficient in Cameroon, but that some promising projects and activities existed that harnessed great potential for synergies. They also suggested possible options for promoting these synergies (ibid.).

There have also been FTA studies of synergies at the local level. For example, in the Shinyanga and Simiyu regions, Tanzania, a range of practices combining traditional methods and modern agroforestry techniques, studied over several years, showed synergies at the local level. The approach, using the traditional ngitili system of regulated grazing, ensured the multifunctionality of the landscapes in providing mitigation, adaptation, development and conservation benefits. Its success was due to multistakeholder engagement through institutional collaborations, long-term investments by financial agencies, use of local practices and new knowledge in the implementation scheme, and ownership of the local communities in restoration efforts (Duguma et al. 2013, 2019).

FTA researchers considered the potential impacts and social return on investment of integrating adaptation into REDD+ initiatives in Indonesia and the Philippines (Pramova et al. 2013a, 2013b). Building on lessons learned from these studies, Pramova and Locatelli (2013) prepared a guidebook on integrating community-based adaptation into REDD+ projects.

Mangroves are an emblematic example of the adaptation/mitigation synergies that forests and trees can provide to climate action (GCA 2020). Coastal blue carbon[10] ecosystems — including mangroves, tidal marshes and seagrass meadows — are an important part of the global carbon cycle. They provide a wide range of ecosystem services that underpin coastal livelihoods and support adaptation to climate change, including habitat and food chain support for many species of commercial fish, nutrient recycling, shoreline stabilization, storm protection and reducing the intensity of floods. These ecosystem services provide the basis for the development of interventions that conserve and restore coastal wetlands for climate change mitigation and adaptation. The document *Guiding principles for delivering coastal wetland carbon projects* (UNEP and CIFOR 2014) provides knowledge-based guidance for a range of interventions, including policy actions, adjusted

[10] Blue carbon is the carbon stored in marine and coastal ecosystems..

management actions or project-based investments that lead to improved coastal wetlands for climate change mitigation and adaptation. Consideration was given to including coastal wetland management under existing and evolving mechanisms, such as REDD+ and NAMAs. This guidance supports policymakers, coastal management practitioners and civil society organizations in designing projects and activities in coastal wetlands that synergize adaptation and mitigation objectives.

Healthy mangrove vegetation growing along the riverside in Berahan Kulon, Indonesia.

Photo by Aulia Erlangga/CIFOR-ICRAF

6.2 Synergies and trade-offs between climate action and the SDGs

FTA research has emphasized the need to jointly consider adaptation and sustainable development and the key contribution that forests and trees can make to this perspective (CIFOR 2013, 2016). Van Noordwijk et al. (2015) noted that adaptation is even more urgent than had so far been accepted, and is closely related to broader development goals. To achieve this, further institutional space for integral "all-land-uses" approaches is needed (van Noordwijk et al. 2018). Most countries that have integrated an adaptation component in their nationally determined contribution (NDC) have defined a long-term goal or vision to guide it. These goals are closely intertwined with development objectives such as poverty eradication, economic development or improvement of living standards, security and human rights; in some cases, they explicitly mention the Sustainable Development Goals (SDGs) (Meybeck et al. 2020).

The recognition and valorization of the climate and non-climate co-benefits of adaptation in National Adaptation Plans (NAPs) can drive wider support among national stakeholders and extend its reach across sectors and scales (Crumpler and Meybeck 2020). Sinclair et al. (2019) focused on the role that agroecological approaches can play in making food systems more agile in adapting to climate change as planetary boundaries are reached and exceeded, with a focus on the field and the farm scales, but also recognizing key interactions with the landscape and food-system scales. They show (ibid.) how agroecological practices on farms can enable adaptation, and what is required to scale these practices up to levels capable of reconciling SDG 2, to end hunger, with SDG 15, to do so while enhancing rather than further depleting natural capital.

For a long time, most international funding for climate action was specialized, aiming strictly for climate action and either for mitigation or adaptation. Co-benefits were not considered or could even play against a project, giving the impression that a project was trying to attract climate finance for business-as-usual development. Things are now changing. The Green Climate Fund (GCF), the largest international climate fund, aims at allocating resources evenly between mitigation and adaptation. It has two results areas that are particularly relevant for forests: forest and land use (under mitigation), and ecosystems (under adaptation), and it looks at them together under cross-cutting mitigation and adaptation projects. FTA has developed an increasingly productive partnership with the fund to contribute to conceptual work (on sectoral guidance) and project development. FTA's findings and experience have been mobilized to develop GCF initiatives in Rwanda and other African countries in collaboration with IUCN. They also ground collaboration with the Governments of The Gambia and Sri Lanka to implement GCF projects and to achieve large-scale ecosystem-based adaptation in community forestry management and country climate action readiness, respectively.

Indonesian Forest Rangers patrol the Tripa peat swamp forest in Nagan Raya, Aceh province, Indonesia,

Photo by Dita Alangkara/CIFOR

7. Moving forward

A lot has changed in the last decade regarding the recognition of the need to adapt to climate change while still trying to reduce human-caused climate change. After many years of international climate negotiations putting the emphasis on mitigation, UNFCCC COP16 in Cancun, in 2010, gave more importance to adaptation. A series of key decisions included the creation of the NAP process and the Adaptation Committee and the fact that the Green Climate Fund would finance mitigation and adaptation equally. The reports of the IPCC (e.g. IPCC 2014b) have confirmed that there are major risks for ecosystems, rural livelihoods and food security, insisting on the need to adapt even if drastic mitigation action has been successful. The Paris Agreement established a global goal on adaptation for enhanced adaptive capacity, strengthening resilience and reducing vulnerability to climate change. The Glasgow Climate Pact urges Parties to further integrate adaptation measures into local, national and regional planning. There is also increasing interest in "nature-based solutions" to climate change, which can also support mitigation and adaptation synergies. Revisiting the last 10 years of FTA's work — and its initial framing of adaptation, its emphasis on ecosystems and social systems, its work on ecosystem-based adaptation, and on the need to consider synergies and trade-offs between adaptation and mitigation as well as with other sustainable development objectives — one can only be impressed by its actuality. There is now a clear need and demand for adaptation solutions, including those provided by forests, trees and agroforestry, as shown in numerous NDCs and NAPs. Having delivered on its program, FTA and its partners are thus particularly well positioned to support governments and other actors in the design and implementation of adaptation plans and measures that integrate forests, trees and agroforestry at the national, sectoral and landscape levels.

With the increasing realization of the changing climate and of the urgency to act come pressing demands for further research. As noted by the first evaluation of FTA more information is needed on the impacts of climate change on ecosystems, especially on the most vulnerable ecosystems and people (CGIAR-IEA 2014). This statement is still true and calls for innovative methods to monitor ecosystems, including natural ecosystems, and to give voice to vulnerable populations, associating Indigenous Peoples and local knowledge with modern technologies. There is also a considerable need and demand for ways to better integrate adaptation to climate change in restoration activities. As shown above there are methods and tools available to do so.

Adaptation planning and projects require the long-term involvement of a range of actors and their engagement in multistakeholder dialogues on the future of a sector or a landscape. The NAP process offers the opportunity to conduct such dialogues. Discussions between actors with different, often conflicting, perspectives can be greatly facilitated by a shared understanding of the issues at stake, with reliable down-scaled climate projections as well as tools to facilitate the understanding and monitoring of the relationships between different elements and dimensions of ecosystems and social systems. Such information will be particularly needed to go beyond incremental adaptation and agree on different futures, especially in situations that may require transformative adaptation. An integrative research framework is needed for enabling transformative adaptation (Colloff et al. 2017).

Adaptation, being very context specific, and because it requires understanding, depicting and anticipating future conditions and changes and their implications, is very knowledge intensive. It is also a relatively new field of research. It has to integrate findings from a context that is itself changing. A lot can be learned from the research conducted in other (not primarily climate-related) domains. This can help people understand the impacts of climate change on ecosystems and social systems and can support adaptation, including on genetic resources and governance, for instance. There is, however, a need to further aggregate this knowledge and make it accessible to actors in ways by which it can inform decision-making processes for adaptation. This requires having clear strategic orientations that are grounded in the identification of stakeholders' needs at various levels, with effective monitoring of the impacts of climate change on ecological and social systems and of the effects of adaptation measures, with periodic feedback loops to integrate both additional findings and additional questions. At the national and subnational level such mechanisms could be linked to the NAP process. FTA has developed databases, tools and methods. More assessment is needed of the changes in natural forests and in managed ecosystems. There is for instance a lack of long-term phenology records to analyze tree biological responses across a wide range of species to climate variability and change, of measurement of adaptation (including the contribution of forestry to the adaptation of other sectors, quantification of co-benefits, and cost-benefit analysis of adaptation actions), and of methods to identify and manage potential trade-offs. Adaptation will also require designing innovative ways to facilitate exchanges between actors and scientists to allow knowledge exchange, integration of lessons learned and learning loops at appropriate levels, whether national, landscape or value chain. A combination of long-term, place-based research, cross cutting analysis and an option-by-context approach can help to address the difficult challenge of facilitating knowledge transfer in different situations and contexts, and can facilitate links between local, national and global perspectives and actors, to fuel a commonly shared action agenda in different geographies.

References

Alfaro RI, Fady B, Vendramin GG, Dawson IK, Fleming RA, Sáenz-Romero C, Lindig-Cisneros RA, Murdock T, Vinceti B, Navarro CM, et al. 2014. The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. *Forest Ecology and Management* 333:76–87. https://doi.org/10.1016/j.foreco.2014.04.006.

Atmadja S, Liswanti N, Tamara A, Lestari H and Djoudi H. 2020. *Leveraging climate finance for gender equality and poverty reduction: A comparative study*. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/007889.

Barlow J, Parry L, Gardner T, Ferreira J, Aragão Luiz EOC, Carmenta R, Berenguer E, Vieira I, Souza C and Cochrane M. 2012. The critical importance of considering fire in REDD+ programs. *Biological Conservation* 154:1–8. https://doi.org/10.1016/j.biocon.2012.03.034.

Bayala J, Öborn I and Dupraz C. 2019. Belowground resource sharing in mixed tree–crop systems: Methods to better understand belowground interactions. *In* van Noordwijk M. ed. *Sustainable development through trees on farms: Agroforestry in its fifth decade*. Bogor, Indonesia: World Agroforestry (ICRAF), 93–109. http://apps.worldagroforestry.org/downloads/Publications/PDFS/BC19012.pdf.

Bee BA and Sijapati Basnett B. 2016. Engendering social and environmental safeguards in REDD+: Lessons from feminist and development research. *Third World Quarterly* 38(4):787–804. https://doi.org/10.1080/01436597.2016.1191342.

Bele MY, Tiani AM, Somorin OA and Sonwa DJ. 2013. Exploring vulnerability and adaptation to climate change of communities in the forest zone of Cameroon. *Climatic Change* 119:857–889. https://doi.org/10.1007/s10584-013-0738-z.

Bernard F, Minang PA, van Noordwijk M, Freeman OE and Duguma LA. eds. 2013. *Towards a landscape approach for reducing emissions: A substantive report of the Reducing Emissions from All Land Uses (REALU) project*. Nairobi: World Agroforestry (ICRAF). http://www.asb.cgiar.org/PDFwebdocs/Substantive%20Global%20Report_REALU%20II_FINAL_15nov_2_standard.pdf.

Boakye EA, Gebrekirstos A, Hyppolite DN, Barnes VR, Porembski S and Bräuning A. 2019. Carbon isotopes of riparian forests trees in the savannas of the Volta Sub-Basin of Ghana reveal contrasting responses to climatic and environmental variations. *Forests* 10:251. https://doi.org/10.3390/f10030251.

Bonnesoeur V, Locatelli B, Guariguata MR, Ochoa-Tocachi BF, Vanacker V, Mao Z, Stokes A and Mathez-Stiefel SL. 2019. Impacts of forests and forestation on hydrological services in the Andes: A systematic review. *Forest Ecology and Management* 433:569–584. https://doi.org/10.1016/j.foreco.2018.11.033.

Bos SP, Pagella T, Kindt R, Russell AJ and Luedeling E. 2015. Climate analogs for agricultural impact projection and adaptation—a reliability test. *Frontiers in Environmental Science* 3:65. https://doi.org/10.3389/fenvs.2015.00065.

Boyd W, Stickler C, Duchelle A, Seymour F, Nepstad D, Bahar NHA and Rodriguez-Ward, D. 2018. *Jurisdictional approaches to REDD+ and low emissions development: Progress and prospects*. Working Paper. Washington, DC: World Resources Institute (WRI). https://www.cifor.org/knowledge/publication/6933.

Brockhaus M, Djoudi H and Kambire H. 2012. Multi-level governance and adaptive capacity in West Africa. *International Journal of the Commons* 6(2):200–232. http://doi.org/10.18352/ijc.331.

Brockhaus M, Djoudi H and Locatelli B. 2013. Envisioning the future and learning from the past: Adapting to a changing environment in northern Mali. *Environmental Science and Policy* 25:94–106. https://doi.org/10.1016/j.envsci.2012.08.008.

Bruley E, Locatelli B and Lavorel S. 2021. Nature's contributions to people: Co-producing quality of life from multifunctional landscapes. *Ecology and Society* 26(1):12. https://doi.org/10.5751/ES-12031-260112.

Carmenta R, Blackburn GA, Davies G, de Sassi C, Lima A, Parry L, Tych W and Barlow J. 2016. Does the establishment of sustainable use reserves affect fire management in the humid tropics? *PLoS One* 11(2):e0149292. https://doi.org/10.1371/journal.pone.0149292.

Carmenta R, Daeli W, Jefferson U, Phelps J, Porter-Jacobs L, Trihadmojo B and Zabala A. 2017. *From perceptions and discourses to policy content: A mixed method analysis of peatland fire management in Indonesia*. CIFOR Infobrief No. 175. Bogor, Indonesia: CIFOR. http://dx.doi.org/10.17528/cifor/006470.

Carmenta R, Parry L, Blackburn A, Vermeylen S and Barlow J. 2011. Understanding human-fire interactions in tropical forest regions: A case for interdisciplinary research across the natural and social sciences. *Ecology and Society* 16(1):53. https://doi.org/10.5751/ES-03950-160153.

Carmenta R, Vermeylen S, Parry L and Barlow J. 2013. Shifting cultivation and fire policy: Insights from the Brazilian Amazon. *Human Ecology* 41(4):603–614. https://doi.org/10.1007/s10745-013-9600-1.

Carmenta R, Zabala A, Daeli W and Phelps J. 2017. Perceptions across scales of governance and the Indonesian peatland fires. *Global Environmental Change* 46:50–59. https://doi.org/10.1016/j.gloenvcha.2017.08.001.

CGIAR-IEA (Consultative Group on International Agricultural Research-Independent Evaluation Arrangement). 2014. Evaluation of CGIAR Research Program on Forests, Trees, and Agroforestry (FTA). Rome: IEA of CGIAR. https://cas.cgiar.org/evaluation/publications/crp-evaluation-forests-trees-and-agroforestry-fta.

CIFOR (Center for International Forestry Research). 2019a. *Participatory action research to community-based fire prevention and peatland restoration*. Bogor, Indonesia: CIFOR. https://www.cifor.org/knowledge/publication/7289.

CIFOR (Center for International Forestry Research). 2019b. *Assessing the efficiency and effectiveness of fire management interventions in Indonesia: Lessons learnt and ways forward*. Bogor, Indonesia: CIFOR. https://www.cifor.org/knowledge/publication/7262.

CIFOR (Center for International Forestry Research). 2016. *CGIAR research program on forests, trees and agroforestry*. Revised phase II full proposal 2017–2022. Bogor, Indonesia: CIFOR. https://www.foreststreesagroforestry.org/forests-trees-and-agroforestry-landscapes-livelihoods-and-governance.

CIFOR (Center for International Forestry Research). 2013. CGIAR Research Program 6. Forests, trees and agroforestry: Livelihoods, landscapes and governance. Proposal. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/004320.
The original version of the FTA proposal was published in 2011 and revised in 2013.

Colloff MJ, Martín-López B, Lavorel S, Locatelli B, Gorddard R, Longaretti PY, Walters G, van Kerkhoff L, Wyborn C, Coreau A, et al. 2017. An integrative research framework for enabling transformative adaptation. *Environmental Science and Policy* 68: 87–96. https://doi.org/10.1016/j.envsci.2016.11.007.

Corbera E, Estrada M, May P, Navarro G and Pacheco P. 2011. Rights to land, forests and carbon in REDD+: Insights from Mexico, Brazil and Costa Rica. *Forests* 2:301–342. https://doi.org/10.3390/f2010301.

Creed IF and van Noordwijk M. eds. 2018. F*orest and water on a changing planet: Vulnerability, adaptation and governance opportunities. A global assessment report.* IUFRO World Series No. 38. Vienna: International Union of Forest Research Organizations (IUFRO). https://www.iufro.org/fileadmin/material/publications/iufro-series/ws38/ws38.pdf.

Crumpler K and Meybeck A. 2020. *Adaptation in the agriculture sectors: Leveraging co-benefits for mitigation and sustainable development*. Rome: Food and Agriculture Organization (FAO). http://www.fao.org/3/ca9195en/CA9195EN.pdf.

Crumpler K, Bloise M, Meybeck A, Salvatore M and Bernoux M. 2019. *Linking nationally determined contributions and the sustainable development goals through agriculture: A methodological framework*. Environment and Natural Resources Management Working Paper No. 75. Rome: Food and Agriculture Organization (FAO). http://www.fao.org/3/ca5003en/ca5003en.pdf.

Dawson IK, Carsan S, Franzel S, Kindt R, Van Breugel P, Graudal L, Lillesø JPB, Orwa C and Jamnadass R. 2014. *Agroforestry, livestock, fodder production and climate change adaptation and mitigation in East Africa: Issues and options*. ICRAF Working Paper 178. Nairobi: World Agroforestry (ICRAF). https://doi.org/10.5716/WP14050.pdf.

Dawson IK, Leakey R, Place F, Clement CR, Weber JC, Cornelius JP, Roshetko JM, Tchoundjeu Z, Kalinganire A, Masters E, et al. 2020. *Trees, tree genetic diversity and the livelihoods of rural communities in the tropics*. State of the world's forest genetic resources. Thematic study. Rome: Food and Agriculture Organization (FAO). https://doi.org/10.4060/cb2488en.

Dawson IK, McMullin S, Kindt R, Muchugi A, Hendre P, Lillesø JPB and Jamnadass R. 2019. Delivering perennial new and orphan crops for resilient and nutritious farming systems. *In* Rosenstock T, Nowak A and Girvetz E. (eds). *The climate-smart agriculture papers*. Cham, Switzerland: Springer, 113–125. https://doi.org/10.1007/978-3-319-92798-5_10.

Dawson IK, Powell W, Sila D, Simons T, Revoredo-Giha C, Odeny DA, Barnes AP, Watson CA , Hoad S, Burnett F, et al. 2018. Supporting human nutrition in Africa through the integration of new and orphan crops into food systems: Placing the work of the African Orphan Crops Consortium in context. Working Paper 276. Nairobi: World Agroforestry (ICRAF). https://doi.org/10.5716/WP18003.PDF.

Dawson IK, van Breugel P, Coe R, Kindt R, van Zonneveld M, Lillesø JPB, Graudal L, Muchugi A, Russell J and Jamnadass R. 2017. A meta-analysis of molecular marker genetic datasets for eastern Africa trees supports the utility of potential natural vegetation maps for planning climate-smart restoration initiatives. *Tree Genetics and Genomes* 13(4):1–17. https://doi.org/10.1007/s11295-017-1155-7.

Dawson IK, Vinceti B, Weber JC, Neufeldt H, Russell J, Lengkeek AG, Kalinganire A, Kindt R, Lillesø JPB, Roshetko J, et al. 2011. Climate change and tree genetic resource management: Maintaining and enhancing the productivity and value of smallholder tropical agroforestry landscapes. A review. *Agroforestry Systems* 81(1):67–78. https://doi.org/10.1007/s10457-010-9302-2.

De Sousa K, van Zonneveld M, Holmgren M, Kindt R and Ordoñez JC. 2019. The future of coffee and cocoa agroforestry in a warmer Mesoamerica. *Scientific Reports* 9(1):8828. https://doi.org/10.1038/s41598-019-45491-7.

De Sousa K, van Zonneveld M, Imbach P, Casanoves F, Kindt R and Ordonez JC. 2017. Suitability of key Central American agroforestry species under future climates: An atlas. Occasional Paper 26. Turrialba, Costa Rica: World Agroforestry (ICRAF). http://apps.worldagroforestry.org/downloads/Publications/PDFS/B17955.pdf.

Devisscher T, Bharwani S, Tiani AM, Pavageau C, Kwack NE and Taylor R. 2013. Current vulnerability in the Tri-National de la Sangha landscape, Cameroon. Working Paper 107. Bogor, Indonesia: CIFOR. http://doi.org/10.17528/cifor/004084.

Dewi S, Khasanah N and Widayati A. 2013. Capacity-strengthening approach to vulnerability assessment (CaSAVA). *In* van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D, eds. Negotiation-support toolkit for learning landscapes. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/region/sea/publications/detail?pubID=3056.

Djoudi H and Brockhaus M. 2011. Is adaptation to climate change gender neutral? Lessons from communities dependent on livestock and forests in northern Mali. *International Forestry Review* 13(2):123–135. https://doi.org/10.1505/146554811797406606.

Djoudi H, Brockhaus M and Locatelli B. 2013. Once there was a lake: Vulnerability to environmental changes in northern Mali. *Regional Environmental Change* 13(3):493–508. https://doi.org/10.1007/s10113-011-0262-5.

Djoudi H, Locatelli B, Vaast C, Asher K, Brockhaus M and Sijapati Basnet B. 2016. Beyond dichotomies: Gender and intersecting inequalities in climate change studies. *Ambio* 45(3):248–262. https://doi.org/10.1007/s13280-016-0825-2.

Duguma LA, Duba D, Muthee K, Minang P, Bah A, Nzyoka J and Malanding J. 2020. *Ecosystem-based adaptation through the lens of community preferences*. Technical Brief No. 3. Nairobi: World Agroforestry (ICRAF). http://apps.worldagroforestry.org/downloads/Publications/PDFS/TB20012.pdf.

Duguma LA, Minang PA and van Noordwijk M. 2014a. Climate change mitigation and adaptation in the land use sector: From complementarity to synergy. *Environmental Management* 54(3):420–432. https://doi.org/10.1007/s00267-014-0331-x.

Duguma LA, Minang PA, Kimaro AA, Otsyina R and Mpanda M. 2019. Shinyanga: Blending old and new agroforestry to integrate development, climate change mitigation and adaptation in Tanzania. *In* van Noordwijk M. ed. *Sustainable development through trees on farms: Agroforestry in its fifth decade*. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program, 139–151. http://apps.worldagroforestry.org/downloads/Publications/PDFS/BC19014.pdf.

Duguma LA, Minang PA, Kimaro AA, Otsyina R and Mpanda M. 2013. *Climate smart landscapes: Integrating mitigation, adaptation and development in Shinyanga Region, Tanzania*. ASB Policy Brief 40. Nairobi: ASB Partnership for the Tropical Forest Margins. http://www.asb.cgiar.org/PDFwebdocs/asb_policy_brief_40.pdf.

Duguma LA, Nzyoka J, Minang PA and Bernard F. 2017. *How agroforestry propels achievement of nationally determined contributions*. ICRAF Policy No. Brief 34. Nairobi: World Agroforestry (ICRAF). http://apps.worldagroforestry.org/downloads/Publications/PDFS/PB17360.pdf.

Duguma LA, Wambugu SW, Minang PA and van Noordwijk M. 2014b. A systematic analysis of enabling conditions for synergy between climate change mitigation and adaptation measures in developing countries. *Environmental Science and Policy* 42:138–148. https://doi.org/10.1016/j.envsci.2014.06.003.

Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez V, van Noordwijk M, Creed IF, Pokorny J, et al. 2017. Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* 43:51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.

FAO (Food and Agriculture Organization). 2016. *The state of food and agriculture: Climate change, agriculture and food security.* Rome: FAO. www.fao.org/3/a-i6030e.pdf.

FAO (Food and Agriculture Organization). 2013. *Climate-smart agriculture: Sourcebook*. Rome: FAO. http://www.fao.org/3/i3325e/i3325e.pdf.

Fedele G, Desrianti F, Gangga A, Chazarin F, Djoudi H and Locatelli B. 2016. Ecosystem-based strategies for community resilience to climate variability in Indonesia. *In* Renaud F, Sudmeier-Rieux K, Estrella M and Nehren U. eds. *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*. Advances in Natural and Technological Hazards Research, Vol. 42. Switzerland: Springer. https://doi.org/10.1007/978-3-319-43633-3_23 .

Fedele G, Locatelli B and Djoudi H. 2017. Mechanisms mediating the contribution of ecosystem services to human well-being and resilience. *Ecosystem Services* 28:43–54. https://doi.org/10.1016/j.ecoser.2017.09.011.

Fedele G, Locatelli B, Djoudi H and Colloff MJ. 2018. Reducing risks by transforming landscapes: Cross-scale effects of land-use changes on ecosystem services. *PLoS One* 13(4):e0195895. https://doi.org/10.1371/journal.pone.0195895.

Fernandes K, Verchot L, Baethgen W, Gutiérrez-Vélez VH, Pinedo-Vasquez M and Martius C. 2017. Heightened fire probability in Indonesia in non-drought conditions: The effect of increasing temperatures. *Environmental Research Letters* 12(5):054002. https://doi.org/10.1088/1748-9326/aa6884.

Franzel S, Carsan S, Lukuyu B, Sinja J and Wambugu C. 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability* 6(1):98–103. https://doi.org/10.1016/j.cosust.2013.11.008.

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 restoration and conservation of tropical dry forests. *Global Change Biology* 26(6):3552–3568. https://doi.org/10.1111/gcb.15028.

Fremout T, Thomas E, Taedoumg H, Siebe B, Gutierrez M, Alcázar Caicedo C, Lindau C, Mounmemi H, Vinceti B, Kettle C, et al. 2021. Diversity for Restoration (D4R): guiding the selection of tree species and seed sources for climate-resilient restoration of tropical forest landscapes. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.14079.

FTA (Forests, Trees and Agroforestry). n.d. *CGIAR research program on forests, trees and agroforestry: Landscape approaches to tackle climate change and achieve sustainable development and food security*. Bogor, Indonesia: CIFOR. https://cgspace.cgiar.org/bitstream/handle/10568/89822/FTA-Web.pdf?sequence=4&isAllowed=y.

Gaisberger H, Kindt R, Loo J, Schmidt M, Bognounou F, Da SS, Diallo OB, 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.

Gautier D, Denis D and Locatelli B. 2016. Impacts of drought and responses of rural populations in West Africa: A systematic review. *WIREs Climate Change* 7(5):666–681. https://doi.org/10.1002/wcc.411.

Gaveau DLA, Salim MA, Hergoualc'h K, Locatelli B, Sloan S, Wooster M, Marlier ME, Molidena E, Yaen H, DeFries R, et al. 2014. Major atmospheric emissions from peat fires in Southeast Asia during non-drought years: Evidence from the 2013 Sumatran fires. *Scientific Reports* 4. https://doi.org/10.1038/srep06112.

GCA (Global Commission on Adaptation). 2020. *State and trends in adaptation report 2020*. Washington, DC: GCA. https://gca.org/reports.

Gebrekirstos A, Bräuning A, Sass-Klassen U and Mbow C. 2014. Opportunities and applications of dendrochronology in Africa. *Current Opinion in Environmental Sustainability* 6(1):48–53. https://doi.org/10.1016/j.cosust.2013.10.011.

Gitz V, Meybeck A, Pinizzotto S, Nair L, Penot E, Baral H and Xu J. 2020. *Sustainable development of rubber plantations in a context of climate change*. FTA Brief 4. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/007860.

Gitz V, Pingault N, Meybeck A, Ickowitz A, McMullin S, Sunderland T, Vinceti B, Powell B, Termote C, Jamnadass R, Dawson I and Stadlmayr B. 2021. *Contribution of forests and trees to food security and nutrition*. FTA Brief 5. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/008006.

González-Orozco CE, Galán AAS, Ramos PE and Yockteng R. 2020. Exploring the diversity and distribution of crop wild relatives of cacao (*Theobroma cacao L.*) in Colombia. *Genetic Resources and Crop Evolution* 67:2071–2085. https://doi.org/10.1007/s10722-020-00960-1.

Graudal L, Lillesø J-PB, Dawson IK, Abiyu A, Roshetko JM, Nyoka I, Tsobeng A, Kindt R, Pedercini F, Moestrup 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, Atmadja S, Baral H, Boissière M, Brady M, Chomba S, Cronkleton P, Djoudi H, Duchelle A, Duguma LA, 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, Locatelli B and Haupt F. 2012. Adapting tropical production forests to global climate change: Risk perceptions and actions. *International Forestry Review* 14(1):27–38. https://doi.org/10.1505/146554812799973226.

Gutiérrez-Vélez VH, Uriarte M, DeFries R, Pinedo-Vasquez M, Fernandes K, Ceccato P, Baethgen W and Padoch C. 2014. Land cover change interacts with drought severity to change fire regimes in Western Amazonia. *Ecological Applications* 24 6):1323–1340. https://doi.org/10.1890/13-2101.1.

Hayasaka H, Yamazaki K and Naito D. 2019. Weather conditions and warm air masses in Southern Sakha during active forest fire periods. *Journal of Disaster Research* 14(4):641–648. https://doi.org/10.20965/jdr.2019.p0641.

Herawati H, González-Olabarria JR, Wijaya A, Martius C, Purnomo H and Andriani R. 2015. Tools for assessing the impacts of climate variability and change on wildfire regimes in forests. *Forests* 6(5):1476–1499. https://doi.org/10.3390/f6051476.

Hiltner U, Bräuning A, Gebrekirstos A, Huth A and Fischer R. 2016. Impacts of precipitation variability on the dynamics of a dry tropical montane forest. *Ecological Modelling* 320:92–101. https://doi.org/10.1016/j.ecolmodel.2015.09.021.

HLPE (High Level Panel of Experts). 2017. *Sustainable forestry for food security and nutrition. A report by the High Level Panel of Experts on food security and nutrition of the committee on world food security*. Rome: Food and Agriculture Organization (FAO). https://www.cifor.org/knowledge/publication/6549.

Huijnen V, Wooster M, Kaiser JW, Gaveau DLA, Flemming J, Parrington M, Inness A, Murdiyarso D, Main B and van Weele M. 2016. Fire carbon emissions over maritime southeast Asia in 2015 largest since 1997. *Scientific Reports* 6:26886. https://doi.org/10.1038/srep26886.

Ickowitz A, McMullin S, Dawson IK, Sunderland T, Powell B, Nurhasan M, Jamnadass R, Meybeck A and Gitz V. 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.

IISD (International Institute for Sustainable Development). 2013. CRiSTAL forest user's manual: Community-based risk screening tool – adaptation and livelihoods focus on forests and ecosystems. Winnipeg, Canada: IISD. https://www.iisd.org/system/files/publications/cristal_forests_user_manual.pdf.

Imbach P, Locatelli B, Zamora JC, Fung E, Calderer L, Molina L and Ciais P. 2015. Impacts of climate change on ecosystem hydrological services of Central America: Water availability. *In* Chiabai A. ed. *Climate change impacts on tropical forests in Central America: An ecosystem service perspective*. Routledge, 65–90. https://www.cifor.org/knowledge/publication/5768.

IPCC (Intergovernmental Panel on Climate Change). 2014a. AR5 climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. *In* Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, et al. eds. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press. https://www.ipcc.ch/report/ar5/wg2.

IPCC (Intergovernmental Panel on Climate Change). 2014b. Climate change 2014: Synthesis report. *In* Core Writing Team, Pachauri RK and Meyer LA. eds. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf.

Jadmiko SD, Murdiyarso D and Faqih A. 2017. Climate changes projection for land and forest fire risk assessment in West Kalimantan. *IOP Conference Series: Earth and Environmental Science* (EES) 58(1):012030. https://doi.org/10.1088/1755-1315/58/1/012030.

Jamnadass R, Gebrekirstos A, Neufeldt H, Muthuri C, Dawson I, Kindt R, Nyberg Y, Dietz J, Bayala J, Kuyah S, Ong CK, et al. 2011. Trees as providers of environmental services in multifunctional landscapes are vulnerable to climate change. *In* van Noordwijk M, Hoang MH, Neufeldt H, Oborn I, Yatich T. eds. *How trees and people can co-adapt to climate change: Reducing vulnerability through multifunctional landscapes.* Nairobi: World Agroforestry (ICRAF), 63–77. http://www.asb.cgiar.org/PDFwebdocs/PDFwebdocs/How%20trees%20and%20people%20can%20co-adapt%20to%20climate%20change.pdf.

Kenney-Lazar M, Wong G, Baral H and Russell AJM. 2018. Greening rubber? Political ecologies of plantation sustainability in Laos and Myanmar. *Geoforum* 92:6–105. https://doi.org/10.1016/j.geoforum.2018.03.008.

Kindt R. 2021. AlleleShift: An R package to predict and visualize population-level changes in allele frequencies in response to climate change. *PeerJ* 9:e11534. https://doi.org/10.7717/peerj.11534.

Kindt R. 2018. Ensemble species distribution modelling with transformed suitability values. *Environmental Modelling & Software* 100:136–145. https://doi.org/10.1016/j.envsoft.2017.11.009.

Kmoch L, Pagella T, Palm M and Sinclair F. 2018. Using local agroecological knowledge in climate change adaptation: A study of tree-based options in northern Morocco. *Sustainability* 10(10):3719. https://doi.org/10.3390/su10103719.

Koffi CK, Djoudi H and Gautier D. 2017. Landscape diversity and associated coping strategies during food shortage periods: Evidence from the Sudano-Sahelian region of Burkina Faso. *Regional Environmental Change* 17(5):1369–1380. https://doi.org/10.1007/s10113-016-0945-z.

Krisnawati H, Imanuddin R, Adinugroho WC and Hutabarat S. 2015. *Estimation of annual greenhouse gas emissions from forest and peat lands in Central Kalimantan*. Bogor, Indonesia: Forestry Research and Development Agency (FORDA). https://www.cifor.org/knowledge/publication/5533.

Lavorel S, Locatelli B, Colloff MJ and Bruley E. 2020. Co-producing ecosystem services for adapting to climate change. *Philosophical Transactions of the Royal Society* B375:20190119. https://doi.org/10.1098/rstb.2019.0119.

Lilleskov EA, McCullough K, Hergoualc'h K, del Castillo Torres D, Chimmer R, Murdiyarso D, Kolka R, Bourgeau-Chavez L, Hribljan J, del Aguila Pasquel J, et al. 2019. Is Indonesian peatland loss a cautionary tale for Peru? A two-country comparison of the magnitude and causes of tropical peatland degradation. *Mitigation and Adaptation Strategies for Global Change* 24(4):591–623. https://doi.org/10.1007/s11027-018-9790-3.

Lillesø JBL, Graudal L, Moestrup S, Kjær ED, Kindt R, Mbora A, Dawson I, Muriuki J, Ræbild A and Jamnadass R. 2011. Innovation in input supply systems in smallholder agroforestry: Seed sources, supply chains and support systems. *Agroforestry Systems* 83:347–359. https://doi.org.10.1007/s10457-011-9412-5.

Lillesø JPB, Harwood C, Derero A, Graudal L, Roshetko JM, Kindt R, Moestrup S, Omondi WO, Holtne N, Mbora A, et al. 2018. Why institutional environments for agroforestry seed systems matter. *Development Policy Review*. 36:O89–O112. https://doi.org/10.1111/dpr.12233.

Liswanti N, Tamara A and Djoudi H. 2020. Climate finance and gender in the ground: Insights from mitigation and adaptation interventions in Indonesia. *Info Brief* 306. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/007857.

Locatelli B. 2016. Ecosystem services and climate change. *In* Potschin-Young M, Haines-Young R, Fish R and Turner RK. eds. 2016. *Routledge handbook of ecosystem services*. New York: Routledge, 481–490. https://www.researchgate.net/publication/315877658_Routledge_Handbook_of_Ecosystem_Services.

Locatelli B, Brockhaus M, Buck A and Thompson I. 2010. Forests and Adaptation to Climate Change: Challenges and Opportunities. *In* Mery G, Katila P, Galloway G, Alfaro RI, Kanninen M, Lobovikov M and Varjo J. eds. *Forests and Society: Responding to Global Drivers of Change*. IUFRO World Series Volume 25, 21–42. https://www.cifor.org/knowledge/publication/3175/.

Locatelli B, Pavageau C, Pramova E and Di Gregorio M. 2015. Integrating climate change mitigation and adaptation in agriculture and forestry: Opportunities and trade-offs. *WIREs Climate Change* 6(6):585–598. https://doi.org/10.1002/wcc.357.

Locatelli B, Pramova E, Di Gregorio M, Brockhaus M, Armas Chávez D, Tubbeh R, Sotés J and Perla J. 2020. Climate change policy networks: Connecting adaptation and mitigation in multiplex networks in Peru. *Climate Policy* 20:354–372. https://doi.org/10.1080/14693062.2020.1730153.

López-Noriega IL, Dawson IK, Vernooy R, Köhler-Rollefson I and Halewood M. 2017. Agricultural diversification as an adaptation strategy. *Agriculture for Development* 30:25–28. https://cgspace.cgiar.org/handle/10568/81378.

Luedeling E, Muthuri C and Kindt R. 2013. Ecosystem vulnerability to climate change: A literature review. Working Paper 162. Nairobi, Kenya: World Agroforestry (ICRAF). https://doi.org/10.5716/WP13034.PDF.

Marlier ME, DeFries RS, Kim PS, Gaveau DLA, Koplitz SN, Jacob DJ, Mickley LJ, Margono BA, and Myers SS. 2015. Regional air quality impacts of future fire emissions in Sumatra and Kalimantan. *Environmental Research Letters* 10(5):054010. https://doi.org/10.1088/1748-9326/10/5/054010.

Martius C and Duchelle AE. 2021. *REDD+: Combating Climate Change with Forest Science*. FTA Highlights of a Decade 2011–2021 series. Highlight No. 11. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008221.

McMullin S, Stadlmayr B, Mausch K, Revoredo-Giha C, Burnett F, Guarino L, Brouwer ID, Jamnadass R, Graudal L, Powell W and Dawson IK. 2021. *Determining appropriate interventions to mainstream nutritious orphan crops into African food systems*. Global Food Security 28:100465. https://doi.org/10.1016/j.gfs.2020.100465.

Meybeck A, Gitz V, Wolf J and Wong T. 2020. *Addressing forestry and agroforestry in National Adaptation Plans: Supplementary guidelines*. Bogor, Indonesia: CGIAR Research Program on Forests, Trees and Agroforestry (FTA) and Rome: Food and Agriculture Organization (FAO). https://doi.org/10.4060/cb1203en.

Meybeck A, Rose S and Gitz V. 2019. *Climate change vulnerability assessment of forests and forest-dependent people – A framework methodology*. FAO Forestry Paper No. 183. Rome: Food and Agriculture Organization (FAO). https://doi.org/10.4060/ca7064en.

Minang PA, Duguma LA, Leimona B, van Noordwijk M, Catacutan D, Ickowitz A, Dewi S, Johana F, Rizvi J, Sarmiento Barletti JP, et al. 2021a. *Governing Forests, Agroforestry and Trees for Delivering on the SDGs*. FTA Highlights of a Decade 2011–2021 series. Highlight No. 14. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008224.

Minang PA, Duguma LA, van Noordwijk M, Sunderland T, Reed J, Leimona B, Ickowitz A, Wainaina P, Dewi S, Chervier C, et al. 2021b. *Multifunctional Landscapes for Sustainable Development*. FTA Highlights of a Decade 2011–2021 series. Highlight No. 13. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008223.

Minang PA, van Noordwijk M, Freeman, OE, Mbow C, de Leeuw J and Catacutan D. eds. 2015. Climate-smart landscapes: *Multifunctionality in practice*. Nairobi, Kenya: World Agroforestry (ICRAF). https://www.worldagroforestry.org/publication/climate-smart-landscapes-multifunctionality-practice.

Munji CA, Bele MY, Idinoba M and Sonwa DJ. 2014. Floods and mangrove forests, friends or foes? Perceptions of relationships and risks in Cameroon coastal mangroves. *Estuarine, Coastal and Shelf Science* 140:67-7. https://doi.org/10.1016/j.ecss.2013.11.017.

Munji CA, Bele MY, Nkwatoh AF, Idinoba, M, Somorin OA and Sonwa DJ. 2013. Vulnerability to coastal flooding and response strategies: The case of settlements in Cameroon mangrove forests. *Environmental Development* 5:54–72. https://doi.org/10.1016/j.envdev.2012.10.002.

Muthee K, Duguma L, Nzyoka J and Minang P. 2021. Ecosystem-based adaptation practices as a nature-based solution to promote water-energy-food nexus balance. *Sustainability* 13(3):1142. https://doi.org/10.3390/su13031142.

Nasi R, Fa JE, van Vliet N, Coad L, Pinedo-Vasquez M, Swamy V and Lee TM. 2021. *Wild Meat*. FTA Highlights of a Decade 2011–2021 series. Highlight No. 6. Bogor, Indonesia: The CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008216.

Ngum F, Alemagi D, Duguma L, Minang PA, Kehbila A and Tchoundjeu Z. 2019. Synergizing climate change mitigation and adaptation in Cameroon: An overview of multi-stakeholder efforts. *International Journal of Climate Change Strategies and Management* 11(1):118–136. https://doi.org/10.1108/IJCCSM-04-2017-0084.

Nyoka BI, Roshetko J, Jamnadass R, Kalinganire A, Lilles JB L, Beedy T and Cornelius J. 2014. Tree seed and seedling supply systems: A review of the Asia, Africa and Latin America models. *Small-Scale Forestry* 4(2):171-191. https://doi.org/10.1007/s11842-014-9280-8.

Paumgarten F, Locatelli B and Witkowski ETF. 2020a. Archetypes of climate-risk profiles among rural households in Limpopo, South Africa. *Weather, Climate and Society* 12(3):545–560. https://doi.org/10.1175/WCAS-D-19-0134.1.

Paumgarten F, Locatelli B and Witkowski ETF. 2018. Wild foods: Safety net or poverty trap? A South African case study. *Human Ecology* 46(2):183–195. https://doi.org/10.1007/s10745-018-9984-z.

Paumgarten F, Locatelli B, Witkowski ETF and Vogel C. 2020b. Prepare for the unanticipated: Portfolios of coping strategies of rural households facing diverse shocks. *Journal of Rural Studies* 80:91–100. https://doi.org/10.1016/j.jrurstud.2020.05.013.

Pavageau C, Butterfield R and Tiani AM. 2013. *Current vulnerability in the Virunga landscape, Rwanda*. Bogor, Indonesia: CIFOR. https://www2.cifor.org/cobam/2014/04/01/current-vulnerability-virunga-landscape-rwanda.

Penot E, Chambon B, and Wibawa G. 2017. History of rubber agroforestry systems development in Indonesia and Thailand as alternatives for sustainable agriculture and income stability. *International Proceedings* of IRC 1:497–532.

Pinizzotto S, Aziz A, Gitz V, Sainte-Beuve J, Nair L, Gohet E, Penot E and Meybeck A. 2021a. *Natural rubber systems and climate change: Proceedings and extended abstracts from the online workshop, 23–25 June 2020*. Working Paper 9. Bogor, Indonesia: CGIAR Research Program on Forests, Trees and Agroforestry (FTA). https://doi.org/10.17528/cifor/008029.

Pinizzotto S, Kadir AASA, Gitz V, Sainte-Beuve J, Nair L, Gohet E, Penot E and Meybeck A. 2021b. *Natural rubber and climate change: A policy paper*. FTA Brief 6. Bogor, Indonesia. CGIAR Research Program on Forests, Trees and Agroforestry. https://doi.org/10.17528/cifor/008375.

Pramova E and Locatelli B. 2013. *Guidebook on integrating community-based adaptation into REDD+ projects: Lessons from Indonesia and the Philippines*. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/004340.

Pramova E, Lavorel S, Locatelli B, Colloff MJ and Bruley E. 2020. *Adaptation in the Anthropocene: How we can support ecosystems to enable our response to change*. Info Brief 283. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/007588.

Pramova E, Locatelli B, Brockhaus M and Fohlmeister S. 2012. Ecosystem services in the National Adaptation Programmes of Action. *Climate Policy* 12(4):393–409. https://doi.org/10.1080/14693062.2011.647848.

Pramova E, Locatelli B, Djoudi H and Somorin OA. 2012. Forests and trees for social adaptation to climate variability and change. *Wiley Interdisciplinary Reviews: Climate Change* 3(6):581–596. https://doi.org/10.1002/wcc.195.

Pramova E, Locatelli, B, Djoudi H, Lavorel S, Colloff MJ and Martius C. 2019. *Adapting land restoration to a changing climate: Embracing the knowns and unknowns*. Info Brief 249. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/007261.

Pramova E, Locatelli B, Liss B, Ignacio GB, Villamor M and Sumaylo VE. 2013a. *Integrating adaptation into REDD+: Potential impacts and social return on investment in Sogod, Southern Leyte, Philippines*. CIFOR Working Paper No. 113. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/004232.

Pramova E, Locatelli B, Mench A, Marbyanto E, Kartika K and Prihatmaja H. 2013b. *Integrating adaptation into REDD+: Potential impacts and social return on investment in Setulang, Malinau District, Indonesia*. CIFOR Working Paper No. 112. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/004231.

Purnomo H, Komarudin H, Ilham QP, Joni A, Aenunaim, Jasnari, Puspitaloka D, Dewi S and Pacheco P. 2018a. *Public policy for strengthening and scaling up community-based fire prevention initiatives of private corporations to benefit the environment and livelihoods*. CIFOR Working Paper 244. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/006346.

Purnomo H, Okarda B, Dewayani AA, Ali M, Achdiawan R, Kartodihardjo H, Pacheco P and Juniwaty KS. 2018b. Reducing forest and land fires through good palm oil value chain governance. *Forest Policy and Economics* 91:94–106. https://doi.org/10.1016/j.forpol.2017.12.014.

Purnomo H, Okarda B, Shantiko B, Achdiawan R, Dermawan A, Kartodihardjo H and Dewayani AA. 2019. Forest and land fires, toxic haze and local politics in Indonesia. *International Forestry Review* 21(4):1–15. https://doi.org/10.1505/146554819827906799.

Purnomo H, Shantiko B, Sitorus S, Gunawan H, Achdiawan R, Kartodihardjo H and Dewayani AA. 2017. Fire economy and actor network of forest and land fires in Indonesia. *Forest Policy and Economics* 78:21–31. https://doi.org/10.1016/j.forpol.2017.01.001.

Ranjitkar S, Sujakhu NM, Merz J, Kindt R, Xu J, Matin MA, Ali M and Zomer RJ. 2016a. Suitability analysis and projected climate change impact on banana and coffee production zones in Nepal. *PLoS One* 11(9):e0163916. https://doi.org/10.1371/journal.pone.0163916.

Ranjitkar S, Sujakhu NM, Lu Y, Wang Q, Wang M, He J, Mortimer PE, Xu J, Kindt R and Zomer RJ. 2016b. Climate modelling for agroforestry species selection in Yunnan Province, China. *Environmental Modelling and Software* 75:263–272. https://doi.org/10.1016/j.envsoft.2015.10.027.

Reed J, van Vianen J and Sunderland T. 2015. *From global complexity to local reality: Aligning implementation pathways for the Sustainable Development Goals and landscape approaches*. Info Brief 129. Bogor, Indonesia: CIFOR. https://doi.org/10.17528/cifor/005865.

Reed J, van Vianen J, Deakin EL, Barlow J and Sunderland T. 2016. Integrated landscape approaches to managing social and environmental issues in the tropics: Learning from the past to guide the future. *Global Change Biology* 22:2540–2554. https://doi.org/10.1111/gcb.13284.

Ripple W, Wolf C, Newsome T, Barnard P and Moomaw W. 2020. World scientists' warning of a climate emergency. *BioScience* 70(1):8–12. https://doi.org/10.1093/biosci/biz088.

Robiglio V, Baca M, Donovan J, Bunn C, Reyes M, Gonzáles D and Sánchez C. 2017. *Impacto del cambio climático sobre la cadena de valor del café en el Perú*. Lima: ICRAF Oficina Regional para América Latina; Cali, Colombia: CIAT Centro Internacional de Agricultura Tropical. https://www.worldagroforestry.org/sites/default/files/outputs/El%20Impacto%20del%20Cambio%20Climático%20en%20el%20Café_FINAL.pdf.

Rosenstock TS, Dawson IK, Aynekulu E, Chomba S, Degrande A, Fornace K, Jamnadass R, Kimaro A, Kindt R, Lamanna C and Malesu M. 2019. A planetary health perspective on agroforestry in Sub-Saharan Africa. *One Earth* 1(3):330–344. https://doi.org/10.1016/j.oneear.2019.10.017.

Sasmito SD, Murdiyarso D, Friess, DA and Kurnianto S. 2016. Can mangroves keep pace with contemporary sea level rise? A global data review. *Wetlands Ecology and Management* 24:263–278. https://doi.org/10.1007/s11273-015-9466-7.

Sayer JF, Margules C, Agni K, Boedhihartono AK, Sunderland T, Langston JD, Reed J, Riggs R, Buck LE, Campbell BM, et al. 2016. Measuring the effectiveness of landscape approaches to conservation and development. *Sustainability Science* 12:465–476. https://doi.org/10.1007/s11625-016-0415-z.

Sayer J, Sunderland T, Ghazoul J, Pfund J-L, Sheil D, Meijaard E, Venter MG, Boedhihartono AK, Day M, Garcia C et al. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *PNAS* 110(21):8349–8356. https://doi.org/10.1073/pnas.1210595110.

Schlenker W and Lobell DB. 2010. Robust negative impacts of climate change on African agriculture. *Environmental Research Letters* 5(1). https://doi.org/10.1088/1748-9326/5/1/014010.

Schoeneberger M, Bentrup G, de Gooijer H, Soolanayakanahally R, Sauer T, Brandle J, Zhou X and Current D. 2012. *Journal of Soil and Water Conservation* 67(5):128A–136A. https://doi.org/10.2489/jswc.67.5.128A.

Scholes R, Montanarella L, Brainich A, Barger N, ten Brink B, Cantele M, Erasmus B, Fisher J, Gardner T, Holland T, et al. eds. 2018. *Summary for policymakers of the assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services*. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Secretariat. https://www.fs.usda.gov/treesearch/pubs/58402.

Schwartz NB, Uriarte MA, Gutierrez-Velez VH, Baethgen W, DeFries R, Fernandes K and Pinedo-Vasquez M. 2015. Climate, landowner residency, and land cover predict local scale fire activity in the Western Amazon. *Global Environmental Change* 31:144–153. https://doi.org/10.1016/j.gloenvcha.2015.01.009.

Sinclair S, Rosenstock T, Gitz V and Wollenberg L. 2017. Agroforestry to diversify farms and enhance resilience. *In* Dinesh D, Campbell B, Bonilla-Findji O and Richards M. eds. *10 best bet innovations for adaptation in agriculture: A supplement to the UNFCCC NAP Technical Guidelines*. CCAFS Working Paper No. 215. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://www.cifor.org/knowledge/publication/7155.

Sinclair F, Wezel A, Mbow C, Chomba S, Robiglio V and Harrison R. 2019. *The contribution of agroecological approaches to realizing climate-resilient agriculture*. Background Paper. Washington, DC: Global Center of Adaptation (GCA). https://gca.org/wp-content/uploads/2020/12/TheContributionsOfAgroecologicalApproaches.pdf.

Sloan S, Locatelli B, Wooster MJ and Gaveau DLA. 2017. Fire activity in Borneo driven by industrial land conversion and drought during El Niño periods, 1982–2010. *Global Environmental Change* 47:95–109. https://doi.org/10.1016/j.gloenvcha.2017.10.001 .

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.

Somarriba E, Orozco-Aguilar L, Cerda R and López-Sampson A. 2018. Analysis and design of the shade canopy of cocoa-based agroforestry system. *In* Umaharan P. ed. *Achieving sustainable cultivation of cocoa*. Cambridge, UK: Burleigh Dodds Science Publishing, 469–499. https://doi.org/10.19103/AS.2017.0021.29.

Somarriba E, Zamora R, González J, Malek M, Vargas E, Sinclair F and Quesada F. 2020. *ShadeMotion: El análisis de patrones de sombra de árboles*. Tutorial. CATIE, Serie técnica. Manual técnico 145. Turrialba, Costa Rica: CATIE. https://repositorio.catie.ac.cr/handle/11554/10311.

Somarriba-Chavez E, Quesada-Chaverri F, Orozco-Aguilar L, Cerda-Bustillos R, Villalobos-Rodriguez M, Orozco-Estrada S, Astorga-Domian C, Deheuvels O, Say-Chavez E and Villegas-Caceres R. 2011. *The shade canopy of cocoa*. Technical series. Extension materials No. 5. Collection Field Schools. Central American Cacao Project. Turrialba, Costa Rica: CATIE. https://www.researchgate.net/publication/324362700_The_Shade_Canopy_of_Cocoa.

Su Y, Biondi C and Liu S. 2019. *Gender and adaptation: An analysis of poverty and vulnerability in Yunnan, China*. Working Paper 293. Kunming, China: World Agroforestry (ICRAF). https://doi.org/10.5716/WP19004.PDF.

Sunderland T, Achdiawan R, Angelsen A, Babigumira R, Ickowitz A, Paumgarten F, Reyes-Garcia V and Shively G. 2014. Challenging perceptions about men, women and forest product use: A global comparative study. *World Development* 64(1):S56–S66. https://doi.org/10.1016/j.worlddev.2014.03.003.

Taufik M, Torfs PJJF, Uijlenhoet R, Jones PD, Murdiyarso D and Van Lanen HAJ. 2017. Amplification of wildfire area burnt by hydrological drought in the humid tropics. *Nature Climate Change* 7(6):428–431. https://doi.org/10.1038/nclimate3280.

Thomas E, Alcázar Caicedo C, Loo J and Kindt R. 2014. The distribution of the Brazil nut (*Bertholletia excelsa*) through time: From range contraction in glacial refugia, over human-mediated expansion, to anthropogenic climate change. *Boletim do Museu Paraense Emílio Goeldi, Ciencias Naturais* 9:267–291. https://www.bioversityinternational.org/e-library/publications/detail/the-distribution-of-the-brazil-nut-bertholletia-excelsa-through-timenbsp-from-range-co.

Thorlakson T and Neufeldt H. 2012. Reducing subsistence farmers' vulnerability to climate change: Evaluating the potential contributions of agroforestry in western Kenya. *Agriculture & Food Security* 1:15. http://www.agricultureandfoodsecurity.com/content/1/1/15.

UNEP (United Nations Environment Programme) and CIFOR (Center for International Forestry Research). 2014. *Guiding principles for delivering coastal wetland carbon projects*. Bogor, Indonesia: CIFOR. https://www.cifor.org/knowledge/publication/5205.

van Breugel P, Friis I, Demissew S, Lillesø J-PB and Kindt R. 2016. Current and future fire regimes and their influence on natural vegetation in Ethiopia. *Ecosystems* 19(2):369–386. https://doi.org/10.1007/s10021-015-9938-x.

van der Wolf J, Jassogne L, Gram G and Vaast P. 2019. Turning local knowledge on agroforestry into an online decision-support tool for tree selection in smallholders' farms. *Experimental Agriculture* 55(51):50–66. https://doi.org/10.1017/S001447971600017X.

van Noordwijk M. ed. 2019. *Sustainable development through trees on farms: Agroforestry in its fifth decade*. Bogor, Indonesia: World Agroforestry (ICRAF). http://www.worldagroforestry.org/downloads/Publications/PDFS/B19029.pdf.

van Noordwijk M, Bargues-Tobella A, Muthuri CW, Gebrekirstos A, Maimbo M, Leimona B, Bayala J, Ma X, Lasco R, Xu J, et al. 2019. Agroforestry as part of nature-based water management. *In* van Noordwijk M. ed. *Sustainable development through trees on farms: Agroforestry in its fifth decade*. Bogor, Indonesia: World Agroforestry (ICRAF), 305–333. http://www.worldagroforestry.org/downloads/Publications/PDFS/B19029.pdf.

van Noordwijk M, Bayala J, Hairiah K, Lusiana B, Muthuri CW, Khasanah N and Mulia R. 2014. Agroforestry solutions for bufering climate variability and adapting to change. *In* Fuhrer J and Gregory PJ. eds. *Climate change impact and adaptation in agricultural systems*. Wallingford, UK: CAB-International, 216–232. https://www.worldagroforestry.org/publication/agroforestry-solutions-buffering-climate-variability-and-adapting-change.

van Noordwijk M, Coe R, Sinclair FL, Luedeling E, Bayala J, Muthuri CW, Cooper P, Kindt R, Duguma LA, Lamanna C and Minang PA. 2021. Climate change adaptation in and through agroforestry: Four decades of research initiated by Peter Huxley. *Mitigation and Adaptation Strategies for Global Change* 26:18. https://doi.org/10.1007/s11027-021-09954-5.

van Noordwijk M, Duguma L, Dewi S, Leimona B, Catacutan D, Lusiana B, Öborn I, Hairiah K and Minang PA. 2018. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: Reinventing agroforestry? *Current Opinion in Environmental Sustainability* 34:33–42. https://doi.org/10.1016/j.cosust.2018.09.003.

van Noordwijk M, Hoang MH, Neufeldt H, Öborn I and Yatich T. eds. 2011. *How trees and people can co-adapt to climate change: Reducing vulnerability through multifunctional agroforestry landscapes*. Nairobi: World Agroforestry (ICRAF). http://apps.worldagroforestry.org/sea/Publications/files/book/BK0149-11.pdf.

van Noordwijk M, Minang PA, Dewi S, Duguma L and Bernard F. 2015. *Transforming REDD+ and achieving the SDGs through support for adaptation-mitigation synergy.* ASB Policy Brief 46. Nairobi: ASB Partnership for the Tropical Forest Margins. https://www.asb.cgiar.org/publication/transforming-redd-and-achieving-sdgs-through-support-adaptation-mitigation-synergy.

Vignola R, Locatelli B, Martinez C and Imbach P. 2009. Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? *Mitigation and Adaptation Strategies for Global Change* 14(8):691–696. https://doi.org/10.1007/s11027-009-9193-6.

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). https://doi.org/10.17528/cifor/008213.

Ward RD, Friess DA, Day RH and Mackenzie RA. 2016. Impacts of climate change on mangrove ecosystems: A region by region overview. *Ecosystem Health and Sustainability* 2(4):1–25. https://doi.org/10.1002/ehs2.1211.

Widayati A, Louman B, Mulyoutami E, Purwanto E, Kusters K and Zagt R. 2021. Communities' adaptation and vulnerability to climate change: Implications for achieving a climate-smart landscape. *Land* 10(8):816. https://doi.org/10.3390/land10080816.

Worbes M, Herawati H and Martius C. 2017. Tree growth rings in tropical peat swamp forests of Kalimantan, Indonesia. *Forests* 8(9):336. https://doi.org/10.3390/f8090336.

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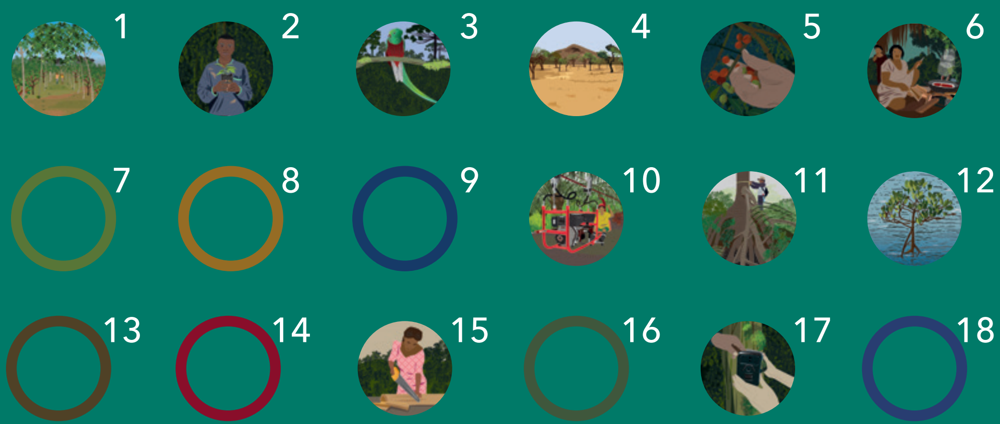

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