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Trees as hotspots: Using forests, trees, and agroforestry to foster diverse sustainable landscapes

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Abstract

Forests, trees, and agroforestry (FTA) are ecosystem hotspots. They exemplify the contributions of biodiversity to sustainable and resilient landscapes, green circular economy and to sustainable agriculture and food systems for healthy diets. However, most research on these topics have been performed separately and lack comparison. The International FTA-Kunming Conference 'Forests, trees and agroforestry for diverse sustainable landscapes' 22nd–24th June 2021, focused on these contributions, brought together scientists NGOs, and policy makers to further the understanding of tree diversity; provided a communication platform for scientists to share their research results; evaluated the role of tree diversity in agroecology and circular agriculture; assessed benefits of landscape restoration; and explored applied research in mountain ecosystems and food security. The goals were to gather evidence that ground the design of solutions that can contribute to the implementation of the post 2020 Global Biodiversity Framework and towards the UN Food Systems Summit, and the overall implementation of the SDGs. This paper summarizes the outcomes of the international FTA Conference in Kunming 2021 and points out the highlights of research involved in six major themes.

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Introduction

The CGIAR research program on Forests, Trees and Agroforestry (FTA) organized with the Kunming Institute of Botany, Chinese Academy of Science (CAS), and the Research Institute for Resource Insects, Chinese Academy of Forestry (CAF), an international conference in Kunming, China, 22nd–24th June 2021, on the theme of forests, trees and agroforestry for diverse sustainable landscapes. The international conference[1] gathered close to 400 participants both on site in Kunming and online, featuring around 100 scientific presentations providing evidence in support of the importance of managed ecosystems, such as agricultural ecosystems and managed forests for ecosystem functioning and services. The conference was

positioned in support to the elaboration of the new Global Biodiversity Framework of the Convention on Biological Diversity (CBD) and for its implementation, highlighting linkages between science and policy, development and implementation. Presentations were organized around six technical themes (sessions):

1. Trees for agroecology and circular agriculture.
2. Tree diversity: realizing economic and ecological value from tree genetic resources to bridge production gaps and promote resilience.
3. Trees in the framework of the CBD.
4. Mountain ecosystems and food security.
5. Assessing benefits of landscape restoration.
6. Trees for a circular green economy.

The conference showcased latest findings from the CGIAR Research Program on Forest, Trees and Agroforestry (FTA)[2], Chinese Academy of Forestry (CAF)[3], Chinese Academy of Sciences (CAS)[4], Chinese Academy of Agricultural Sciences (CAAS)[5] and partners on the roles of forests, trees and agroforestry for diverse sustainable landscapes.

Forests, trees and agroforestry exemplify the contributions of biodiversity and agrobiodiversity to sustainable and resilient landscapes, to green and circular bioeconomy and to sustainable agriculture[6] and food systems for healthy diets[7]. Conserving and sustainably managing biodiversity is indispensable for the future health of our planet[8]. Conserving, planting and growing trees is a concrete investment for future generations.

There is an urgency to act, to genuinely mainstream biodiversity in different sectors and objectives (such as climate change, sustainable consumption and production), as a primary consideration and not only as an ancillary objective[9]. As much as biodiversity conservation is an end in itself[10], it is also a critical means[11] to many objectives for managed ecosystems and landscapes, contributing to the productivity and resilience of agriculture, rural and urban environments, food systems and more globally of the whole economy. The agenda to 'build forward better' from the Covid-19 pandemic lends further importance to building the resilience of our natural environment and for people[12]. The key to doing so are integrated landscape approaches, that stem from integrated leadership and policies, governing land use in ways that balance goals from different sectors.

Summary of outcomes from six thematic sessions

Trees for agroecology and circular agriculture

Session 1 covered seven key aspects: agroforestry, biodiversity conservation, animal husbandry and nutrition, sericulture, soil remediation and fungal biodegradation of plastic wastes. Agroforestry is a highly developed form of agroecology because trees are functionally distinct from annual crops and livestock, enlarging the scope of managed interactions among components within agricultural systems to achieve synergistic outcomes. However, knowledge and implementation gaps constrain widespread uptake. Trees in agricultural systems represent an investment in ecological infrastructure that can increase farm income using high-value products and diversify production to increase resilience as, for example, with *Moringa*, *Magnolia*, *Phyllanthus*, rattan, rubber and coffee, with the first three also providing fodder and contributing to animal health and productivity in integrated systems. Fungi, with their unique ability to decompose agricultural waste and breakdown plastics in soil, can also significantly contribute to circular agriculture.

Tree diversity: realizing economic and ecological value from tree genetic resources to bridge production gaps and promote resilience

Session 2 recalled that the diversity of tree products (fruits, nuts, vegetables, timber, medicinal, fodder, gums, resins, etc.) and services (carbon sequestration, biodiversity, soil biomass, erosion control, water storage/filtration, etc.) is associated and adapted to local social, cultural, economic and ecological values, needs, and landscapes. Human disturbances, habitat degradation, over-exploitation and climate change have increased the risk of genetic erosion and extinction of diverse trees, many of which are of high value to local communities. To halt and reverse this, many ambitious global and national targets have been set to restore degraded land, diversify farming systems and create a range of income-generating opportunities. A rising enthusiasm around the world for tree-planting is leading to a cascade of ambitious initiatives. And no wonder: trees don't just absorb CO_2, hence mitigating climate change, but they also help farms and rangelands adapt to climate change. Trees help rural families boost their financial, and nutritional security through the products and services they provide and the increased resilience they offer. But the rush to get tree seedlings into the ground can often result in planting the wrong trees in inappropriate places, or planting poor seeds of low quality that can actually inflict damage, causing harm to existing ecosystems, or simply failing to deliver expected outcomes. A grower who has dealt with the negative consequences and disappointment of investing in the wrong tree is unlikely to try again. A range of knowledge products, decision prototypes, support tools, technologies and methodologies (genetic, biophysical, ecological, socio-economic and indigenous knowledges) are being developed and used to assess the genetic and biological characteristics, values, uses and threats to tree diversity as well as provide guidance for the provision of quality planting material and building-up solid tree seed and seedlings systems.

Trees in the framework of the CBD

Session 3 noted that agricultural land must be recognized for its multiple contributions to sustainable use and biodiversity conservation:

1. As a habitat for species and varieties, cultivated or otherwise, and used by humans (agrobiodiversity, including agricultural species and beneficial species) to support food production;
2. As a habitat for wild biodiversity that uses agricultural landscapes to fulfil all or part of their niche requirements, as well as strictly forest-dwelling species that use the agricultural matrix to move between forest fragments;
3. For ecosystem services that support human health, food security, climate change adaptation and mitigation, and water supply.

International trade agreements have important effects on diversification through both behaviour-leading and placing obligatory rules on the producers, transformers, buyers and consumers. High Conservation Value Forests, remnant patches of natural forests and an integrated landscape management approach are crucial to strengthen landscape resilience, biodiversity conservation and other environmental and sustainable

development goals. While not a replacement for natural ecosystems, managed ecosystems do provide important habitat for species and contribute to habitat connectivity. Agroforestry, reforestation and the management of related ecosystem services are allies, not adversaries of biodiversity in needed native forest restoration.

Mountain ecosystems and food security

Session 4 recalled that mountains occupy more than one-fifth of the Earth's land surface and host some 12% of the global human population. They encounter key challenges: the constraints of terrain and climate, high production and transportation costs, low productivity, poor infrastructure, limited access to market, physical isolation and vulnerability to natural risks. Around 245 million people living in mountain areas are estimated to be vulnerable to food insecurity. A wide range of issues were covered in this session from soil, cropping systems, to management strategies, landscape restoration, livelihood systems, governance, etc. Mountain systems in Northwestern Vietnam have seen a shift from grain production to cash crop farming, primarily fruit tree cultivation. This shift has shown positive impacts on farmers' income, but challenges remain for measuring other socioeconomic (e.g. economic resilience of production system, gender equity) and environmental benefits resulting from this ongoing land use change. Varieties of indigenous and captive crops are cultivated under traditional mixed-farming systems in the Eastern Himalayas, and these can contribute to nutritional and food security of the region. The use of endophytic fungi as biocontrol agents and biofertilizers can also play an important role in suppressing pathogens (reducing damage at pre- and post-harvest stages), enhancing agricultural productivity and protecting mountain ecosystems. In the mountains of the Indonesian archipelago, such as in Timor-Leste, traditional agroforestry systems help to protect the soil against erosion, crops against violent rains; conserve biodiversity; store carbon; and sustain basic needs of households. However, it is necessary to better valorise such secular systems, to make them attractive for the next generation of farmers.

Assessing benefits of landscape restoration

In session 5 it was noted that using native and mixed species in forest landscape restoration can maintain regional carbon stocks and increase other related ecosystem services, including the prevention of invasive species. These native, and often neglected and underutilized tree species (NUS), can also provide great economic benefits for smallholders. Growth-promoting bacteria in the soil can benefit the growth of legumes and help improve the environment for cultivation. The establishment of leguminous shrubs on farmlands can contribute to multiple benefits, including carbon storage, climate change mitigation with adaptation, biodiversity conservation, poverty reduction and food security.

Trees for a circular green economy

Session 6 showed that non-timber forest products, such as mushrooms, bamboo, wood twig charcoal production, and rattan products can be used to generate income and contribute towards rural development programs. Forests can be used as natural capital in the context of reducing carbon emissions, which can also provide revenue streams shareable among stakeholders. Woody plants have the potential for use as animal feed, adding to the diversity of products coming out of forest systems. Biomass energy is an important use of wood and bamboo from both naturally regenerated and planted forest ecosystems. The use of woody residues for mushroom cultivation and charcoal production increases resource efficiency and provides value-addition to local rural livelihoods.

All conference material is now available on the FTA Science Conference webpage[13]. Presentations and discussions facilitated the identification of actionable solutions to scale up biodiversity mainstreaming and transform food systems.

Key recommendations for research and policy makers

The following are 12 key recommendations resulting from the technical and plenary sessions. These are formulated to the attention of governments and all actors, public and private, the Rio platforms and conventions (CBD, UNFCCC, UNCCD), trade related bodies and international organizations, to consider them as overarching global recommendations for strategic orientations under which specific action plans would need to be elaborated with stakeholders in diverse national and regional contexts. References in the below text concern research undertaken by, or with contribution from, the CGIAR Research Program on Forests, Trees and Agroforestry and are available from its open database[14].

1. Protect forests and acknowledge their contributions to biodiversity conservation, climate change action and sustainable food systems

Forests are a major reservoir of biodiversity worldwide. They are an important source of food for many communities all over the world. Not only do they provide wild fruits, leaves, nuts and mushrooms[15] – they also provide homes for game animals, insects and fish that are key sources of nutrients for vulnerable populations[16]. They are a main source of energy for cooking as well as for the provision of renewable packaging materials. Their indirect role in food production is equally important; forests provide important ecosystem services for agriculture – pest control, pollination services[17], water regulation[18], flood prevention[19] and soil enrichment. These important benefits of forests – including bamboo forests[20] – need to be better understood, appreciated and recognized in land planning, management and policies so that forests are no longer seen as barriers to food production, but as key components of sustainable food systems. More research, development and policy work on the contribution of Non-Timber Forest Products (NTFPs) towards sustainable development, and how to protect the forest resource that sustains NTFPs[21] is required to leverage the true value of forest products to rural communities.

2. Support forest and landscape restoration

It is estimated that, at the global level, up to 25% of all land (forests, cropland, rangelands and grassland) is highly degraded and 36% is slightly or moderately degraded[22]. Degraded land provide fewer ecosystem services, contribute to and exacerbate the effects of climate change and biodiversity loss, and are less productive, causing hunger, poverty and conflicts, which in turn further drives deforestation and land degradation in an effort to compensate for lost productivity. Restoring and sustainably managing land is needed to improve the environmental, economic and social sustainability of food systems. Secondary and degraded forests show huge potential for restoration to improve both biodiversity and productivity

goals[23,24]. Fast-growing species like bamboo can provide bioenergy and biomaterials for renewable food packaging[25]. Fungi can play an important role for soil reclamation and remediation. Forest and landscape restoration requires collaborative long-term action between multiple actors, including the government and private sector, driven by needs and priorities of local actors that depend on and manage the land[26]. This requires specific care in governance[27], participatory management and attention to the right set of tree species for restoration, favouring indigenous species in conjunction with proper adapted species, seed and planting material quality, and diversity[28,29]. Care must also be taken with the use of non-native species to prevent tree-invasions[30]. Appropriate decision support tools[31] and more accurate assessments of costs and benefits of specific restoration interventions[32] should facilitate implementation. Landscape approaches involving local communities shall be adopted in ecological restoration in order to meet not only environmental needs but also social and economic needs.

3. Promote agroecological transformation

Agroecological approaches can play an important role in the transition to sustainable food systems[33]. They are based on the principles of: input reduction; renewable inputs; better use of ecological processes and the biodiversity underpinning them; preservation of plant, animal and soil health; diversification; synergy; co-creation of knowledge; social values; better connectivity between farmers and consumers; equitable governance and participation[34]. Agroecological transitions are conducive to preserving biodiversity, to leveraging the role of biodiversity for farmers and helping to reconnect producers and consumers. Many of these transitions can leverage the role of trees[35] and improve biodiversity. These transitions at scale require, in many contexts, to reform policies and install a proper enabling environment, technical support, market incentives and regulations.

4. Recognize and promote the benefits of diversity from field and landscape to systems and diets

Diversity in production systems, from plot to landscape scales, contributes to the conservation of biodiversity, allows for better, more adaptive use of natural resources and provides livelihood opportunities[36] for women and vulnerable social groups. It is an essential component of the resilience of landscapes[37], farming systems and households to shocks, whatever their origin: climatic, biological (pests and diseases), anthropogenic (land use change) or economic (price volatility). Landscape and agricultural diversity is key to ensuring balanced and healthy diets. The considerable pressure for simplification, driven by economies of scale and by the industrialization and standardization processes from production to transformation and distribution, needs to be counteracted by efficient measures that preserve and foster diversity across all food systems, from production to consumption.

5. Leverage the full potential of trees on farms for agrobiodiversity, ecosystem services, resilience and productivity and to meet national and global biodiversity targets

Trees in agro-ecosystems play a critical role in contributing to biodiversity conservation in agricultural landscapes through in-situ conservation, by providing habitats to wild species, connecting fragmented habitats and providing steppingstones between protected area networks[38]. Trees and forest patches are also useful and profitable to farmers as they provide a range of goods and services for soil health and fertility along with fuelwood, management of pest and diseases, erosion control and water runoff. There is huge potential that the new biodiversity framework can leverage trees on farms to contribute to biodiversity objectives as well as resilience and the long-term environmentally sound productivity of agricultural landscapes. This will require appropriate information about agroforestry species and their uses and values[39], building upon local knowledge, as well as proper mainstreaming in agricultural policies, economic incentives, technical back-stopping and appropriate tree tenure regulations. It will also require investing in production, delivery and use of quality tree seeds/seedlings, as well as appropriate market development to add maximal value to the range of tree products.

6. Mainstream orphan crops into cultivation

Many tree foods found in forests are 'orphan crops', also called 'neglected and underutilized species' that have been overlooked by agricultural research and industry, but have great potential to diversify farming systems to support both human and environmental health. The application of new tree domestication, selection and breeding methods provides opportunities for modest investments to upgrade the 'status' of these 'orphan' species to mainstream them in cultivation and food systems, at the condition of being supported by enabling policies from production and markets to consumption[40]. Broad gene pools, with new selection methods, provide rapid productivity gains, while appropriate consumer-based interventions, support local use and integration into domestic and global markets. From a scientific perspective, ethno-biological studies need to be supported to avoid the loss of knowledge on the use of orphan crops. There is need to foster a 'systems approach' to plant breeding that utilizes both novel and traditional methods to meet the call for broader participation, increased emphasis on the environment, advances in biotechnology and the evolution of markets[41].

7. Support innovations in knowledge, technology and institutions for a resilient mountains' future

Mountain ecosystems are hotspots of biodiversity and crucial areas for natural resources management, such as water quantity and quality, soil, nutrients, genetic resources and adaptation to climate change. They are also particularly vulnerable to global change, climate change, anthropogenic pressures, land-use change and inappropriate management. How mountains are managed often conditions the environmental and productive health of landscapes downstream, including resilience to climate change. Due to their specificity, mountain communities have developed identities, cultures and livelihoods that are strongly connected to the land and ecosystems, often involving knowledge and practices formed over thousands of years of holistic land, farm and forest experience[42]. There is a potential to combine local knowledge and scientific research to support innovations in knowledge, technologies, approaches, tools[43] that can in turn strengthen practices, policies and institutions for brighter and more resilient mountain futures[44].

8. Better mainstream biodiversity in climate change-related discussions, instruments and implementation

Climate change is a major threat to biodiversity conservation (including to biodiversity hotspots) and ecosystem services. Biodiversity conservation, sustainable management and leveraging ecosystem services (e.g. through preserving ecosystem functionality and ecosystem services provision and delivery) are

essential approaches often overlooked in climate change mitigation and adaptation planning. There is a need for appropriate tools and mechanisms to monitor and assess changes in ecosystems, particularly in forests, mountains, small islands, coastal areas, Arctic zones, arid and semi-arid areas, and other highly vulnerable areas. To do so, engaging indigenous peoples and local communities, citizen science can facilitate broad observation, awareness raising and societal ownership. There is also a need for appropriately integrating biodiversity concerns and prioritizing biodiversity hotspots in climate-change-related measures. In forests, biodiversity is grounding climate-change adaptation and is key to maintaining forest health that enables long-term mitigation. In agriculture, agroforestry can help to increase the resilience of farmlands and landscapes to climatic stresses[45,46]. Forest, trees and agroforestry systems' key role in climate change adaptation and mitigation can be strengthened by better integrating biodiversity conservation and sustainable management into climate action[47,48].

9. Promote fruit, nut, vegetable and mushroom consumption and production, and leverage the potential of insects as a resource for sustainable food systems

Fruits, nuts and vegetables are among the most nutrient-dense foods, but they are under-consumed in most countries[49–51]. Mushrooms are low in calories and fat and contain modest amounts of fibre and various nutrients. Edible insects contain high-quality protein, vitamins and amino acids, and are produced with low environmental footprint. Their high food conversion rate makes them particularly interesting as a source of high-protein food and feed for sustainable food systems. The gathering and production of all these foods can increase and diversify income, particularly for smallholders. This requires a reorientation of agricultural and food policies[52], and the growth and diversification of the agricultural markets, to fully integrate the specificities and benefits provided by the production of fruits, nuts, vegetables and mushrooms, and to leverage the potential of insects as a resource for food systems.

10. Understand, recognize, support and draw lessons from indigenous culture, traditional production systems and indigenous food systems

Indigenous food systems, including the knowledge and values embedded in them, model the sustainable use of natural resources. Their preservation is essential to protect and sustainably manage forests, biodiversity and other natural resources. They are wellsprings of inspiration for effecting a global transformation of food systems towards more sustainability in terms of values (sustainable management of resources, reduced waste, social values, sharing, health linkages), responsibility (towards land and biodiversity, society, future generations) and practices. The contributions of traditional diets, rich in diverse nutritious foods, to health and sustainable food systems need to be better taken into account by all food systems actors and policy-makers, in that regard they deserve greater research investment, including ethnobiological studies[53], and greater promotion by public and private players. This is yet another reason why inclusive governance needs to be promoted, including care for women, Indigenous peoples and other under-represented groups in multi-stakeholder forums[54].

11. Harness the potential of forests, trees and agroforestry to transition to a circular bio-economy

Forests, trees, agroforestry and associated biodiversity have considerable potential for the development of bioenergy and biomaterials, including the utilization of co-products, by-products and waste. Fungi and insects can recycle tree, crop and livestock waste and transform it into feed, plant nutrients and biomaterials[55]. Food systems are major producers of waste: food loss, non-edible waste, and food packaging (that is increasingly non-renewable and one of the main sources of plastic waste). Trees, bamboo and rattan[56] can provide alternative sources of fibre, furniture[57] and packaging material. Circular bioeconomy is more reliant on the cycling and recycling of bio-based natural products and residues, optimizes material fluxes, storage and processing, and reduces post-harvest losses and waste. It calls for enlarging the notion of value chains to value webs, where multi-cropping systems give rise to several products. A holistic approach to all material fluxes optimizes input/output flows in agriculture, forestry and fisheries, and diversifies farm and forest revenues, thus reducing risks[58]. It needs to be based on proper assessments for the sustainability of the resource[59]. These developments require supportive regulations, public procurement, incentives and consumer engagement.

12. Promote instruments that facilitate joint consideration of landscapes and value chains for sustainable management of natural resources

The landscape level is where diverse land-uses and other economic activities and value chains interact. To sustainably manage natural resources and optimize the production of ecosystem goods and services, proper landscape-scale planning and management is needed, integrated together with sustainable national, regional and global value chains (including those related to trade and markets). This requires adequate knowledge and information, evidence-based, inclusive and transparent decision processes as well as management and governance mechanisms and instruments to maximize synergies and balance trade-offs[60] between different objectives, with due consideration to inclusiveness and to social equity[61–63]. There is thus a need for appropriate mechanisms to foster sustainability across the entirety of the value chains operating in a given landscape, with special emphasis to forest-risk commodities[64] and the related investment decisions and international trade instruments. These sustainable value-chain mechanisms need to integrate local communities concerns and landscape-specific biodiversity concerns and objectives.

Conclusions

To support all these recommendations, for transformational change, there is a need for conducive policies, to establish a proper enabling environment for research, innovation, capacity building and to facilitate integration across sectors and scales. Some key measures will also necessitate innovative financing mechanisms.

At national level, governments need to overcome historical administrative silos; legal and administrative measures and budgets need to be in place to support ministries and their line agencies to develop and implement integrated plans and programmes for the conservation, sustainable use, management, and restoration of biological diversity and ecosystems.

At the international level, these recommendations can inform the work of the international mechanisms under the Rio conventions of the United Nations, such as the UNFCCC COP in Glasgow, UK in November 2021, especially the Glasgow forests

and land-use declaration, the upcoming decisions on the Global Biodiversity Framework expected to be agreed at CBD COP 15 in Kunming, China, UNCCD agenda, as well as the UN decade on Ecosystem restoration. These 12 recommendations are relevant to the respective implementation, work agenda and roadmaps of all these bodies within their own mandates, and they can also help build bridges and synergies between them, contributing to multiple objectives. Importantly, all these measures can benefit from solutions that can be engineered locally and shared globally through the reinforcement of international cooperation. Equally critical will be long term observatories, and to link global information with local contexts and engagement of different stakeholders and citizens in research (and vice-versa) and in policy.

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Conflict of interest

The authors declare that they have no conflict of interest.

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