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TOWARDS MORE RESILIENT AND DIVERSE PLANTED FORESTS

Highlight

TreeDivNet,
a global research network on mixed-species planted forests

How can new models of planted forests help achieve Agenda 2030?

Exploring the contributions of planted forests to Global Forest Goal 1 through the work of FAO and partners

Planted forests and restoration: impacts on the environment, production and livelihoods

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Editorial

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With the world population projected to reach 9.8 billion people by 2050, the need for food, fuel, fibre and other biobased products and services is set to rise sharply. One business-as-usual scenario for the forest sector suggests that roundwood production will need to increase by 37 percent between 2020 and 2050 to meet consumption growth.[1] But climate change and the ongoing degradation of ecosystems show the need for great changes in global production and consumption patterns. Many societies are responding by decarbonizing their economies and restoring the environment – including through nature-based solutions, such as protecting, restoring and adapting forests and other tree-based land-use systems.

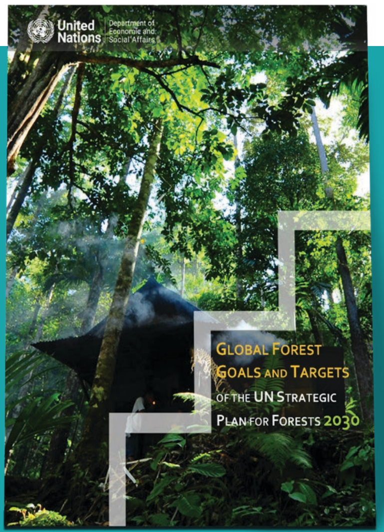
To enhance the contributions of forests and trees to the 2030 Agenda for Sustainable Development, especially Sustainable Development Goal 15, "Life on Land", **the United Nations Strategic Plan for Forests 2017–2030[2] adopted a target to increase forest area globally by 3 percent by 2030**[3] – implying an increase of 120 million hectares over the period. The United Nations General Assembly proclaimed 2021–2030 the United Nations Decade on Ecosystem Restoration,[4] with the goal of supporting and scaling up efforts to prevent, halt and reverse the degradation of ecosystems worldwide.

[1] **FAO.** 2022. *Global forest sector outlook 2050: Assessing future demand and sources of timber for a sustainable economy.* Background paper for The State of the World's Forests 2022. FAO Forestry Working Paper No. 31. Rome. https://doi.org/10.4060/cc2265en

[2] United Nations strategic plan for forests 2017–2030 and quadrennial programme of work of the United Nations Forum on Forests for the period 2017–2020. Economic and Social Council, 2017. E/RES/2017/4

[3] Global Forest Goal 1: Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change (www.un.org/esa/forests/news/2017/01/six-global-forest-goals/index.html).

[4] www.decadeonrestoration.org



The **United Nations' Global Forest Goals** support the objectives of the international arrangement on forests and are aimed at contributing to progress on the Sustainable Development Goals, the Aichi Biodiversity Targets, the Paris Agreement adopted under the United Nations Framework Convention on Climate Change and other international forest-related instruments, processes, commitments and goals.

15 LIFE ON LAND

Source: UNDESA. 2019. Global Forest Goals and targets of the UN strategic plan for forests 2030

Planted forests can be a winning strategy to increase global forest cover when diverse, resilient and inclusive models of planted forests are deployed. Reforestation and forest restoration can support livelihoods, reduce the risk of rural and urban disasters, help protect biodiversity, increase global forest carbon absorption, and supply long-lived wood products that also contribute to decarbonization. Comprising only about 7 percent of forest cover in 2020,[5] planted forests already contribute an estimated 46 percent of the global industrial roundwood supply. But to meet the increasingly complex demands of human societies, including for ecosystem services, the planted forests of the future will need to be more than wood factories.

The aim of this edition of *Unasylva* is to raise awareness about the contributions of diverse, resilient and inclusive planted forests to the 2030 Agenda. It explores the data, tools and approaches available to help increase both the quality and quantity of planted forests to meet the target of increasing the global forest area by 3 percent by 2030. It presents novel findings and state-of-the-art models of planted forests that perform the essential function of production while also helping conserve biodiversity, restore degraded ecosystems, adapt to and mitigate climate change, and boost livelihoods.

The edition features a mix of science-based articles, interviews with leading global experts and public figures, and case studies from FAO's fieldwork on planted forests. There are three main sections, as follows:

1. **Meeting Global Forest Goal 1.** This group of eight articles examines the need to increase forest area and production by 2050, presents data on currently available planted forest resources, and explores avenues through which planted forests might fill the expected production gap while also meeting societal expectations.
2. **Towards diverse planted forests.** This section, comprising seven articles, presents recent findings on resilient and multifunctional alternatives to monocultural tree plantations. It provides an overview of lessons learned from scientific studies, knowledge gaps, and the advantages and disadvantages of monocultures.
3. **Reconciling production and restoration.** The seven articles in this section explore the role and integration of diverse planted forests in mosaic landscapes. They showcase projects and initiatives helping deliver a balanced suite of ecosystem services and thereby contributing to the acceptability of – and benefits derived from – diverse planted forests at the landscape scale.

This edition of Unasylva *was coordinated by FAO's Sustainable Forestry Value Chains, Investments, and Innovation Team under the overall supervision of Thaís Linhares-Juvenal, led by Faustine Zoveda with the support of Lena Bismark. It was conceived and produced together with Kris Verheyen, Lander Baeten, Jürgen Bauhus, Joannès Guillemot and Rita Sousa-Silva from TreeDivNet*[6] *and Martin Weih, Chair of the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC),*[7] *as a contribution to the International Union of Forest Research Organizations (IUFRO) Task Force on Resilient Planted Forests Serving Society and the Bioeconomy.*[8]

5 **FAO**. 2020. *Global Forest Resources Assessment 2020: main report*. Rome. https://doi.org/10.4060/ca9825en

6 TreeDivNet (https://treedivnet.ugent.be) is a global platform designed to improve understanding of the relationship between forest diversity and ecosystem functioning and to increase the use of this knowledge in policies and management. The network provides a platform for multidisciplinary and multifunctional research in specific studies, as well as synthesis studies across the globe.

7 The IPC is one of the oldest statutory bodies of FAO. Its mission is to reduce poverty and improve ecosystem services worldwide by fostering the sustainable management of all fast-growing trees. It does so through knowledge transfer, technical exchange, standard setting, and the conservation and sustainable management and use of fast-growing forests and trees.

8 IUFRO's Task Force on Resilient Planted Forests Serving Society and the Bioeconomy is an inclusive expert group that brings together leading global scientists and private-sector, non-governmental and intergovernmental organizations.

Foreword

Aerial view of a TreeDivNet tree diversity experiment in Montreal, Canada, captured by drone

July 2023 was the hottest month on Earth ever recorded – and yet another warning that we must urgently address climate change and its widespread impacts. Limiting global warming to 1.5 °C will require immediate deep reductions in greenhouse-gas (GHG) emissions, but we must also actively remove carbon dioxide from the atmosphere. Afforestation, reforestation and ecosystem restoration are among the carbon dioxide removal solutions with the highest mitigation potential. Forests also supply wood products which, if sustainably sourced, can be used as substitutes for GHG-intensive products.

Throughout the world, governments have made major pledges and commitments and launched initiatives,[9] which, combined, constitute a highly conducive platform for increasing the global forest area by 3 percent by 2030, an ambition articulated in the United Nations' Global Forest Goal 1. There are concerns, however, that large-scale tree planting will focus only on a small number of species, which could exacerbate climate risks. Today, most of the world's productive forests are monospecific plantations, which are vulnerable to biotic and abiotic stresses induced by climate change.

As Messier *et al.* (2021)[10] suggest, mixed-species planted forests are a key nature-based solution for climate-change mitigation and adaptation. More resilient than monocultures, these relatively diverse forests are generally less susceptible to biotic and abiotic disturbances such as pest outbreaks and extreme weather events. In addition to wood, they have the potential to deliver multiple ecosystem services at higher levels than monocultures. The biomass production of mixed-species planted forests is often similar to or higher than that of monospecific plantations, and they harbour greater biodiversity. Nev-

[9] Such as the Bonn Challenge, the New York Declaration on Forests, and the UN Decade on Ecosystem Restoration, 2021–2030.

[10] **Messier, C., Bauhus, J., Sousa-Silva, R., Auge, H., Baeten, L., Barsoum, N., Bruelheide, H. *et al.*** 2022. For the sake of resilience and multifunctionality, let's diversify planted forests! *Conservation Letters*, 15(1): e12829. https://doi.org/10.1111/conl.12829

ertheless, there remains a wide gap between robust scientific evidence for the multiple benefits of diverse planted forests and their widespread adoption, as well as societal support for them.

This edition of *Unasylva* has been produced to help close this gap. It has benefited from the wealth of knowledge obtained through the projects MixForChange, funded by the European Biodiversity Partnership, and Cambio, funded by the BNP Paribas Foundation, which respectively are aimed at promoting mixed-species planted forests as nature-based solutions to climate change and at studying the role of tree diversity in countering climate change. Both projects are being implemented in the context of TreeDivNet. This edition also builds on the knowledge accumulated through the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC) and from critical insights and perspectives offered by globally leading experts, especially at a workshop on the state of the art in the management of mixed and pure planted forests, which was convened at FAO headquarters in Rome in 2022.

This edition of *Unasylva* shows we have come a long way since the seminal 1992 FAO Forestry Paper by T.J. Wormald, *Mixed and Pure Forest Plantations in the Tropics and Subtropics*. Thanks to projects such as those referred to above, systematic experimentation such as that supported through TreeDivNet, and a great deal of other research, we now have a much stronger evidence base on the ecological functioning of mixed-species forests and their potential for providing ecosystem services. This edition brings together the perspectives of decision-makers, landowners, academia and international organizations, enabling us to distil the most important lessons learned from scientific studies; highlight those planted-forest systems that are most promising for the provision of ecosystem services in support of the Sustainable Development Goals; and identify shortcomings in forest management and policies, and gaps in awareness, that need to be addressed to realize the full potential of diverse planted forests.

We thank everyone who contributed to this edition – especially Ben Caldwell, who initiated this collaboration as forestry officer with FAO a few years ago. We look forward to continuing to support the expansion of more resilient and diverse planted forests.

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Sustainably meeting future world needs for wood fibre with planted forests

Kenya | A worker smoothens pieces of wood to make some furniture at Francis Ndewga's

©FAO/Luis Tato

Thaís Linhares-Juvenal, Team Leader, Sustainable Forestry Value Chains, Investments and Innovation and Secretary of the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC), FAO

Highlights

- Global demand for primary processed wood products is expected to increase by 37 percent or more between 2020 and 2050.
- An additional 33 million ha of highly productive planted forests could supply this extra wood fibre. Optimal outcomes will require policies, tenure systems and institutional arrangements that encourage effective landscape planning, smallholder engagement, and sustainable production.

In a business-as-usual scenario, the global demand for primary processed wood products is expected to increase by 37 percent in the 2020–2050 period, reaching 3.1 billion cubic metres (m^3) roundwood equivalent (RWE) in 2050, according to the *Global forest sector outlook 2050* published by FAO (FAO, 2022a). This increase could be 32.5 percent higher when also considering the potential increase in consumption of mass timber in construction and manufactured cellulose fibre as substitutes for non-renewable and carbon-emitting materials (FAO, 2022a). While a gap in the supply of this increased demand (known as the "wood gap") has not been identified, the pathways to meeting the additional demand will depend on policy-driven market decisions. The opportunity for planted forests and trees is clear. While wood supply needs could be met by an additional 33 million hectares (ha) of highly productive plantations (FAO, 2022a), other types of planted forests and trees could also contribute to meeting the increased demand, with significant benefits for landscapes and

livelihoods. The mobilization created by the Bonn Challenge and the United Nations Decade on Ecosystem Restoration, can trigger political change and encourage the creation of an enabling environment to support a virtuous cycle of ecosystem restoration and fostering sustainable landscapes with an increased supply of wood fibre to achieve carbon neutrality and resilience. Expansion of planted forests and trees, including with fast-growing species, is a strategic consideration within the mix of restoration options.

Wood production trends

The global consumption of primary processed wood products is expected to reach 3.1 billion m^3 in 2050, which represents an increase of 37 percent compared to 2020, in a business-as-usual scenario. If wood substitution for fossil-intense materials continues to advance, considering only the products already on the market, such as mass-timber products and manufactured cellulose fibre, the demand in 2050 may increase by an additional 272 million m^3 (FAO, 2022a).

The relevance of planted forests for timber production is deemed to increase to support projected industry growth. In 2020, planted forests accounted for around 46 percent of global industrial roundwood demand, while 44 percent of this demand was supplied by naturally regenerated temperate and boreal forests (FAO, 2022a). Tropical timber from naturally regenerated forests met only 9 percent of global demand, assuming a marginal role (FAO, 2022a). The area and productivity of naturally regenerated forests under sustainable forest management are not expected to expand significantly as increased generation of other ecosystem services such as biodiversity protection needs to be secured. Planted forests and trees could meet most of the demand increase through expansion and productivity improvements, under a variety of models and production regimes (FAO, 2022a).

The *Global Forest Resource Assessment* 2020 (FRA 2020) defines planted forests as those predominantly composed of trees established through planting or deliberate seeding, or both (FAO, 2018). Planted forests and plantation forests are not synonymous. The latter are defined as intensively managed and include short-rotation plantations for wood, fibre and energy. In line with FRA terminology, other planted forests (not classified as plantation forest) accounted for 55 percent of global planted forests in 2020.

Globally, plantations represented 45 percent of planted forests in 2020 (FAO, 2020). They comprised almost all planted forests in South America and Oceania, at respectively 99 percent and 91 percent. Conversely, in Europe, 95 percent of planted forests fall under the "other planted forests" category, meaning that they are not plantations. In 2010–2020, Asia was the region with the highest increase in planted forest area, and South America the region with the highest rate of area growth.

As policy-driven management of forests for carbon and biodiversity may limit expansion of production forests in Europe, much of the growth will come from the tropics (FAO, 2022a). South America has consistently led the rates of growth in forest plantation area, followed by North America and Asia. Africa is emerging as an important plantation area, having shown an area growth rate in 2015–2020 below South and North America, but higher than Asia (FAO, 2020).

Scarcer land availability, higher land prices and policies promoting increased sustainability and social inclusion could create market opportunities for other planted forests and trees. The recent trends in production from naturally regenerated forests and planted forests indicate that 33 million ha of highly productive plantations need to be added in order to meet the business-as-usual demand by 2050, and it is likely that at least 30 million ha will be established by that date (FAO, 2022a). This expansion will rely on the private sector and is likely to take place in tropical and subtropical forest. Increased knowledge on fast-growing species and mixed-species stands, dissemination of experiences on mixed-tree stands and investments, combined with a stronger uptake of sustainable wood products on a global scale, could lead to forest sector growth being less dependent on plantations.

Agroforestry

In 2020, agroforestry and tree crop production over 45.4 million ha generated wood for commercial purposes (FAO, 2022a). However, it is difficult to assess the scale and reliability of this contribution due to lack of global data, as most of this production is reported under planted forests (FAO, 2022a). Asia reported the largest area under agroforestry systems, at 31.2 million ha, followed by Africa with 12.8 million ha (FAO, 2022a). In India, case studies have confirmed the prominence of wood from agroforestry, with estimations of 90 percent of the country's domestic wood supply being sourced from agroforestry and trees outside forests (FAO, 2022a).

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Expansion of planted forests at the scale needed to meet global objectives will preferably include agroforestry and smallholders, due to physical feasibility (area availability, participation of smallholder properties in degraded ecosystems) and social legitimacy (net benefits for the poorest). The *Global forest sector outlook 2050* highlights that the integration of small producers will require investments as well as enabling conditions for meaningful engagement (FAO, 2022a). Even though information on timber production from agroforestry is limited, evidence from Latin America and the Caribbean shows that the potential exists to achieve high productivity from fast-growing trees in agroforestry systems (FAO, 2022a). Rubberwood also represents an agroforestry option, even though productivity and quality vary across the globe and do not provide for a more reliable assessment of its potential. Efforts under the United Nations Decade on Ecosystem Restoration can create opportunities while addressing the challenges and providing the implementation capacity – through policies, technology and finance – to expand forest and tree planting in smallholder properties.

Furthermore, results from the *Global Forest Resource Assessment Remote Sensing Survey 2020* (FRA RSS 2020) show that 28 percent of croplands and 21 percent of grasslands comply with the FAO definition of trees outside forests (FAO, 2022b), confirming the potential for wood production in farms. Income and employment generated by wood production have been identified as relevant for fighting poverty in rural areas (FAO, 2022b; Miller *et al.*, 2021).

Enabling the virtuous cycle of restored ecosystems, sustainable landscapes and increased supply of wood fibre

The most recent IPCC report (2022) presents a strong case for enhanced contribution of planted forests and forest products to addressing climate change. Sustainably sourced agricultural and forest products, including long-lived wood products, can be used instead of more greenhouse gas-intensive products in other sectors. Enhanced use of wood is among the six mitigation options with the potential to deliver substantial emission reductions in the building sector by 2030 (IPCC, 2022). Effective adaptation options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture (IPCC, 2022). The potential climate benefits are clear, but their realization will depend on the integration of biophysical, socioeconomic and other enabling factors, as well as on the choices regarding the forest systems that are implemented, the types of wood products that are produced and substituted, and the technologies adopted (IPCC, 2022).

Restoration costs are high financially as well as socially, depending on the approach (Erbaugh *et al.*, 2020; Erbaugh and Oldekop, 2018; Santala *et al.*, 2022). Forests planted for commercial purposes, including monoculture plantations, are in the second lowest-cost range for forest restoration in tropical and subtropical countries, while agroforestry entails high establishment costs but low annual maintenance costs (FAO, 2022c). Consideration of commercial planting of forests and trees in pure or mixed-species plantation models can reduce the cost of restoration per capita while improving livelihoods and attracting investments. Within climate finance, plantations and reforestation, and carbon-neutral value chains such as using wood for construction, are areas where the private sector has shown positive investment signs (IPCC, 2022). Adopting policies, tenure systems and institutional arrangements that provide for appropriate landscape restoration planning, can enable the inclusion of sustainable production and successfully engage smallholders (Erbaugh and Oldekop, 2018; Santala *et al.*, 2022; Stanturf *et al.*, 2019).

Planted forests in all their forms will be instrumental in meeting global wood supply needs. They also have the potential to support accelerated progress in ecosystem restoration, while fostering more sustainable landscapes, carbon neutrality, and increased resilience and livelihoods. However, evidence shows that such a positive outcome depends on moving away from the business-as-usual trend, and this will require appropriate policies and tenure and institutional arrangements, and effectively harnessing science, technology and investments. Landscape and ecosystem planning with clearly identified management objectives, can contribute to embracing the role of planted forests and trees in all their modalities, taking into account the contributions and challenges associated with each model, management approach and species in their specific context.

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Optimizing the role of planted forests in the bioeconomy

Bolaina plantation in an agroforestry system

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Highlights

- Maximizing alignment between the bioeconomy and planted forests will require holistic approaches that balance the requirements of sourcing, processing and use.
- There is huge potential to leverage a much greater diversity of trees in planted forests.
- Action to increase demand for bioproducts needs to be coordinated with measures to develop the planted-forest sector and downstream capacities.

Planted forests and the bioeconomy: a typology of value chains

The biobased economy idea emerged from societal concerns and expectations for sustainable sourcing, curbing the use of fossil-based and non-renewable materials and reducing environmental impacts. Greenhouse gas (GHG) emissions from material production have risen from 5 gigatonnes CO_2-equivalent ($GtCO_2$-eq) in 1995 to 11.5 $GtCO_2$-eq in 2015, representing 23 percent of all global GHG emissions (Hertwich, 2021). In comparison, the global harvested wood products pool represented a net sink of 335 million tonnes CO_2-equivalent ($MtCO_2$-eq) in 2015 (Johnston and Radeloff, 2019). Consumption of raw materials, driven by population and economic growth, is projected to increase by 88 percent, from 89 gigatonnes (Gt) in 2017 to 167 Gt in 2060; and biomass demand by 68 percent, from 22 Gt to 37 Gt, mainly as wood rather than as food and feed (OECD, 2019). Shifting demand towards bioproducts is not enough: similar attention is needed to adjust production and sourcing of biomass so that the bioeconomy can be truly sustainable. Most of the increase in production will need to meet the Sustainable Development Goal (SDG) targets to halt deforestation and halt and reverse land degradation by 2030, while preserving primary ecosystems.

The relatively broad understanding of the bioeconomy concept as per the definition in Box 1 implies intersectoral linkages, including through sharing of data and information, and opportunities to tie the development of planted forests to broader economic and social development objectives, as clarified in the communiqué of the Global Bioeconomy Summit 2020 (IACGB, 2020).

We identify here three types of forest-based bioeconomy products and value chains, which bear different characteristics in terms of development constraints or enabling factors:

- conventional wood products and uses (e.g. roundwood, woodfuel and pulp);
- novel emerging wood products, comprising either innovative ways of using wood as a raw material (to substitute traditional roundwood uses), like engineered wood products (EWPs) used as structural elements in buildings, such as mass timber (Verkerk *et al.*, 2022), or using wood where it was not used before, leading to totally new uses of wood (like where replacing plastics); and
- non-wood forest products (NWFPs), which are quite diverse, resulting from modern innovations but often stemming from an original traditional or Indigenous knowledge and practice, for food, oils, fibres, aromatics, medicine, pigments, rubber, waxes and tanners.

This distinction is useful to analyse the development of forest-bioeconomy value chains, as their dynamics, structure and investment needs are quite different, as are their linkages to planted forests.

Box 1

Definition of the bioeconomy

The bioeconomy can be defined as "the production, utilization, conservation and regeneration of biological resources, including related knowledge, science, technology and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy."*

Note: * **GBS**. 2018. *Global Bioeconomy Summit 2018 – Conference Report. Innovation in the Global Bioeconomy for Sustainable and Inclusive Transformation and Wellbeing*. Berlin. https://gbs2020.net/wp-content/uploads/2021/10/GBS_2018_Report_web.pdf

Where will the production growth potential of the bioeconomy come from?

The first question is the physical availability of materials, such as wood for conventional and emerging uses, and for NWFPs. Global wood production has increased by only 16.5 percent from 2000 to 2020 (FAOSTAT, 2023). This is a very slow increase compared to other key global agricultural productions: during the same period, global crop production increased by 52 percent (FAO, 2022a). In fact, wood production does not follow population growth, which was 28 percent over the period considered (UN, 2023). This means that the wood sector is decoupled from global growth, and that there is a supply-constrained market, also evidenced in many regions by the increasing price of wood (USBLS, 2023), and growing competition for softwood timber between novel emerging uses, such as mass timber, and traditional uses (Nepal, Johnston and Ganguly, 2021). In general, production volumes of EWPs and NWFPs are not recorded as separate products in national and international forest products statistics (FAO, 2022b). According to analyses by market research groups,[11] EWPs represented about 275 million cubic metres (m^3) in 2021, equivalent to 7 percent of the overall roundwood removals of 3 967 million m^3 in 2021 (FAOSTAT, 2023).

The potential for production growth in the three categories (conventional wood, novel wood uses and NFWPs) comes from the following:

- **Better use of existing natural forests, but with a limited potential for production growth**. In 2020, 18 percent of the world's forests were protected areas, and 54 percent were under a long-term management plan (FAO, 2020). Roundwood production from naturally regenerated forests tends to be stable or slightly decreasing. In boreal forests, despite growing

[11] See for example: https://www.imarcgroup.com/engineered-wood-market

biomass stocks, industrial roundwood productivity gains would be limited by biodiversity- and carbon-driven policies. In tropical and subtropical regions where production has been relatively stable since the 1990s, there is room for productivity gains through higher efficiency in harvesting and primary processing, and use of lesser-known species (FAO, 2022b). Statistics on NWFPs do not reflect global consumption or production trends. Nevertheless, increased recognition of customary rights and clarification of tenure, measures to improve management plans and co-create knowledge with smallholders, local communities and Indigenous Peoples, and better access to markets could result in a significant production increase (FAO, 2022c).

- **Better wood use efficiency, and better hierarchy of uses and reuses of bioproducts**. For instance, half of the wood produced is currently used for energy, whereas energy uses could be seen as an end use only after several other uses and reuses of wood have taken place. Engineered wood product technologies can allow for the use of scrap, waste or less dense wood material for structural and construction uses, which previously relied only on denser woods with better mechanical properties.
- **Growth of planted forests, including in secondary forests and on degraded lands** (see article on the United Nations Decade on Ecosystem Restoration on p. 68). Planted forests now represent 7 percent of the forest area (294 million ha) and produce 46 percent of roundwood (FAO, 2020). Looking at projections for roundwood alone, projected demand is outstripping projected production. Held, Meier-Landsberg and Alonso (2021) estimate that the gap between roundwood demand (7.9 billion m^3) and production (4.3 billion m^3) will reach 3.6 billion m^3 by 2050. Closing this gap would require at least an additional 33 million ha of highly productive plantation forests, provided that productivity also increases from 2.3 m^3/ha to 8.3 m^3/ha (FAO, 2022b).
- **More diverse uses of both wood and non-wood products from different types of planted forests**. For instance, new wood technologies may allow processing and use of different species, encouraging their cultivation. Also, the growth and formalization of different NWFP value chains may provide a clear source of growth for the forest economy. For instance, in Brazil, in 2020, 40 percent of the revenue from products legally extracted from the forest was from NWFPs, compared to only 18 percent in 1998 (MAPA/SFB, 2022) (Box 2).

Key questions for sustainable sourcing

Growing the bioeconomy will require more planted forests and trees. However, whether on a small (Ratnasingam *et al.*, 2021) or larger scale (Pirard *et al.*, 2016), plantations have at times been negatively perceived, and it is therefore reasonable to assume that any significant expansion without careful management of the social and environmental concerns, could exacerbate such negative perceptions by local populations and global consumers. A sustainable bioeconomy will therefore require planted forests to fully address the concerns of negative social and environmental impacts (Malkamäki *et al.*, 2017).

Key questions are:

- How can planted forest development contribute to rural poverty alleviation, and how can we learn from good practices and mainstream them? How can marketing the corresponding bioeconomy products bring socioeconomic benefits to local communities where these products originate, and not just to downstream, often distant actors? (see Box 3). How can local actors become central agents of the bioeconomy, not just as producers, but also as transformers of raw materials into sophisticated products, and as innovators who add value to their landscapes?
- Where should we plant? What tools and approaches should be used to identify the right places to plant?

Box 2

The boom of açaí as an example of opportunities created by the growth of non-wood products

Until 1995, açaí was used mostly in the northern region of Brazil. In the last 20 years, its use has spread to the rest of Brazil and global markets, particularly the United States of America, Europe and Japan. Açaí pulp production now exceeds 250 000 tonnes per year, benefits more than 300 000 producers and adds at least USD 1 billion to the Amazon economy each year. Net income from açaí production ranges from USD 200/ha per year in unmanaged systems to up to USD 1 500/ha per year in managed agroforestry systems in the State of Pará, Brazil,* making it about ten times more profitable on a per hectare basis than cattle ranching in the Amazon.**

Notes: * **MAPA/SFB (*Ministério da Agricultura, Pecuária e Abastecimento/ Serviço Florestal Brasileiro*).** 2022. *Bioeconomia da floresta: a conjuntura da produção florestal não madeireira no Brasil*. Second edition. Brasília. ** **Braga, D.P.P.** 2019. *How well can smallholders in the Amazon live: an analysis of livelihoods and forest conservation in cacao- and cattle-based farms in the Eastern Amazon, Brazil*. Universidade de São Paulo. https://doi.org/10.11606/T.11.2019.tde-22082019-101655

How should we best grow a wide range of planted forest types and species (with intensified management) within a particular landscape while protecting biodiversity and providing ecosystem services such as soil protection, water regulation and erosion control?

- How can we ensure that decision-making is legitimate and shared among all stakeholders in the landscape, with regard to developing plantations that coexist with areas for conservation, and optimizing the restoration potential of degraded areas?
- What is the potential for agroforestry systems, trees on farms and well-designed, mixed-species planted forests, which can provide a wide range of uses and ecosystem services, as well as habitat connectivity for wildlife populations?
- What enabling policies and legal, regulatory and institutional frameworks are needed to facilitate the development of planted forests and their governance?

As solutions and answers to the above questions begin to take shape, it is essential to encourage evidence-based communication in order to sustain the demand for sustainability, legitimize perceptions of sustainability and fight misinformation (West and Bergstrom, 2021). This is one of the key objectives of the Collaborative Partnership on Forests' joint initiative "Sustainable Wood for a Sustainable World".[12] The need to be recognized as sustainable, including in the sourcing of raw materials, and through the use of sustainability labelling and certification, is critical since "recognized sustainability" is a main driver of demand growth as consumers are looking for sustainable options more than ever before (Economist Intelligence Unit, 2021).

[12] See: https://www.fao.org/collaborative-partnership-on-forests/initiatives/sustainable-wood-for-a-sustainable-world/en

Towards a coordinated approach to leverage the bioeconomy for the development of planted forests

Bioeconomy development is often supported by a variety of policies and incentives, market regulations, and recycling and reuse regulations, such as for mandatory incorporation of bioproducts into construction and housing, or rules governing plastic use – several countries have recently introduced bans on disposable plastic plates and cutlery – or incentives for integrating NWFPs into public sourcing programmes.

Development of planted forests and the bioeconomy should go hand in hand. Action to increase demand for a variety of bioproducts needs to be coordinated as much as possible with measures to develop the planted forest sector and downstream capacities. Failing to do so poses two risks: (i) introducing capacity gaps in production, or ending up with a forest

Yangambi engagement landscape in Yanonge, Democratic Republic of the Congo economy that delivers on product categories that are not aligned with the potential bioeconomy demand; and (ii) having products that while considered sustainable from a "use" perspective – for instance substituting plastic with wood, or improving nutrition by incorporating new NWFPs into the diet – are not sustainable from a production or landscape perspective.

Avoiding misalignment between the bioeconomy and planted forests will require an "all-in-one", holistic and context-specific approach that balances the requirements of sourcing, transformation and varied uses: the right production systems, for the right trees, in the right places, for the right products, and for the right uses and reuses. There is huge potential in leveraging a greater diversity of trees than those currently planted and used, from the pool of more than 14 000 useful tree species available worldwide (Kindt *et al.*, 2022).

For instance, maximizing the possibilities for reuse and recycling of wood needs to combine meaningful choices on wood processing technologies, suitable wood species and appropriate silvicultural practices. Also, a key issue is to leverage the potential of short value chains for bioeconomy products and to develop spatial logistics, physical markets and infrastructure, as well as local capacities and competencies for wood and bioproduct conversion in rural areas.

Coordination across sectors and along value chains is crucial for identifying where the many demands originate (e.g. from construction, chemicals, energy, food and medicine), how to prioritize uses and reuses for different raw materials, their conversion and their uses. This should lead to the identification of key bottlenecks, and support and capacity-building needs for different actors (especially in the transformation part of these value chains). All of this should link to land-use planning for plantations and logistics infrastructure, and should take into account the potential of short value chains and local ownership and employment (EC, 2022). The model of bioeconomy clusters such as the Amazon 4.0 model considered for the Amazon (Nobre and Nobre, 2020) is particularly promising, where technological innovation, business model construction, business incubation, research and development, value chain development and discussion about incentives and regulations can all happen at the same time. Marketing NWFPs on a larger scale while building on traditional agricultural systems (e.g. açaizais for açaí) will require intersecting priorities for planted forests with priorities for farming systems (Abramovay *et al.*, 2021; Fernandes *et al.*, 2022).

Such a coordinated enabling environment can attract funding and investment to the forest sector and planted forests, and towards innovation downstream in the value chains, such as for innovation support, mobilizing concessional loans and blended finance. This can be complemented by capacitation, including from regional and international levels and actors, to allow the sharing of South–South and North–South experiences.

The successful integration of planted forests into the bioeconomy will require pulling the right levers but also careful planning, value chain coordination and consideration of environmental and social factors. If successful, it will represent one key example of how to combine economic development with environmental stewardship.

Box 3

Connecting smallholder plantations to formal markets: the case of bolaina in Peru

On-farm timber production can be an important subsistence and economic activity of smallholder farmers around the world. The bolaina (*Guazuma crinita*, see photo on p. 11) value chain in Peru provides a valuable example of the coordinated package of actions that is required to develop value chains. This fast-growing species grows naturally on fallow land, thus providing a simple and cost-effective way of producing timber that can be integrated into agricultural activities. The value chain has developed organically, but as a forest product, bolaina timber falls under conventional forestry regulations, which are not always smallholder friendly.* The challenge is to formalize the sector while ensuring that it remains fully inclusive of smallholders. One way forward is the creation of a network of small producers working with medium to large "anchor companies" with modern plantation management technologies, thereby allowing the generation of products for the national market and the creation of jobs with good working conditions.**

Notes: * **Sears, R.R., Cronkleton, P., Miranda Ruiz, M. & Pérez-Ojeda del Arco, M.** 2021. Hiding in Plain Sight: How a Fallow Forestry Supply Chain Remains Illegitimate in the Eyes of the State. https://doi.org/10.3389/ffgc.2021.681611

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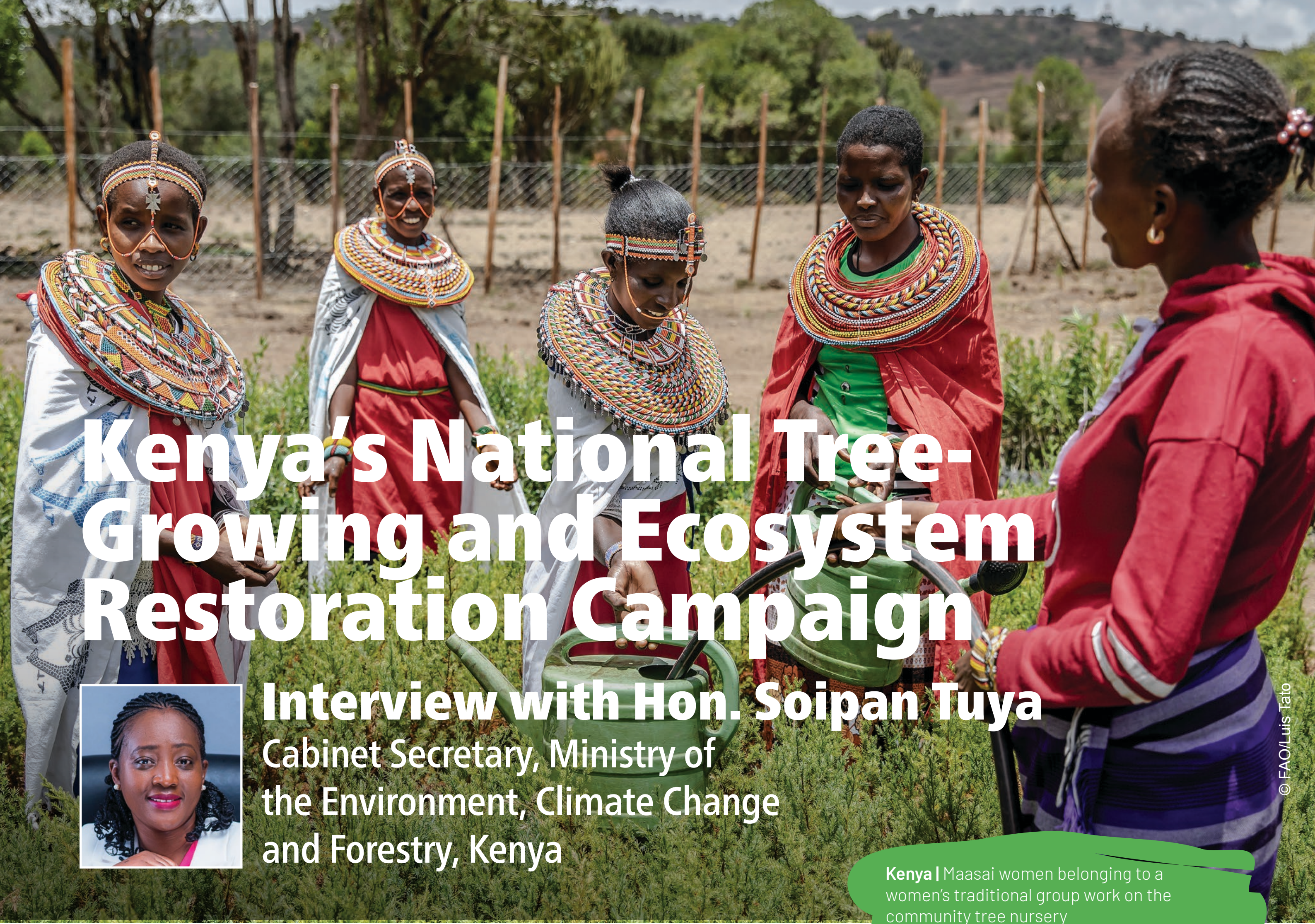

Kenya's National Tree-Growing and Ecosystem Restoration Campaign

Interview with Hon. Soipan Tuya

Cabinet Secretary, Ministry of the Environment, Climate Change and Forestry, Kenya

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Kenya | Maasai women belonging to a women's traditional group work on the community tree nursery

Can you tell us about guiding priorities, challenges and opportunities for the forest sector in Kenya?

ST: The forest sector is at the core of the socioeconomic transformation of Kenya, as outlined in the current administration's Bottom-up Economic Transformation Agenda (BETA), which prioritizes the opening-up of key value chains, including forestry, for wealth and employment creation.

To demonstrate this commitment, the government has created 7 300 jobs through the recruitment of 2 700 forest rangers, 600 forestry officers and 4 000 Green Army workers to support seedlings production and provide forestry extension services.

The Green Army are the first cohort of 100 000 youth that the government intends to progressively recruit to support our country's National Tree-Growing and Ecosystem Restoration Campaign, which is targeting to plant 15 billion trees by 2023.

The Green Army will be involved in the propagation of adequate seedlings to support our ambitious tree-growing initiative and provide extension support to communities, individuals and investors involved in agroforestry and commercial forestry.

Key challenges in forest management in Kenya are:

i. Bridging the gap between supply and demand for wood, with demand estimated at 48 million cubic metres (m^3) against a sustainable supply of 32 million m^3, and 70 percent of the national energy needs met by wood.

ii. Optimizing the supply of forest goods and services against competing demands from industry, livelihoods and meeting our environmental ambitions.

iii. Reducing pressure for conversion of forestland to agriculture, settlements and other developments.

iv. Enhancing efficient utilization of timber by forest industries by attracting modern technologies for wood conversion.

v. Mobilizing adequate finance to support forest sector development.

vi. Strengthening tenure security to support forest investments, especially in community and private forests.

vii. Promoting forestry as viable commercial enterprises to support rural livelihoods and reduce poverty.

The greatest opportunity for our country's forest sector is in the National Tree-Growing and Ecosystem Restoration Campaign, which broadly seeks to raise the national tree cover to 30 percent by 2032 by planting 15 billion trees.

At the core of this national flagship programme championed by His Excellency President Dr William Ruto, is the opening-up of the Kenyan forest

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Kenya | Maasai women belonging to a women traditional group work on the community tree nursery

sector to increased private sector investment, especially in agroforestry and commercial forestry.

In this regard, the ministry has mapped out potential landscapes for commercial forestry across the country. These areas are mostly in the vast northern rangelands, which have high potential for ecosystem restoration.

My ministry therefore calls on the international and local private sector interested in investing in Kenya's emerging commercial forestry to partner with us.

With a Kenyan population projected to reach over 95 million by 2050 (UN DESA, 2017), domestic consumption of wood is expected to increase sharply. What levers is the Government of Kenya activating to increase local wood supply?

ST: Kenya has an estimated annual wood supply deficit of 15 million m^3 and which is expected to rise to 24 million m^3 by 2030. This deficit is met by imports from neighbouring countries and harvesting from unsustainable sources. This manifests as deforestation and land degradation in the various landscapes across the country.

Bridging the gap between supply and demand of forest products requires policy interventions that incentivize scaling-up of sustainable wood production and use by the public and private sector. This will involve improved efficiency in the management and utilization of public forest plantations and establishment of commercial forest enterprises by the private sector on community and private lands. The arid and semi-arid lands present the best opportunities for commercial wood production at scale. This has been identified as a key focus of the National Tree-Growing and Ecosystem Restoration Campaign.

To incentivize actions on the ground, the government is investing in the following policy actions:

i. Review of the National Forest Policy to provide incentives for private sector investments in commercial forestry.

ii. Review of the 2016 Forest Conservation and Management Act, to provide for sustainable management of public forest plantations.

iii. Investments in mass production of high-quality seeds and seedlings by the public and private sector.

iv. Development of a framework for public–private partnership to catalyse investments in the forestry value chain, including the furniture and construction industries.

v. Development of regulations, standards, certification schemes and codes of practice for the timber industry as an opportunity for attracting investments in high-efficiency timber manufacturing technologies and value addition.

As mentioned earlier, as a ministry, one of our foremost priorities is the promotion of agroforestry and commercial forestry, as part of the National Tree-Growing and Ecosystem Restoration Campaign and its ambitious 15 billion tree target. Our motivation for prioritizing agroforestry and commercial forestry is threefold.

The first reason is to open up the sector for the creation of wealth and employment, which are key deliverables for the government. The second is to meet our climate action ambitions of expanding our carbon sinks and safeguarding water sources. And the third reason is to bring social and economic benefits to households where ordinary Kenyans involved in tree growing can draw monetary and social value from their wood, fruit and nut trees.

We believe that it is through enhanced private sector investment in agroforestry and commercial forestry that Kenya will be able to meet its growing demand for wood, and end illegal logging of natural forests and the destruction of life-sustaining ecosystems, such as wetlands and water towers.

In December 2022, the Government of Kenya under President Ruto launched a national tree-planting initiative aimed at planting 15 billion trees by 2032. How can finance and investments be triggered into a sustainable forest sector to achieve this?

ST: As a ministry, we have developed and are rolling out a comprehensive strategy to help us deliver the National Tree-Growing and Ecosystem Restoration Campaign and its 15 billion tree-planting target.

As part of this strategy, we have worked on several financing and investment models that include public-private partnerships, private investments and adoption of degraded ecosystems for restoration, among other arrangements.

As mentioned earlier, we see agroforestry and commercial forestry as having the greatest potential for ensuring that we have a sustainable and thriving forest sector in Kenya. Sustainability for us as a country means that the forest sector should be able to meet our climate action obligations, contribute more to our socioeconomic well-being through wealth and employment creation, and meet Kenya's growing wood requirements going forward.

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Kenya | Woodlot farmer Ruth Wairimu gets some fuelwood from the trees at her wood farm

Increasing the resilience and social acceptance of planted forests to safeguard production

New Zealand | Radiata pine plantation

Serajis Salekin, Senior Forest Scientist, Scion (New Zealand Forest Research Institute Ltd)

Tim Payn, Principal Scientist, Scion (New Zealand Forest Research Institute Ltd)

Highlights

- The capacity of forests, especially planted forests, to meet increased forest product demand is pivotal for the transition towards a bioeconomy.
- Climate-change risks and community perceptions suggest a need for more climate-resilient and socially accepted planted forests.
- Such forests will need to provide a wider range of products and services, and have higher productivity, than they do currently.

Introduction

Forests account for 31 percent of the total land area of the world, but this forested area is neither equally distributed among geographic regions nor proportionally allotted to the populations that they harbour. The dynamics of global forest cover and its resources are varied in a complex way (MacDicken, 2015) even though a continuum of forest ecosystems services exists between different forest states (Harris, Goldman and Gibbes, 2019).

In addition, the global forest area is slowly but consistently decreasing over time (FAO, 2020). This process is modulated by various human and climatic impacts (Alkama and Cescatti, 2016; Lucas, 2023). As part of this, a growing global population and increasing demand for wood products to support a lower-carbon, biobased economy are putting extra pressure on forests (Eyvindson, Repo and Mönkkönen, 2018).

On a broad scale, forests can be placed on a continuum of human disturbance spanning natural forests to intensively managed plantations (Payn, 2021). In this paper, we are focusing on trends in planted forests globally. Planted forests are defined as "forest that at maturity is predominantly composed of trees established through planting and/or deliberate seeding of native or introduced species" (FAO, 2020, p. 27). Planted forests are managed for a wide range of goods and services but predominantly for timber production and have a long history, with some early references from the sixteenth century in the United Kingdom of Great Britain and Northern Ireland (Evans, 2009).

Plantation forests (a subset of planted forests) originated in their modern, organized form in Germany during the eighteenth century (Evans, 2009). According to the *Global Forest Resources Assessment (FRA) 2020*, plantations are planted forests that are intensively managed and meet all the following criteria at planting and stand maturity: one or two tree species, even-age class, and regular spacing which can readily distinguish them as artificial (Evans, 2009; FAO, 2020). Plantation forests are conceptually and practically established to fulfil the diverse global demands for goods and services from forests, for example, soil and water protection, biodiversity conservation and other non-timber social services (Bauhus *et al.*, 2010). Introduction of exotic tree species, and a focus on intensive management, have accelerated the development of plantations and their new management approaches (Evans, 1999). Since their inception, production of industrial wood, the initial purpose of plantation forests, has increased and has been predicted to grow more rapidly in the future (Payn *et al.*, 2015; Sedjo, 1999). In addition, plantation forests have significantly expanded to satisfy a variety of global needs, for example, forest protection and restoration, climate regulation, and protection of soil and water resources (Barua, Lehtonen and Pahkasalo, 2014; Charnley, 2005). Additionally, a new suite of forest products that can support a low carbon bioeconomy through replacement of fossil carbon is emerging and places more demands on production forests (Howard *et al.*, 2021).

This article explores the role of planted forests, including plantations, in meeting these future needs to 2050 and identifies some of the challenges and solutions.

Global planted forest areas continue to increase in 2020

All planted forests

Globally, all planted forests (plantations and other planted forests) comprised 7 percent of the total forest area in 2020. While the natural forest area decreased from 2000 to 2020, the planted forest area increased from more than 210.7 million hectares (ha) to approximately 294 million ha, an increase of approximately 81.9 million ha, partially compensating the decrease in global forest area (Figure 1), though rates of increase in planted forest area have slowed over the last two decades. The availability of annual remote-sensing data from 2015 onwards reinforces this observation. Scale and rates of increase varied across both climate domains and regions. Similar to global forest cover, most planted forest area

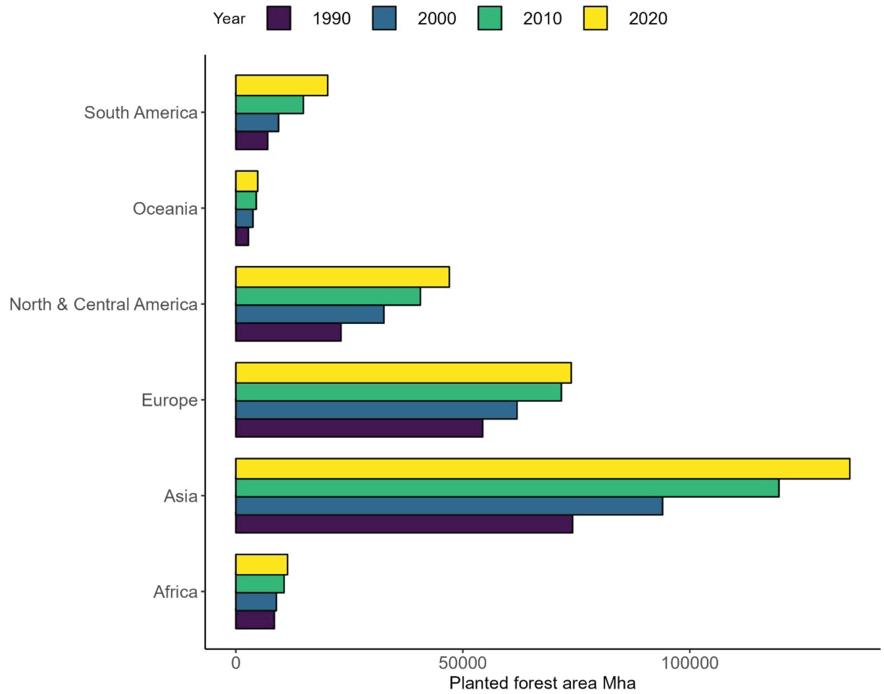

Figure 1. Trends in area of planted forests by FAO region

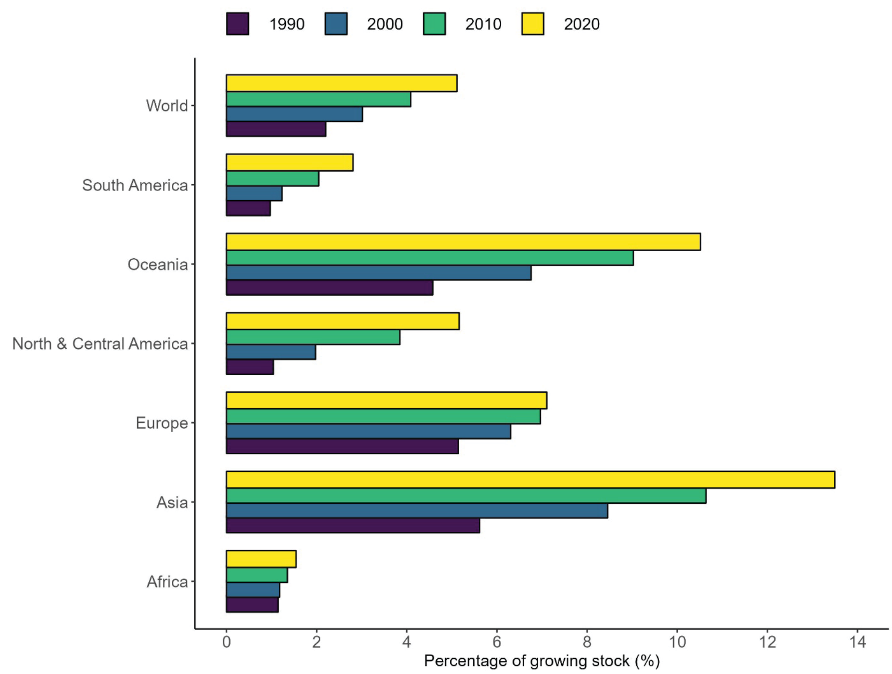

Figure 2. Growing stock in planted forest by region as a percentage of total forest growing stock in 1990–2020

Source: Adapted from **FAO.** 2020. *Global Forest Resources Assessment 2020: main report*. Rome. https://doi.org/10.4060/ca9825en

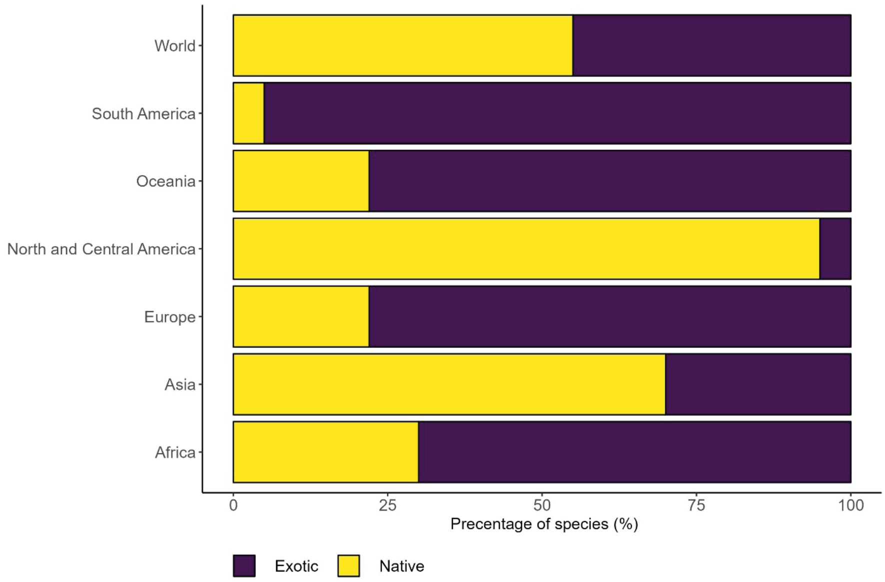

Figure 3. Proportion of native and introduced species in plantation forest, by region in 2020

Source: Adapted from **FAO.** 2020. *Global Forest Resources Assessment 2020: main report*. Rome. https://doi.org/10.4060/ca9825en

is found in the tropical and boreal climatic domains, and the Asia and European regions, respectively.

In 2020, growing stock in planted forests made up just above 5 percent of the total global forest growing stock, increasing by over 2 percent since 1990. As with area, the growing stock also increased and varied with climate domain and region. In 2020, Asia had the highest proportion of growing stock in planted forests, followed by Oceania (Figure 2). The growing stock in planted forests is dominated by conifers (*Pinus* spp. and *Picea* spp.) with very little contribution from hardwoods, reflecting the worldwide demand for softwood timber and fibre (WWF, 2012).

Plantation forests

Between 1990 and 2020, the rate of increase in plantation forest area was greater than for other planted forests. According to FRA 2020, the highest proportion of plantation forest is in South America and constitutes about 99 percent of the total planted forest area (FAO, 2020). The second largest is in Oceania (91 percent). The tree species choice in plantations can be more tailored towards end use – for instance introduced fast-growing softwoods (e.g. pines) or hardwoods (e.g. eucalypts). According to FRA 2020 (FAO (2020), global plantation forest species composition has a ratio of 56 percent of native to 44 percent of introduced species (Figure 3) overall. However, this varies regionally, with South America, Oceania, Europe and Africa having a higher proportion of introduced species, while Asia and North and Central American plantations comprise more native species.

Discussion

The area of planted forests has been steadily increasing over the past 30 years, and this increase is expected to continue until 2050, though at a slower rate. Korhonen *et al.*, 2021 projected this increase by taking into consideration the impact of development pathways on planted forest area expansion and concluded that the increase could, depending on scenarios, be around 20 million ha to 40 million ha. In concert with this, planted forest growing stock is also expected to increase globally. In 2015, planted forests were estimated to contribute around 46 percent of the global industrial roundwood production (Nepal *et al.*, 2019). As natural forest deforestation is expected to continue, planted forests will therefore make up an increasing proportion of global forests and become even more important as a source of forest products and ecosystem services.

Consumption of forest products is projected to increase significantly by 2050. Projections of consumption beyond 2020 range between 37 percent under a business-as-usual scenario and 60 percent on new bioeconomy-related scenarios, including the use of wood to substitute non-renewable materials (FAO, 2022). Beck-O'Brien *et al.* (2022) projected a 28 percent increase in consumption by 2050 and noted that none of the range of supply considerations that they developed could match this increase in demand, pointing to a demand-driven expansion of the area of planted forests.

Planted forests, and especially intensive plantations, are one of the most important mechanisms to meet this demand. FAO (2022) calculated an additional 33 million ha of plantations would be needed to meet future wood-based needs. Establishment of significant areas of new forests and ensuring incremental growing stock will be critical if demand is to be met. However, meeting these demands is predicated on achieving a sustainable increase as well as providing the required products, predominantly roundwood. Major countries with significant amounts of plantation forests are also focusing more on management of forest ecosystem services in addition to timber (Yao *et al.*, 2021). These changes in focus could lead to a decrease in supply due to trade-offs between timber production and other ecosystem services.

There are three major risks to meeting the projected demand by 2050.

Climate change impacts, such as increase of fire, intense and frequent droughts, plus introduced pests and diseases are the largest risk to productivity of existing and new planted forests (Soucy *et al.*, 2020).

Social perceptions and the acceptability of planted forests, especially intensive industrial plantations are putting pressure on existing management approaches and the ability to establish new forests (Palátová *et al.*, 2023).

Understanding the world's forests: the Global Forest Resources Assessment process

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`Since 1946, FAO has been conducting Global Forest Resources Assessments (FRA) at 5- to 10-year intervals. The reporting content has evolved over time to respond to the needs of the times. Recent and ongoing developments in the international forest policy arena, such as the 2030 Agenda for Sustainable Development, the United Nations Strategic Plan for Forests 2017–2030 (UNSPF), the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework have had an impact on the scope of FRA 2025. Furthermore, FRA has evolved thanks to technical guidance from international specialists and organizations provided through expert consultations. To reduce the reporting burden on countries, FAO has streamlined the FRA reporting content and improved the online reporting and review platform, with the aim of enhancing efficiency and transparency of the data collection process. FRA 2025 collects data for the planted forest category, which includes other planted forest and plantation forest, with a subcategory of plantation forest of introduced tree species.

FAO provides technical support to the network of officially nominated national correspondents for the compilation of country reports. A series of regional workshops were organized during 2023 to facilitate this process. The FRA 2025 data collection was initiated in early 2023, and the reported data will be validated and analysed during 2024. The key findings, main report, 236 country reports, an interactive database and other related products are being released in 2025.

Note: For more information, see https://www.fao.org/forest-resources-assessment/en/ and **FAO.** 2023. *Country reporting process and voluntary updates. FRA 2025*. Forest Resources Assessment Working Paper 192. https://www.fao.org/3/cc4687en/cc4687en.pdf

The purpose of forests and the mix of products and services are also an emerging factor potentially reducing roundwood supply, due to increasing interest in forests for their ecosystem services such as carbon or soil protection and the potential increased demand for new bioeconomy-related products, such as liquid biofuels or bio-plastics rather than timber and timber products (Soucy *et al.*, 2020).

In light of these risks, there is a great deal of uncertainty around the ability of planted forests to meet the increased demand. There are a number of mitigation approaches that can be used: mitigating climate risk by developing more resilient forest systems; working with communities on improving social acceptance of planted forests; and evaluating opportunities to enhance productivity from planted forests. All of these responses will require changes to the way forests are designed and managed.

Climate change-related risks have been reported in Payn *et al.* (2015). To address these risks, forests need to be looked at from a resilience perspective to ensure persistence, recovery and reorganization processes (Falk *et al.*, 2022; Messier *et al.*, 2022), especially when considering monospecific plantation forests (Messier *et al.*, 2022). Paquette and Messier (2011) proposed a more complex and multipurpose plantations strategy, where plantations, including monocultures, can be improved by applying appropriate site preparation to reduce soil disturbances, or spatio-temporal diversification to increase biodiversity conservation. This idea was revisited and refined by Jones *et al.* (2023) through a transitional forestry approach, focusing on purpose-led forestry that is diversified and socially connected.

WWF's New Generation Plantations programme[13] (refer to the article on the contribution of properly governed plantations on p. 91 with others such as The Forests Dialogue[14] (see article on p. 84) are focusing on socially acceptable plantation models. Perceptions of planted forests can be negative and hard to improve. This can lead to challenges to both existing forests and their management, and also opposition to expansion of forest area where for instance, there are concerns about effects on local communities or land lost from food production or biodiversity. The social challenge is likely to be the biggest issue facing the ability to expand forest area to meet demand. Adapting new management models, dialogue and education are solutions.

One big opportunity to mitigate risk of social acceptance of forest expansion is to increase productivity in existing forests. This avoids most of the social issues from afforestation and expansion of the forest area. This can be done through improvements in genetics deployed on replanting harvested areas; new silvicultural regimes, such as crop stocking and pruning; and intensification through appropriate site preparation and use of fertilizers, vegetation and pest control, and technical innovations and processes, such as precision forest management and automated forestry operations.

Conclusion

Demands for products and services from forests are projected to continue to increase globally, and these demands will be affected by a range of

[13] https://newgenerationplantations.org/
[14] https://theforestsdialogue.org/

factors such as increasing population and climate change responses. Also, the mix of products and services is broadening away from the past predominant focus of timber production. Planted forests have a major role to play in meeting these demands, especially intensively managed plantations. However, projections of positive, slower and variable increase in area and growing stock cast uncertainty around the ability to meet the future demand. Challenges to be overcome include development of resilience to climate risks and social barriers to planted forest area expansion. In addition to these challenges, we suggest that focus on increasing productivity from existing planted forests would be an area worthy of further exploration.

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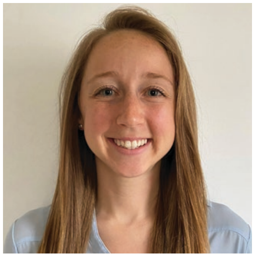
Mapping planted forests on a global scale



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Highlights

- Data from satellite imagery typically do not distinguish between natural and planted forests or provide species information.
- The Spatial Database of Planted Trees (SDPT) enables the creation of planted-forest maps on a global scale.
- The accuracy of the SDPT will continue to improve due to local and national mapping efforts and ongoing advances in large-scale mapping.

Earth observation data have made it increasingly easier to monitor the world's forests. The free availability of quality, high-resolution imagery and improved processing capabilities have resulted in numerous maps of tree-cover change, such as the Global Forest Change product, as well as deforestation alerts for rapidly detecting changes in forests (Hansen *et al.*, 2013, 2016; Reiche *et al.*, 2021). The online Global Forest Watch (GFW) platform aims to increase public accessibility of these and other datasets derived from Earth observation data, enabling anyone to see how forests are changing around the world. However, these data typically identify tree cover, or tall woody vegetation, and do not distinguish between forest types, such as old-growth primary forest, secondary natural forest or planted forest, or provide information on species composition.

It is important to distinguish between these forest typologies for a comprehensive view of how forests are changing. Planted forest maps specifically can aid with sustainable forest management, and better account for carbon stocks. In removing planted forest areas from Earth observation data, natural forest can be identified, which is needed for a variety of applications, including assessing international commitments related to zero deforestation.

But creating these forest typology maps remains a challenge. It is hard to distinguish forest types within tree cover mapped by Earth observation data, especially at a global or even regional scale. The spectral and structural characteristics of tree canopy needed to separate forest types using automated algorithms are often indistinguishable between natural and planted forest and even tree crops in satellite imagery, especially in areas of mixed-species plantations and mixed land uses. Hand digitization can yield high-quality maps, but they are time-consuming to create and become outdated quickly. Many country and subnational plantation maps exist via automated classification or hand digitization methods, but few datasets are available for larger geographies, and attribute information such as species information is limited.

Given current capabilities with Earth observation data, these disparate national level spatial data are needed to map planted forests on a global scale. While this can lead to inconsistencies, it also allows for local representation in a global product.

To meet the need for planted forest maps on a global scale, researchers at the World Resources Institute created the Spatial Database of Planted Trees (SDPT), a harmonized database of the world's planted forests and tree crops. The database aims to spatially differentiate plantation forests and tree crops from natural and semi-natural forests on a global scale. At the time of its publication in 2019, no method had been developed to delineate forest plantations and tree crops from satellite imagery in a globally consistent way, and the SDPT served to fill that gap. The creation of the database involved extensive outreach to compile, synthesize and harmonize national and regional maps of planted forests into a global map. It allows for reporting on tree-cover change statistics within natural vs. planted forests, while also increasing public access to planted forest data. The SDPT acts as a living database that will continue to be updated as new data products are released.

Version 1.0 (v1.0) of the database covered a total of 94 countries (Harris, Goldman and Gibbes, 2019). While reference years differed by country, the database as a whole was nominally representative of the year 2015 and represented 59 percent of the total planted forest area reported by the *Global Forest Resource Assessment 2015* (FRA 2015) (FAO, 2016). Version 2.0 (v2.0), released earlier this year, includes data for 166 countries and is representative of the year 2020 (Figure 1; Richter, Goldman and Harris, forthcoming). The SDPT is sourced from a mix of independent researchers, governments and non-governmental organizations (NGOs), with priority given to the most recent, detailed and localized data available. In v2.0, most countries have data sourced from a combination of individual researchers and NGOs. However, many include a mix of government and individual researchers as well. The database now reaches global coverage, making up 264 million hectares (ha) or 90 percent of the total planted forest area reported by the *Global Forest Resource Assessment 2020* (FRA 2020)(FAO, 2020).

Major challenges still remain in mapping planted forests in a harmonized manner, including definitional and temporal inconsistency, absence of a uniform accuracy assessment and minimal species information. Definitions for planted forest change over time and differ across countries, making it difficult to conform to a common definition on a global scale. Therefore,

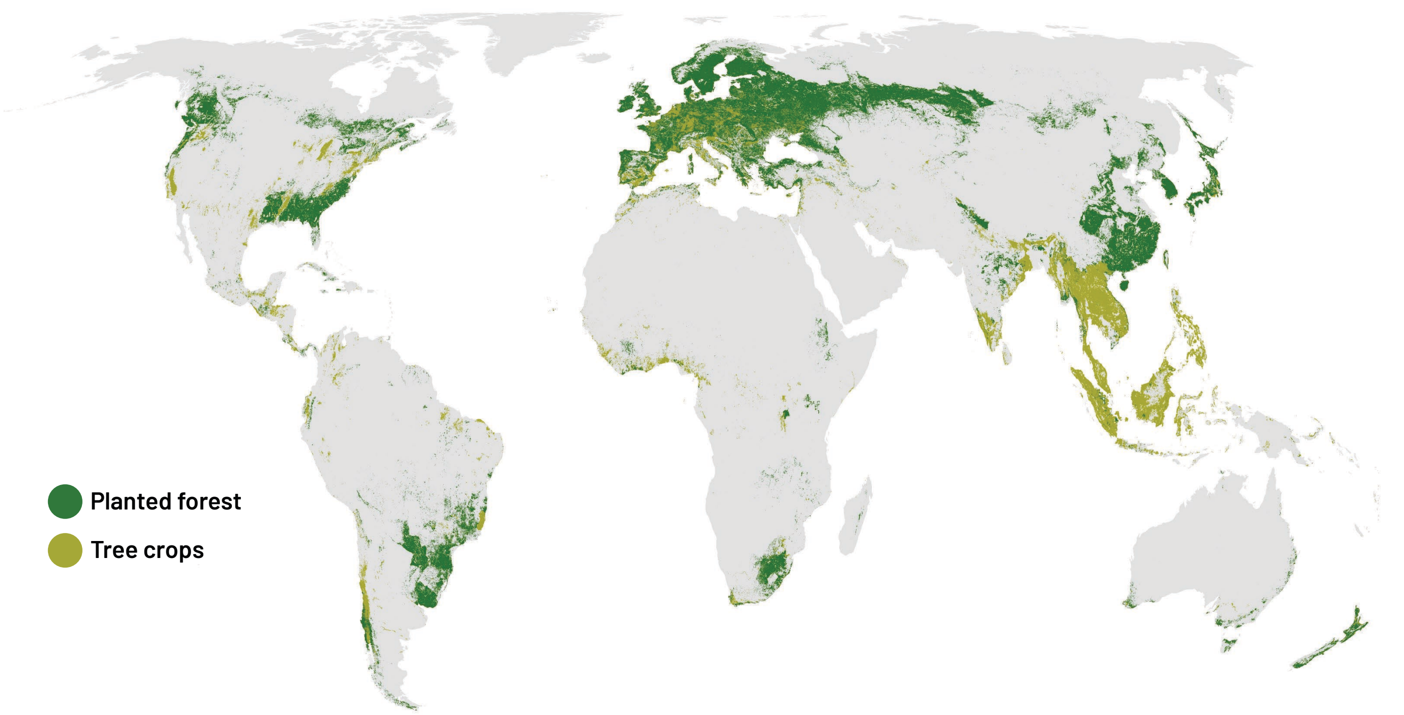
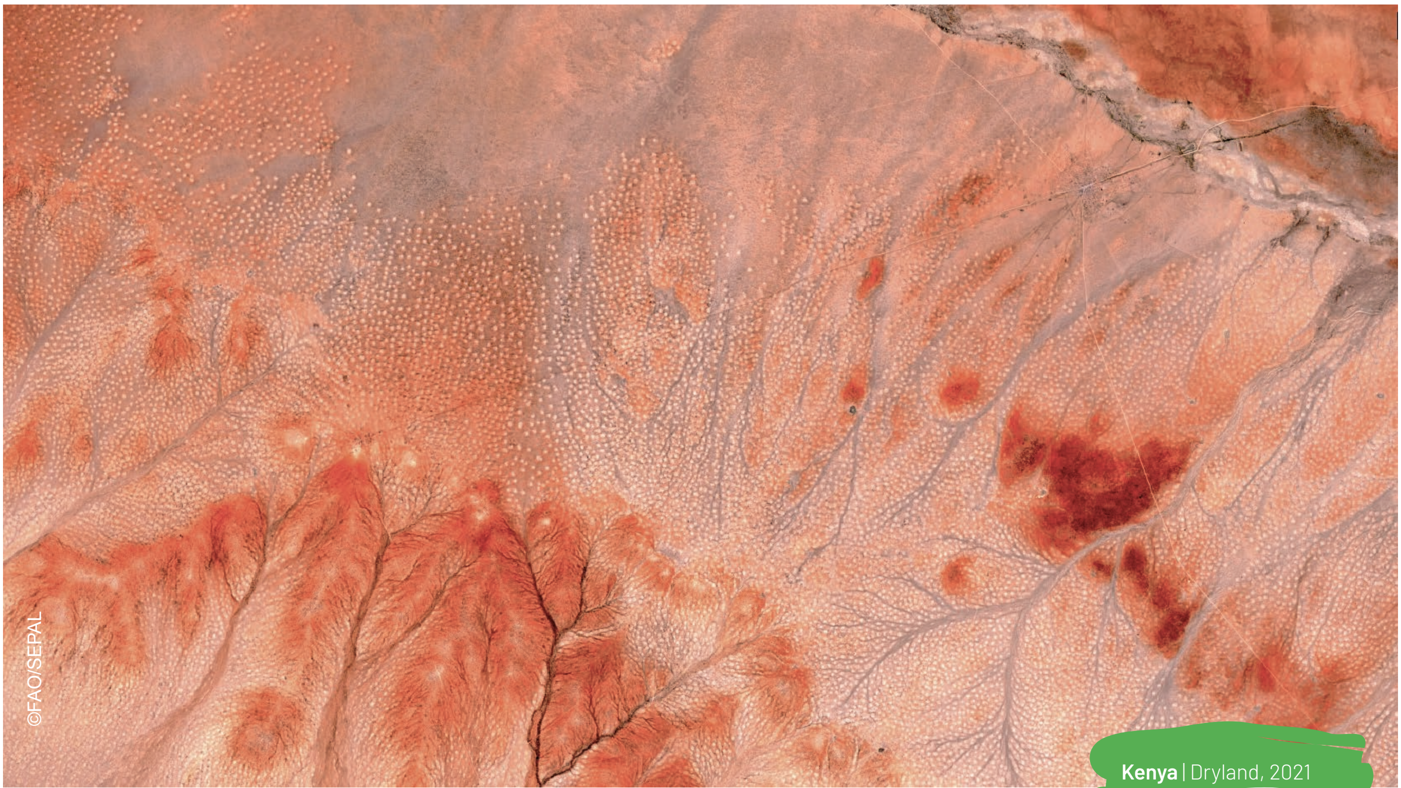


Figure 1. Global map of planted forests and tree crops in SDPT v2.0

Source: compiled by the World Resources Institute. Basemap source: **GADM**. 2022. *GADM* [shapefiles]. Cited 6 November 2023. https://gadm.org/



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Kenya | Dryland, 2021

planted forest areas have been included in the SDPT on a case-by-case basis, depending on the unique classification structure of each data source. The SDPT was not intended to resolve definitional debate but rather to increase access to planted forest data in a consistent, organized format. Temporal inconsistency also remains a challenge as planted forest and tree crop data are available across different representative years. In SDPT v2.0, data ranges from 2000 to 2021 with a mode year, that is, the most frequent year in the dataset, of 2020. A planted year attribute will be added in v2.0 to allow users to control temporal variation across national and global scales.

In addition to definitional and temporal inconsistencies, a lack of uniform accuracy assessment is also a limitation. Accuracy information for each dataset, when available, is documented in Richter, Goldman and Harris (forthcoming). Most maps compiled for the SDPT were derived from Landsat, SPOT or RapidEye satellite imagery, with a spatial resolution of 30 metres or finer. The method for image interpretation varied from country to country. Some used visual interpretation of images while others used automated per-pixel classification methods. In v2.0 of the SDPT, maps were compiled "as is", therefore some sources do not have any validation information and may contain substantial biases that have not been evaluated. Global validation of the SDPT in its current form would be challenging due to the absence of uniform definitions, different dates of the datasets and, in some cases, mapping of mosaic plantation classes rather than actual locations of planted trees. As mapping methodologies improve among national and regional sources, accuracy assessments are likely to be more readily available.

Species information will also be more readily available as mapping methodologies improve over time. Currently, only a third of countries in SDPT v2.0 contain species information. The utility of the database will certainly improve with the addition of more species information, as sustainable forest management and carbon stock accounting both benefit from the inclusion of species characteristics. The detection and tracking of illegal logging activity will also progress as the harvesting of species within natural vs. planted environments often has differing legal implications.

Despite the challenges characterizing planted forests in a globally consistent way, local- and national-scale mapping efforts are progressing. International initiatives, such as the United Nations Decade on Ecosystem Restoration are encouraging efforts to identify and monitor planted forests, especially as a driver of land restoration (Marshall *et al.*, 2022).

The ubiquity of open-source software and processing platforms (Coetzee *et al.*, 2020) and large amounts of freely available satellite remote-sensing data, including high spatial and temporal resolution data provided via the NICFI/Planet data agreement (Planet Labs PBC, 2020) enable anyone from individual landowners to large government agencies to map planted forests in a more transparent way, potentially incentivizing greater consistency and accuracy as monitoring efforts mature.

As locally relevant datasets on planted forests are produced, these can feed back into the SDPT and support national FAO FRA reporting. The aforementioned challenges facing the consistency of mapping planted forests on a global scale will remain, of course. Through continual improvement and concerted efforts to increase information collection on species and operationalize detection and monitoring, however, the utility of planted forests databases will certainly increase.

Already, significant advances in large-scale planted forest mapping have materialized, including recent efforts by Descals *et al*. (2021) and Lesiv *et al*. (2022), which used consistent definitions and methods, respectively, to map planted forests and tree crops on a global scale. Improvements in Earth observation across all scales – national, regional and global – will be key to mapping planted forests efficiently and effectively over the next decade and will inform future forest management across the globe.

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Expanding China's tropical planted forests to meet future timber demand

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Highlights

- China's tropical planted-forest estate, especially eucalypt species, is expanding.
- Nevertheless, domestic production cannot meet demand, and China is a major importer of tropical primary wood products.
- The aim of the National Strategic Timber Reserve and Production Base Programme is to establish an area of 20 million hectares of planted forest by 2035 for ongoing industrial supply.

The global wood product market has been changing rapidly in the last few decades, and China is playing a significant role in driving some of these changes by influencing the demand and supply of tropical wood products. In this article, we review the status of tropical planted forests in China, and forecast the future supply of tropical primary wood products.

Tropical planted forests in China

China's planted forests span over an area of 84.7 million hectares (ha), making up 38.5 percent of the total forest area in the country. Plantations account for 54 percent of China's planted forests (FAO, 2020). According to the Ninth National Forest Inventory (2015–2018), 6.23 percent of the total forest area across the country was classified as tropical forest.[15] While 48.87 percent of the total tropical forested area was considered planted forests (6.71 million ha) in 2018, the growing stock of tropical planted forest only amounted to a quarter of the total growing stock of tropical forest in

[15] Tropical forests are forests that are similar in ecology and floristics to forests in Southeast Asia, occurring on lowlands at below 1000–1200 metres. See Zhu (2017).

the country. The natural forest logging ban policy implemented nationwide in 2017 (Liu, Zhao and Chen, 2023) has led to changes in the sourcing of tropical wood in China. Consequently, tropical wood in 2018 came mainly from planted forests, with the main species being eucalyptus (*Eucalyptus globulus* Labill., *Eucalyptus citriodora, Eucalyptus robusta* and *Eucalyptus grandis*) and rubber (*Hevea brasiliensis*). Although the productivity of existing plantations still needs to be improved, China has already made progress in recent years. Tropical forest stock amounted to 1 186 million cubic metres (m^3) in 2018, an increase of 37.5 percent compared to 2008. Over the period, not only have the areas of tropical forest and planted forest increased respectively by 6.1 percent and 6.7 percent, but the per-hectare growing stock in plantations has increased by 117.2 percent. Advances in eucalyptus breeding and in optimizing intensive management systems, particularly the improvement of fertilization practices, have enabled this increase. A series of special fertilizers for eucalyptus have been developed, and a detailed fertilizing system has been formulated, covering fertilizing time, method and frequency.

In addition, since 2014, the Chinese forestry authorities have paid more attention to the establishment of mixed planted forests, the adjustment of tree species structure, the cultivation of large-diameter timber and the development of precious tree species, to improve tree species, stand and biological diversity. This will improve the stability and anti-interference ability of the planted forest ecosystem. For example, Guangxi Province listed the structure adjustment of eucalyptus planted forest as an important task, and gradually transformed the pure eucalyptus planted forest into a multi-layered mixed forest of different ages by replanting after harvesting, and required that the area of non-eucalyptus tree species must account for at least 20 percent of the total area of newly established eucalyptus planted forests in 2017.

Chinese tropical logs are mainly produced in the Guangxi Province, which accounted for 73 percent of tropical log production between 2009 and 2018. This is due to the rapid development of eucalyptus plantations in the province. The climatic conditions of Guangxi Province are very suitable for the growth of eucalyptus, and the forest land resources are rich. In the 1980s, the Sino-Australian Eucalyptus Cooperation Project was carried out in Guangxi Province, and since then, Guangxi has begun to promote eucalyptus and established eucalyptus plantations. The rapid development of the forest industry in Guangxi Province in recent years further promoted the expansion of the eucalyptus plantation area and the improvement of management technology. Other important tropical producer provinces were Guangdong, Hainan and Yunnan.

Data on tropical log production have been published in the China Forestry Statistical Yearbooks since 2002. These data show that the tropical log output has increased gradually since then, with a substantial increase in production levels in 2013, by 66 percent. In 2010–2018, China's output of tropical industrial logs increased by over 152 percent, from 5.57 million m^3 in 2010 to 14.03 million m^3 in 2018.[16]

End uses of tropical timber

As Chinese plantations mainly feature small-diameter eucalyptus species growing in 5-year rotations, the end-use options are limited. Tropical timber produced in China is currently mainly suitable for manufacturing paper, fibreboard and particle board. It is estimated that the proportion of small-diameter tropical timber is as high as more than 80 percent.[17] Market opportunities have been identified for domestic plywood production as there have been improvements in processing techniques and equipment in recent years. Developing plywood production would require the rotation to be extended to 7–8 years.

[16] From the China Forestry Statistical Yearbooks 2009–2018 (National Forestry and Grassland Administration, n.d.).

[17] From the China Forestry and Grassland Statistical Yearbook 2018 (National Forestry and Grassland Administration, n.d.).

Imports of tropical primary wood

The rapid economic development of China, reflected by an annual gross domestic product (GDP) growth rate averaging 8.97 percent (1989–2023) (Trading Economics, 2023) has led to sharp increases in the demand for raw wood materials, especially tropical primary wood. Despite governmental efforts to support increasing cultivation of rare species and larger diameters, such as *Pinus koraiensis*, *Picea abies*, *Fraxinus mandshurica*, *Phellodendron amurense, Juglans mandshurica* Maxim., *Tilia tuan* Szyszyl., *Liquidambar formosana*, *Taxus chinensis* var. *mairei* W.C.Cheng and L.K.Fu, *Phoebe zhennan*, *Tectona grandis*, *Castanopsis hystrix* and *Butula alnoides*, domestic production of tropical timber is limited and cannot meet the increasing demand. As a result, China heavily relies on imports from tropical countries and is one of the largest importers of tropical primary wood products in the world. Chinese industrial users of tropical timber will continue to rely on imports in the near future.

While imports of tropical roundwood and sawnwood increased gradually in 2010–2019, there was a sudden and sharp increase in imports of tropical veneer logs in 2011. China's free trade zones with the countries of the Association of Southeast Asian Nations (ASEAN) implemented in 2010 facilitated Chinese forest exploitation in those countries. However, Chinese manufacturers struggled to establish local factories to produce value-added products due to poor local infrastructure, a lack of skilled workers and unclear sales channels. Therefore, they processed timber into easily transportable veneer in the countries of origin. Main countries exporting veneer to China were Viet Nam, Thailand, the Lao People's Democratic Republic and Myanmar, as well as Gabon and Equatorial Guinea, where circumstances were similar.

Investments in plantation establishment

To reduce pressure on natural forests and to increase wood production to meet the demand, the government funding of plantations has increased rapidly in recent years: while public investment in 1998 amounted to USD 680 million, it increased to USD 70.16 billion in 2018. Out of six government-funded forestry programmes, three are focused on establishing plantations.

The Fast-Growing and High-Yielding Timber Plantation Development Programme aims to ease commercial timber supply gaps through the planting of highly productive species. The programme's working areas are pulp material, wood-based panel material and large-diameter (rare) timber forests.

The National Strategic Timber Reserve and Production Base Programme aims to establish an area of 20 million ha of planted forest as the timber supply base by 2035. The programme further aims to improve the stock of rare native tree species and large diameter-class timber.

The Conversion of Croplands to Forests and Grasslands Programme, launched in 1999, targets farmers with croplands on slopes, providing incentives to convert fields to forests and grasslands.

Challenges

One of the challenges Chinese tropical plantations are facing are wildfires: in 2022, 3 959 forest fire alerts were reported. From 2001 to 2021, China lost 893 000 ha of tree cover from fires (Global Forest Watch, 2023). To counteract this, the Chinese forest sector has established a fire management system.

Production zones in coastal areas, such as Beihai or Zhanjiang in Guangxi are affected by typhoons, which are being managed by a natural hazard response mechanism.

The third big challenge that the Chinese tropical forest sector is facing is pests and diseases, which affected 12.2 million ha in 2018. Forest managers are encouraged to implement an integrated pest management and silviculture system, which minimizes the use of chemical pesticides. It aims to prevent, mitigate or repair damage to the environment and human health.

Conclusion

Due to the small diameter and high proportion of eucalypt species found in the tropical forest region, tropical timber produced in China is suitable for paper making and the manufacture of fibreboard and particle board, and is seldom used for the manufacture of furniture and plywood. It is predicted that China's tropical timber market will continue to rely on imports for a long time.

There is still much to improve regarding the forestland productivity potential in China, including regarding stand quality and growth. The domestic tropical timber supply capacity in China could be increased by expanding forest resources and improving stand quality.

Thanks to the establishment of a tropical forestland base of large-diameter broadleaved timber species and strengthening of science-based management, it is expected that China's capacity to supply large-diameter timber will improve step by step.

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Bringing science to bear on the management of planted forests

Viet Nam | Researchers for the National Forest Assessment using laser technology devices

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Lena Bismark, Junior Sustainable Forestry Specialist, FAO

Highlights

- Good-quality science is essential for the sustainable management of planted forests, in fields as diverse as monitoring; tree genetics; forest modelling; pest management; and socio-economics.
- Given the rate at which change is occurring globally, scientific collaboration across borders is more important than ever.
- Multistakeholder networks are vital for knowledge transfer on planted forests among forest scientists and practitioners worldwide.

Connecting science and practitioners is key to advancing sustainable management of forests. The International Union of Forest Research Organizations (IUFRO) was founded in 1982 to provide a platform for this cause by facilitating global cooperation in forest-related research. Today, IUFRO is the leading global network for forest science, bringing together more than 650 organizations and 15 000 scientists. The Institut européen de la forêt cultivée (European Institute of Planted Forest) leads the IUFRO Taskforce on Resilient Planted Forests Serving Society and the Bioeconomy, which focuses on planted forest research. The IUFRO taskforces were launched in 2015 to open up the IUFRO networks initially focused on scientists to stakeholders – a vision also shared by the IEFC – by disseminating knowledge and coordinating exchanges between the research, education and forest sectors. The IUFRO taskforce on planted forests brings together a wide range of organizations from research and development cooperation to the private sector, such as FAO, CIFOR-ICRAF, WWF and Scion. In this article, we aim to shed light on the different contributions of science to the development of planted forests.

To support the various objectives of planted forests, including meeting the increasing demand for wood, the IUFRO taskforce on planted forests is supporting action-oriented research activities through its member organizations. Among other topics, IUFRO taskforce member organizations conduct research on factors influencing productivity in mixed plantations. Combining two or multiple species can lead to overyielding in plantations and improving resilience, but these complex systems still need to be better understood. For further information, the article on TreeDivNet on p. 40 reviews the research outcomes of the world's largest global tree diversity research network.

A growing number of scientific tools, such as Arena and Silvalert, help produce and analyse monitoring information on planted forests. Developments in remote sensing, the Internet of Things (IoT) for ecosystem monitoring[18] and artificial intelligence ensure improved collection and evaluation of data on forest resources. Remote-sensing tools have advanced significantly in recent years. Remote-sensing data now support forest managers in their strategic and operational decisions. In-depth understanding of the suitability of genetic resources to sites is critical for precision silviculture. Combining improved remote-sensing information with strategic ground information allows for high-resolution mapping and measurement of forest attributes.

In the field of genetics, scientific knowledge has greatly progressed in recent years, contributing to increasing production in planted forests. The EU-funded Horizon 2020 project Adaptive BREEDING for Better FORESTs (B4est), which ended in 2022, demonstrated how genetic diversity and key ecological functions can be maintained while increasing productivity, resilience, and resistance to droughts and pests (B4est, n.d.).

Applying models to planted forests is comparatively easy because of their known age and composition. By introducing improved data into models, we can better estimate the empirical growth and yield of trees, as well as the effects of climate change, pathogens and other factors. To support managers, IEFC provides an open source database for static and dynamic forestry models, which include models for specific species and forest types combining biotic and abiotic factors.


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Social science also produces research of high importance and interest to planted forests. An emerging body of evidence suggests that resilience is increasingly important to forest stakeholders, and to forest managers and owners when making management decisions. This contrasts with the widespread assumption that the management objectives of planted forests are limited to yield and productivity. A study recently showed that all stakeholders are concerned about global change, emerging pests and diseases, droughts and fire risk (Roitsch *et al.*, 2023). Economic science is also developing a new typology for planted forests. There is an emerging demand for planted forests to sequester carbon and restore biodiversity. This creates an opportunity to explore new business models through economic science (Silva, Freer-Smith and Madsen, 2019).

Intraspecific variability plays an important role when selecting species for planted forests, as the genetic component is key to achieving management objectives. Traditionally, species substitution has been the preferred solution to problems such as damage induced by pests or diseases, or extreme climate events. However, using different variations within one species or within the distribution range of a species can be a good alternative, which is particularly relevant in the context of climate change adversity. As climate change is a global threat to forests, there is a need for increased cross-border cooperation and international trials in the field of genetics. The research project REINFFORCE aims to better understand how certain species will react to changing climatic conditions by testing them outside their distribution range. Another example is the IUFRO geneticist network, which has demonstrated successful international cooperation in research on Douglas fir for over 30 years.

In the light of climate change, interactions between pathogens and genetics are another urgent issue for research. There is much to learn on how sensitive certain species are to emerging pests and diseases, or on which exotic pests and diseases are likely to spread to lower latitudes. Sentinel plantations, such as the ones installed with HOMED, an EU-funded project on the Holistic Management of Emerging Forest Pests and Diseases, are being established in different climatic zones to better understand the potential threat from other continents and the influence of rising temperatures on tree pathogens. International stakeholders have to work together to tackle the risk of introduction of new diseases and pests. In this context, FAO is leading advancements in the

[18] Using IoT techniques to network smart devices to collect and process environmental data for ecosystem monitoring.

field of wood treatment for example, with its Guide to implementation of phytosanitary standards in forestry. A challenge that we still face is the spreading of pests and diseases through container traffic, which particularly threatens the forests we use for wood production.

To facilitate uptake and access to knowledge by everyone, IUFRO and its members advocate improving cooperation and overcoming political barriers to exchanges of genetic material. In times of global change, we need to be able to make the most of genetic resources worldwide. IEFC is launching the resource centre plantedforest.org to make information available to all interested stakeholders. Another important initiative worth noting is the International Congress on Planted Forests (ICPF). The ICPF is a shared effort by multiple organizations in the field of planted forests to disseminate the latest scientific developments in the field. The fifth edition of the ICPF is taking place in 2023 in Nairobi and focuses on planted forests as "an essential nature-based solution to meet growing needs in wood products, restore forest ecosystems and mitigate climate change."

Science-based information is playing a key role in supporting advancements in the management of planted forests. Global networks have a critical role to play to keep facilitating the development of knowledge-sharing platforms, organization of events and development of normative products to achieve broad impact through upscaled collaboration.

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Ensuring diversity and maintaining quality in planted forests in the United States of America

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USA | Planted forest of poplars grown as one of 16 agroforestry phytoremediation buffer systems in the Lake Superior and Lake Michigan watersheds

Ronald S. Zalesny Jr., Supervisory Research Plant Geneticist, United States Department of Agriculture Forest Service

Highlights

- Planted forests comprise 11 percent of timberlands in the United States of America.
- Tree-breeding programmes aim to introduce genetic diversity through hybridization and other tree improvement tools and technologies.
- The integration of traditional approaches and new production systems provides an opportunity to enhance the benefits for communities while maintaining profitability for growers.

Planted forests are an integral part of life for rural and urban communities throughout the United States of America. Beyond wood and wood products, these forests provide essential ecosystem services such as healthy soils, clean and abundant water, and carbon sequestration, while also enhancing livelihoods for producers and consumers (Caputo and Butler, 2017; Domke *et al.*, 2020; Liu *et al.*, 2022). Silvicultural prescriptions for these forests are based on sustainable best management practices that incorporate diversity at the stand and landscape level (through establishment of multiple species and hybrids and clones within species) as well as resilience to changing climates and biological challenges such as diseases and insects (McEwan *et al.*, 2020; Pawson *et al.*, 2013).

The distribution of planted forests throughout the United States follows trends in forest ownership; the western United States is dominated by large tracts of public forest land, while eastern forests are predominantly privately owned (Perry, Finco and Wilson, 2022; Sass, Butler and Markowski-Lindsay, 2020). Across the country, federal- and family-owned forests account for nearly two-thirds of all forest and woodland area (Oswalt *et al.*, 2019). Most planted forests in the United States are on private corporate lands, which are distributed across 27 percent, 22 percent and 17 percent of regional forestland in the South, Pacific coast and North, respectively (Perry, Finco and Wilson, 2022).

At its peak, the forest and woodland area in the United States reached 333 million hectares (ha) – an area over one-third of the country's total land area, and which contained enough wood volume (28 billion cubic metres) to fill the Roman Colosseum 21 000 times (Oswalt *et al.*, 2019). Today, although two-thirds of forestland is legally available for harvesting, tree removal occurs on less than 2 percent of forestland each year (Oswalt *et al.*, 2019). The timberlands of the United States consist of natural stands (89 percent) and planted forests (11 percent), with over half of all harvests occurring in the "woodbasket" of the country, that is, forest plantations of the Southeast (Oswalt *et al.*, 2019).

Despite a small proportion of its harvestable area being harvested and challenges such as increased occurrence of wildfires and landscape-level insect and disease outbreaks, the United States is the leading global producer of industrial roundwood (17 percent of worldwide production) and has the greatest industrial roundwood consumption per capita (Oswalt *et al.*, 2019). Of the roundwood harvested, 40 percent is used in solid wood products for new housing and furniture manufacturing, while 38 percent is used to produce paper and paper products (Brandeis *et al.*, 2021). The United States also produces 26 percent of global wood pulp and wood pellet supplies, and is the second largest producer and consumer of sawnwood, paperboard, wood-based panels and paper (FAO, 2020). Recent trends have shown that consumption of solid wood products has increased, while consumption of paper, paperboard and pulpwood has decreased, and wood for energy has remained neutral (Brandeis *et al.*, 2021).

Given the broad geographic distribution and varying soils and climate throughout the country, the most common planted species across the United States (i.e. Pacific coast: *Pseudotsuga menziesii* (Mirbel) Franco; Rocky Mountain: *Pinus ponderosa* Doublas ex C.Lawson; North: *Pinus strobus* L., *Pinus resinosa* Sol. Ex Aiton; South: *Pinus taeda* L., *Pinus echinate* Mill.) are those that are regionally adapted and developed to maximize biomass production and other ecosystem services. Diversity and resilience are achieved through extensive tree breeding programmes that aim to introduce genetic diversity through hybridization and other tree improvement tools and technologies (e.g. marker assisted selection or genomic prediction) (Vance, Maguire and Zalesny, 2010). Regional adaptation of deployed trees aids in optimizing resilience to changing climates, insects, diseases and other biotic challenges (Pawson *et al.*, 2013; Ray *et al.*, 2022).

Planted forests of the United States provide social and ecological benefits to communities throughout the country, and newer production systems may contribute to livelihoods in novel ways. For example, planted forests help to reduce stress, lower blood pressure and improve psychological well-being. In addition, there is great potential to use planted forests for ecological restoration of mining areas, brownfields, landfills and other liability sites while providing roundwood supplies and enhancing soil health, water quality and carbon sequestration (Zalesny *et al.*, 2019). Similarly, incorporating planted forests into agroforestry systems increases the diversity and resilience of timberlands (Bishaw *et al.*, 2022) and the production of non-timber forest products (NTFPs) (Trozzo *et al.*, 2021). Overall, integrating traditional approaches with new productions systems provides an opportunity to enhance quality of life and stewardship of ecosystem services while maintaining profitability for growers across the landscape (Caputo and Butler, 2017).

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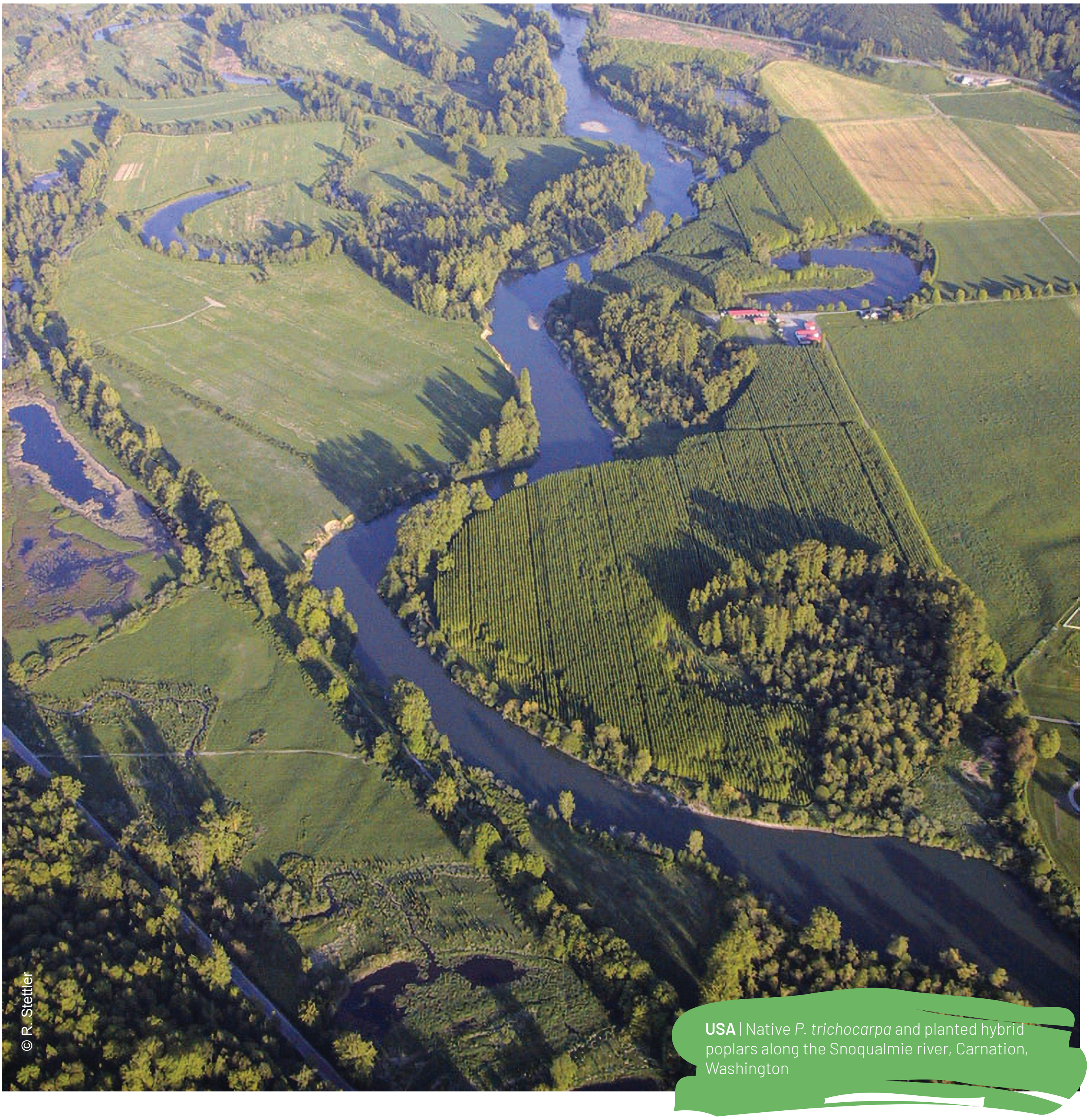
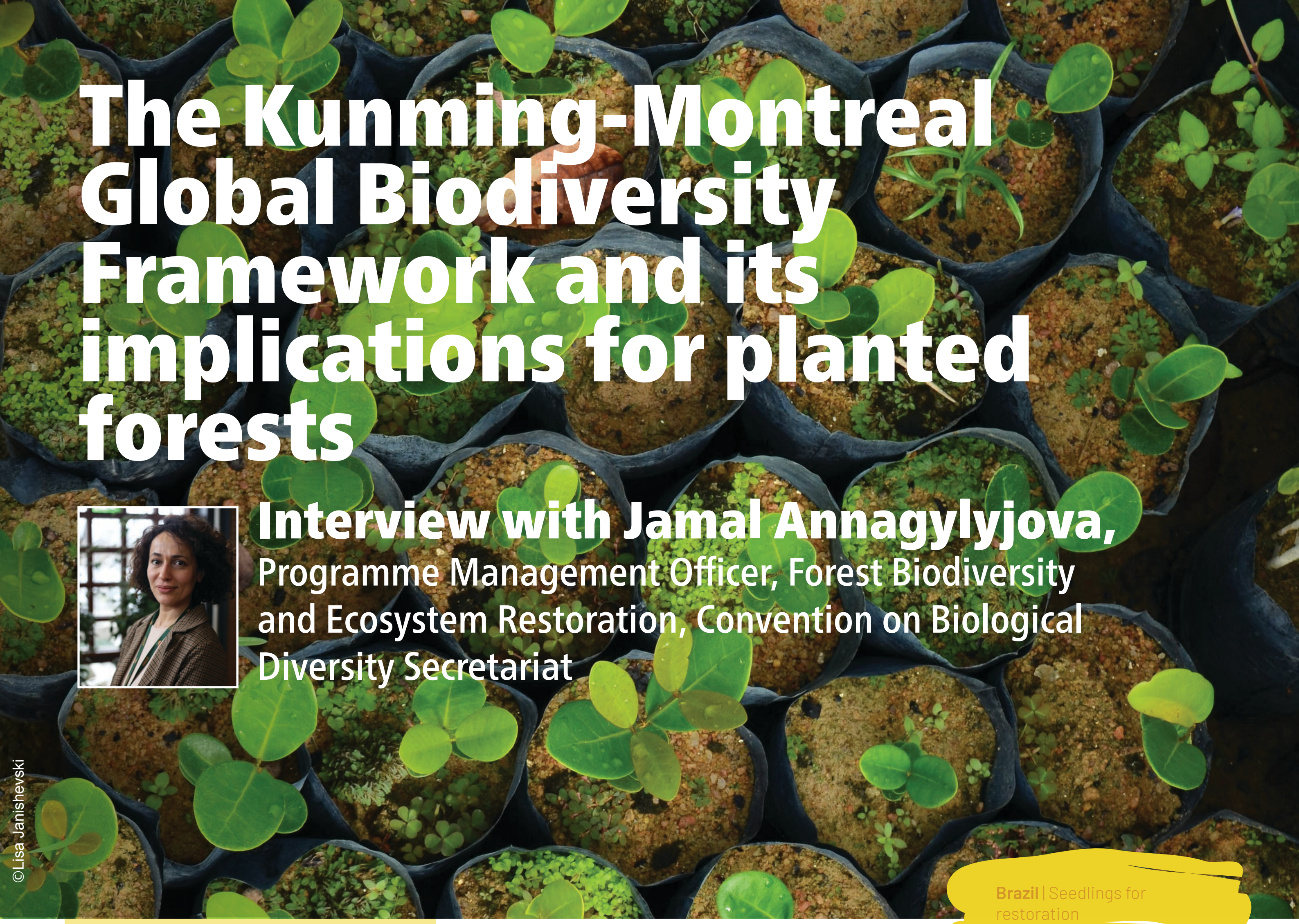


USA | Native *P. trichocarpa* and planted hybrid poplars along the Snoqualmie river, Carnation, Washington

The Kunming-Montreal Global Biodiversity Framework and its implications for planted forests

Interview with Jamal Annagylyjova,

Programme Management Officer, Forest Biodiversity and Ecosystem Restoration, Convention on Biological Diversity Secretariat



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Brazil | Seedlings for restoration

Highlights

- The Kunming-Montreal Global Biodiversity Framework (GBF) is a game-changer for many reasons, including its emphasis on communities and Indigenous Peoples.
- Planted forests can contribute to various GBF targets, such as those related to climate-change mitigation, sustainable production, and restoration, in particular if a diversity of native species are planted using ecological principles.
- FAO's new global programme on forest biodiversity mainstreaming is a timely response to the challenge of integrating biodiversity into productive landscapes.

How do you expect the Kunming-Montreal Global Biodiversity Framework (GBF) to be a game-changer in the conservation and sustainable use of forest biodiversity, and in benefit sharing from the utilization of tree genetic resources?

JA: The GBF is a historic agreement which includes urgent action targets to halt and reverse biodiversity loss. It will put nature on a path to recovery for the benefit of people and the planet by 2030 and work towards the global vision of living in harmony with nature by 2050.

This framework is a game-changer on many levels. For instance, the role of communities and of Indigenous Peoples is emphasized, and the value of Indigenous territories and Indigenous-led conservation models is recognized throughout the agreement. Also, some of the targets, such as protecting and conserving 30 percent of ecosystems and restoring 30 percent of degraded ecosystems, double the ambition compared to its predecessor agreement.

I would also like to note the participation of business and finance companies at the fifteenth meeting of the Conference of the Parties (COP 15) to the Convention on Biological Diversity (CBD). These companies called for a strong target on disclosing their dependency and impact on nature, which is a huge deal. Also, establishing a dedicated GBF fund will help developing countries to move swiftly from agreement to action.

The new framework is ambitious but achievable. However, its success depends on urgent action and a whole-of-society approach.

To which targets of the GBF have planted forests the potential to contribute, and how?

JA: Forests are home to almost 80 percent of terrestrial biodiversity, and that biological diversity results from evolutionary processes over thousands and even millions of years, including ecological forces such as climate, fire, competition and disturbance. The diversity of forest ecosystems results in high levels of adaptation, a feature of forest ecosystems that is an integral component of their biological diversity (CBD, 1995). While the GBF places utmost importance on increasing the area of natural ecosystems, it also recognizes the importance of biodiversity's sustainable use to further ensure nature's contribution to people.

There are several GBF targets directly linked to planted forests. **Target 2** calls for effectively restoring at least 30 percent of degraded ecosystems, including reforestation initiatives. Planting a diversity of native species could help restore lost forests, add diversity to existing stands and create ecological corridors connecting fragmented forest areas. Forests that bring positive biodiversity and conservation outcomes could be an effective solution for enhancing other effective area-based conservation measures, which is part of **Target 3** on conserving at least 30 percent of terrestrial and inland water areas, and marine and coastal areas.

Target 8 addresses the links between biodiversity and climate change, including the role of nature in mitigation, adaptation and disaster risk reduction. Forests, due to their carbon sequestration potential, are a commonly used mitigation measure. When appropriately designed, using ecological principles, planted forests have the potential to deliver multiple benefits for climate, biodiversity and human well-being.

Forests and trees can contribute to sustainable production systems, a critical element to achieving **Target 10**. Many countries will also undoubtfully include forest management as a part of **Target 11** on providing regulatory services, such as air, water, climate, soil health, pollination and disaster risk reduction.

Contributing to **Target 12**, forests and trees in cities have important positive impacts on human health and well-being and can support urban biodiversity and connect ecosystems outside cities.

Management of planted forests is important for sustainable business and supply chains, supporting smallholder producers and reducing dependencies on natural resources, thus contributing to **Target 15.**

From the perspective of the CBD, how can conservation targets and production needs be met simultaneously?

JA: Research and observation prove that biodiversity can increase the resilience and long-term sustainability of planted forests. At least two elements of the framework should guide decision-makers and practitioners – avoiding the conversion of natural forests into plantations and introducing management regimes favouring biodiversity at genetic, species and landscape levels. All producers, from large- to small-scale, should prioritize balancing biodiversity outcomes with production to reap multiple benefits.

What practices have the potential to enhance biodiversity in planted forests while contributing to their long-term productivity, and what is needed to scale up these biodiversity-friendly practices?

JA: Various management practices could be applied to enhance biodiversity in planted forests. Such decisions should be made at the stage of selecting planting materials in order to ensure resilience and genetic diversity over several generations. At the species level, consideration should be given to the choice of monoculture vs. mixed-species planted forests. Silvicultural practices that reduce clearcuts, allow uneven-aged plantations and understory growth, and keep dead wood biomass, along with many other practices, will have a positive impact on biodiversity while contributing to the forest's long-term productivity. Mosaic landscapes consisting of natural ecosystems and planted forests could help balance land-use management decisions, which could be supported by integrated and biodiversity-inclusive spatial planning in the spirit of **Target 1**.

GBF **Target 10** provides a framework for a substantial increase in applying biodiversity-friendly practices, such as sustainable intensification, and agroecological and other innovative approaches. Implementation of these practices at scale will require incentives for producers to monitor, disclose and progressively reduce their harmful impact on biodiversity, in line with **Target 15.**

FAO is setting up a global programme on forest biodiversity mainstreaming. How is this topic and partnership with FAO strategic for the CBD?

JA: The CBD and FAO are long-term technical partners on a broad array of themes. The FAO global programme on forest biodiversity mainstreaming is a timely response to a key challenge of the GBF – how to integrate biodiversity into productive landscapes. Implemented in multiple countries, the programme could provide nationally and regionally sound solutions at policy, institutional and site levels. It will engage diverse groups of society, including governments, local communities, businesses and Indigenous Peoples, and include gender considerations. Hence, the programme will contribute to the achievement of many of the framework's targets and will be critically important for the CBD and its thematic programmes of work, including Forest and Agricultural Biodiversity, Ecosystem Restoration and many others. This programme could be a true flagship of FAO's and the CBD's collaborative efforts!

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TreeDivNet

A global network for experimental research on mixed-species planted forests

Aerial photo of ORPHEE tree diversity experimental site





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Highlights

- TreeDivNet is a global network for investigating the benefits and drawbacks of mixed-species planted forests.
- After 23 years, TreeDivNet is yielding evidence in favour of mixing tree species in stands to increase tree performance.
- More research is needed, especially in the global South, to identify optimal species mixes and to translate scientific knowledge into operational guidelines.

Introduction

Forest restoration and afforestation are increasingly recognized as critical nature-based solutions to mitigate several global crises, including climate change, biodiversity loss and rural poverty (Bastin *et al.*, 2019; Chazdon and Brancalion, 2019; Lewis *et al.*, 2019). However, climate change-related stressors, such as droughts and insect outbreaks, are putting forests under pressure and are compromising their ability to provide ecosystem services, including acting as carbon sinks. To ensure ecosystem service provisioning in the long run, we need to boost the resilience of forests, so that they are able to better endure and recover from disturbances. A growing body of evidence suggests that mixed forest plantations, where several tree species are planted together within a stand, can be more efficient in sequestering carbon. At the same time, mixed forests also cope better with climate change-related stress and other biotic disturbances, compared to monoculture plantations that rely on the performance of a single tree species (Grossman *et al.*, 2018; Messier *et al.*, 2021). Monocultures still dominate forest plantations globally (Liu, Kuchma and Krutovsky, 2018). Moreover, 45 percent of all pledges for forest restoration involve planting vast monocultures of fast-growing trees (Lewis *et al.*, 2019). The lack of information on evidence-based, resilience-enhancing strategies is likely at the root of landowners' and stakeholders' reluctance to adopt mixed plantations. Scientific research can demonstrate the benefits of mixed plantations and show the feasibility of their establishment and management.

TreeDivNet, the largest network of biodiversity experiments worldwide

TreeDivNet is the largest global network of tree diversity experiments (treedivnet.ugent.be) (Paquette *et al.*, 2018). Working in various environmental contexts and with different tree species, the experiments have an important commonality in their design: tree species in all experiments are grown in both monocultures and mixtures, which allows the robust testing of the effect of different levels of tree species diversity on several ecosystem services. In this way, TreeDivNet provides a unique platform to investigate the benefits and drawbacks of mixed-species plantations. At present, it consists of 29 experiments, spread across 21 countries, in the boreal, temperate, Mediterranean, and subtropical and tropical zones (Infographic on pp. 44–45). The oldest experiment was planted in 1999 (Satakunta, Finland), and the most recent experiment was established in 2022 (BEF-Agroforestry, Plurinational State of Bolivia).

Linking tree diversity effects to tree performance

We consistently reviewed all scientific publications emerging from research in TreeDivNet experiments that looked at effects of tree diversity on tree performance. Tree performance can refer to a variety of aspects. Tree productivity, survival and damage level from infestation by pathogens were the most common aspects studied within TreeDivNet. The specific interpretation of tree performance thus depended on the context of each study, but, in general, we assumed that good tree performance was a prerequisite for healthy, resilient and productive trees. There were several underlying pathways through which the performance of a target tree was related to the diversity and composition of the surrounding trees (Figure 1). The term "target tree" here refers to an individual tree that is evaluated for its performance and how it relates to the diversity and composition of its neighbours. In a stand of trees, each tree can be considered a target that is influenced by the trees that surround it, which can be of the same or another species. Together, the trees, which are both target and surrounding trees for each other, determine the performance of the stand. The surrounding trees can alter the **growing conditions** for the target tree. Abiotic growing conditions include soil properties and microclimate. Biotic growing conditions include for instance the presence and activity of herbivores, soil microbes, etc. In addition, the surrounding trees can alter the availability, uptake and use efficiency of three key **resources** for the target tree: water, light and nutrients. Our systematic review mapped out all publications and represented them on a conceptual diagram (Figure 1), to identify those pathways that received much attention and those that are still poorly understood.

How and where are TreeDivNet research efforts focused?

A large share of the TreeDivNet studies investigated the direct relation between tree diversity and tree performance, without looking at the underlying biological mechanism (Figure 1). Most of these studies found a higher or similar productivity in mixed stands, compared to either the average productivity of the monoculture stands of all the species in the mixture, or compared to the best-performing monoculture. Only very few studies observed lower productivity when mixing tree species. For the studies that did look at particular pathways explaining species diversity effects on tree performance, those that looked at the effect of tree diversity on biotic conditions in the plantation were most represented, with especially high attention given to the impact of tree diversity on invertebrate and microbial communities, and to tree damage by herbivory or pathogens. Unlike for the studies on direct effects of tree diversity on productivity, studies looking at diversity effects on biotic conditions were less consistent in their outcomes, as negative effects, positive effects or no effects at all were equally spread across the studies, which suggests that other processes play a role in the many observed positive mixing effects on productivity. Across all types of studies, it was clear that not only the number of different surrounding species, but also the identity of the species present affected tree performance (whether or not this was via an underlying mechanism). This effect of tree species composition suggests that not only the number of different species, but also the species choice itself needs to be considered when optimizing tree performance in mixed plantations.

Emerging knowledge gaps

We currently lack a proper understanding of how tree diversity may alter abiotic growing conditions, such as soil and microclimatic conditions. Also, the impact of diversity on the availability of light and water has received

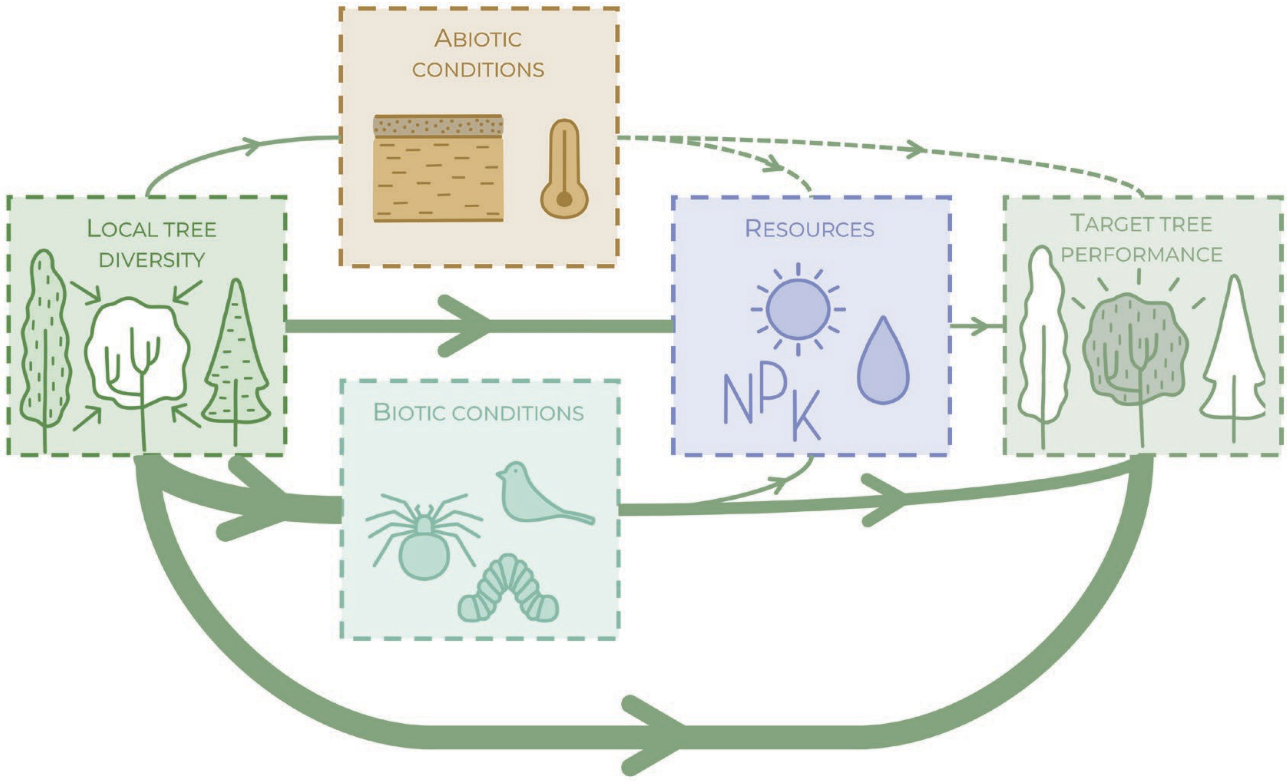

Figure 1. Overview of the different relationships between local tree diversity and tree performance that have been studied in TreeDivNet experiments

Note: The width of the arrows indicates how often a process or relationship has been investigated. Note that the direct arrow from tree diversity to tree performance does not refer to an underlying biological mechanism but represents the number of studies that have simply looked at the direct diversity–performance relationship.

little attention in TreeDivNet research, especially in comparison with nutrient availability. Resource-use efficiency in general has not been frequently explored, even though it is commonly perceived as one of the main mechanisms linking biodiversity to ecosystem functioning (Hodapp, Hillebrand and Striebel, 2019). In contrast to microbiota and invertebrates, biotic actors such as birds and plants have received little attention. Besides these knowledge gaps in the pathways through which tree diversity affects tree performance, the way "performance" has been studied is also limited in scope. We found a strong focus on different variables linked to productivity or damage to target trees, for example by herbivores, but how this translates into survival and other aspects of tree performance remains largely understudied. Finally, the very unbalanced research across biomes remains a crucial knowledge gap (see infographics on p. 44). While the temperate biome is very well studied, subtropical, tropical and boreal forest systems are underrepresented in TreeDivNet. As afforestation and reforestation ambitions are high, including in countries of the global South where wood demand is increasing, we need to urgently expand our knowledge base on mixed forest plantations in subtropical and tropical biomes, to ensure the establishment of future-proof forest plantations.

Future research agenda

The set-up and more than two decades of monitoring in a global network of tree diversity experiments has demonstrated that there should be no compromise on tree performance when prioritizing a strategy of mixing tree species over planting monocultures. However, translating the scientific knowledge obtained from TreeDivNet experiments into operational management guidelines remains challenging due to: (i) their relatively small scale compared to real-world forest plantations; (ii) the young age of most experiments; and (iii) the experimental design that prioritizes answering fundamental research questions. Still, the value of the experiments for applied forestry will increase as experiments are getting older and reach the next, stem-exclusion phase. In this phase, there is much to learn in terms of their development and management. For instance, these experiments will soon require decisions on thinning strategies that we should tailor to the operational questions of managers. We are at a cross-roads for management decisions and should take this as an opportunity to make the experiments more relevant for management. Challenges in operational management will coincide with economic challenges: the financial aspect of managing and harvesting mixed stands compared to monocultures should be a future research focus, as it will be key to making mixed forests commercially feasible.

A central question of forest managers is effectively "what species combinations should we now promote and where?" The high importance of species identity found in many studies supports the relevance of this question, which remains largely unresolved, including in large-scale studies in mature forest (Baeten *et al.*, 2018). One key reason is that the relative importance of mechanisms that cause particular mixtures to outperform monocultures and other mixtures, depends on the environmental context. We encourage operational managers to dare experiment with planting different species combinations, using mixtures of tree species that are known to be complementary while including some that are drought resistant, and monitor this across operational scales. At the same time, research should further focus efforts on identifying optimal mixtures across different environmental contexts based on functional groups, but also on revealing trade-offs and synergies between ecosystem functions or services in mixtures in general.

This article was developed with the input from TreeDivNet network.

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Aerial photo of ORPHEE tree diversity experimental site

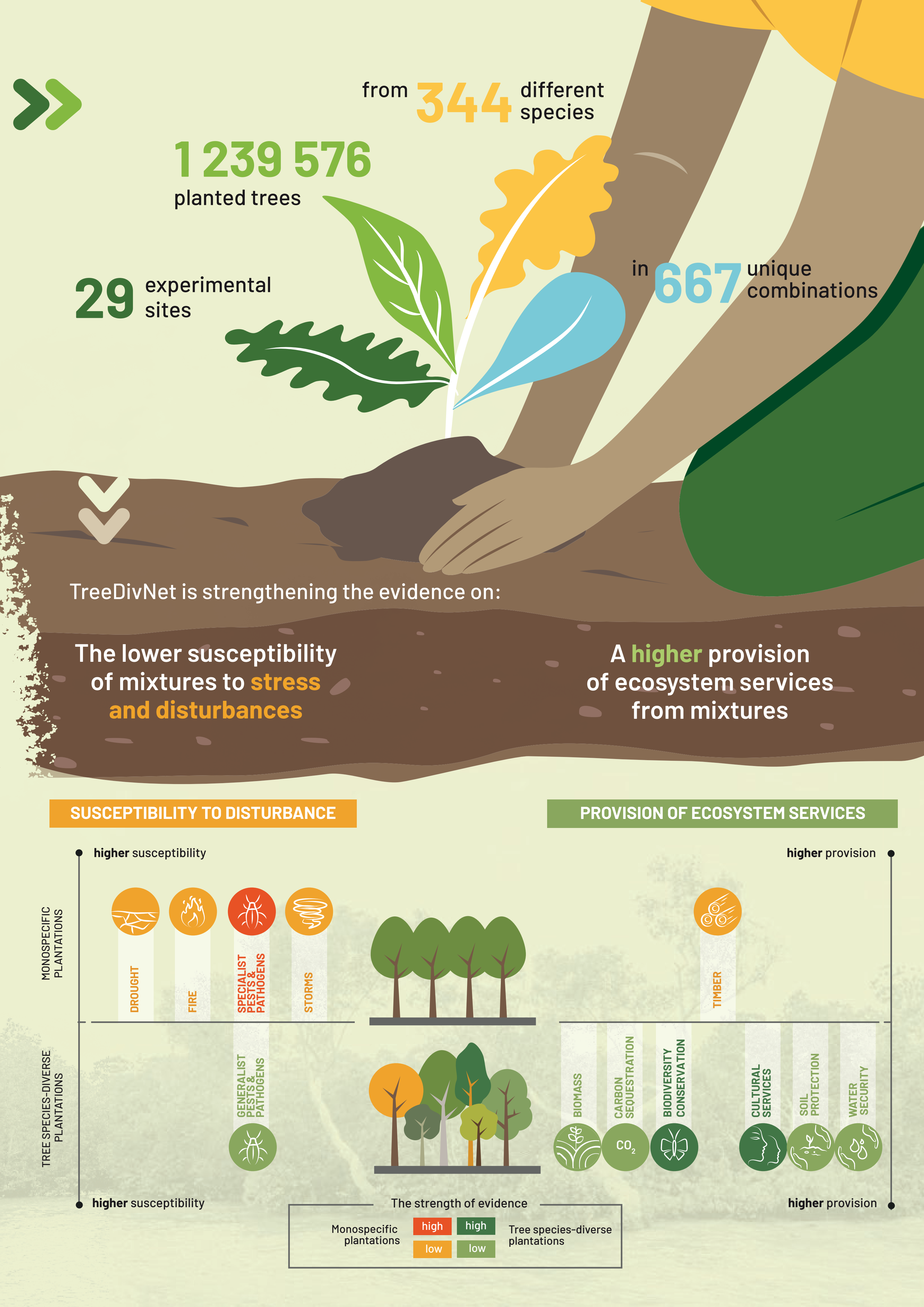
TreeDivNet

is the largest global network of biodiversity experiments testing the relationship between tree species diversity and ecosystem functioning in major forest types worldwide.

Climatic zone

- Boreal
- Mediterranean
- Temperate
- (Sub) tropical

1 1 1	IDENT
2	SIDE
3	BiodiversiTREE
4	BangorDIVERSE
5	Climate Match
6	FORBIO,TWIG
7	Communitree, ORPHEE
8	ECOLINK-Salix
9	BIOTREE HighDiv-SRC MyDiv, Kreinitz
10	B-Tree
11	Satakunta
12	UADY
13	Sardinilla, Agua Salud
14	BEF-Agroforestry
15	BrazilDry
16	MataDIV
17	ForestInnov
18	Gazi Bay
19	BEF-China
20	CADE
21	Sabah
22	EFForTS-BEE
23	Ridgefield



from 344 different species
1 239 576 planted trees
29 experimental sites
in 667 unique combinations
TreeDivNet is strengthening the evidence on:
The lower susceptibility of mixtures to stress and disturbances
A higher provision of ecosystem services from mixtures
SUSCEPTIBILITY TO DISTURBANCE
PROVISION OF ECOSYSTEM SERVICES
higher susceptibility
higher provision
MONOSPECIFIC PLANTATIONS
TREE SPECIES-DIVERSE PLANTATIONS
DROUGHT
FIRE
SPECIALIST PESTS & PATHOGENS
STORMS
TIMBER
GENERALIST PESTS & PATHOGENS
BIOMASS
CARBON SEQUESTRATION
BIODIVERSITY CONSERVATION
CULTURAL SERVICES
SOIL PROTECTION
WATER SECURITY
CO_2
higher susceptibility
higher provision
The strength of evidence
Monospecific plantations
high
low
high
low
Tree species-diverse plantations

Diversifying tree species to boost resistance to insect pests

©G.Mamadashvili

Cydelima perspectalis

Hervé Jactel, Research Director, French National Research Institute for Agriculture, Food and Environment (INRAE)

Highlights

- Stressors, led by climate change, are increasing the risk posed to forests by insect pests.
- A meta-analysis of 600+ scientific studies showed that, in boreal and temperate forests, insect damage is lower in mixed-species stands than in pure stands.
- Two hypotheses for the ecological mechanisms of this phenomenon could lead to improvements in the management of mixed-species planted forests.

The condition of the world's forests is alarming. In most regions, tree mortality is increasing (Hartmann *et al.*, 2022), and forest resilience is declining (Forzieri *et al.*, 2022). A major cause of this forest degradation is climate change, which is accompanied by an increase in stresses such as drought, fire and storms (Anderegg *et al.*, 2020). These hazards often result in increased outbreaks of insect pests, which take advantage of more favourable temperature conditions to multiply their generations, and trees that are less able to defend themselves against their attacks (Jactel, Koricheva and Castagneyrol, 2019). Another important driver of forest degradation is the increase in global trade, which leads to an exponential increase in the introduction of invasive alien insects and pathogens that can cause significant damage to forests (Brockerhoff and Liebhold, 2017). This has major consequences for the provision of goods and ecosystem services, and the risk of forests changing from carbon sinks to carbon sources.

It is therefore necessary to implement methods to better control forest pests. The challenge is that these pest management methods must not only be effective and environmentally friendly, they must also be generic enough to be able to deal with any new emerging or invasive insect pest. These constraints rule out conventional chemical and genetic control methods from the outset. On the other hand, the observation of a much higher frequency of herbivorous insect outbreaks in extensive tree monocultures than in hyperdiverse tropical forests (Wylie

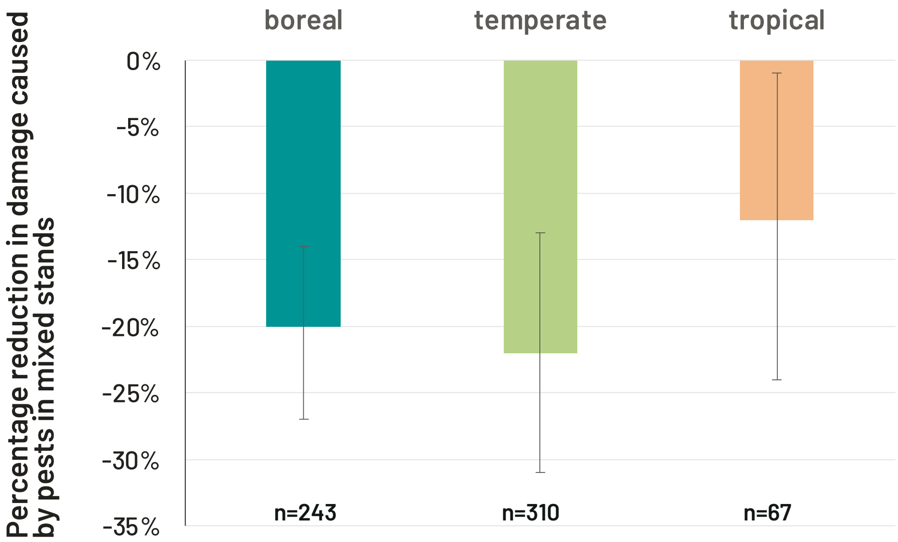


Figure 1. Mean percentage (± confidence interval) reduction in damage caused by a given pest species on a given tree species in mixed stands compared with pure stands, in three different forest biomes

Note: n is the number of case studies used in the meta-analysis published in: **Jactel, H., Moreira, X. & Castagneyrol, B.** 2021. Tree Diversity and Forest Resistance to Insect Pests: Patterns, Mechanisms, and Prospects. *Annual Review of Entomology*, 66(1): 277–296. https://doi.org/10.1146/annurev-ento-041720-075234

and Speight, 2012) led to the hypothesis that the resistance of forests could increase with their species diversity.

This hypothesis was tested using a meta-analysis of more than 600 scientific studies (Jactel, Moreira and Castagneyrol, 2021). This analysis showed that the damage inflicted by a given insect species on a particular tree species is significantly lower when this tree species is managed in a mixed stand compared to a pure stand (Jactel, Moreira and Castagneyrol, 2021). The reduction in damage is around 40 percent for specialist pests and 15 percent for more generalist insects (Castagneyrol *et al.*, 2014). This phenomenon is called associational resistance (Barbosa *et al.*, 2009), that is, resistance conferred by an association of host and non-host tree species. This associational resistance is observed for all trophic groups of insects attacking trees, such as defoliators, aphids, wood borers or galling insects. Recently, it has been shown that associational resistance is as effective against native as against non-native (alien) pests. However, it must be acknowledged that there is a lack of data to confirm this effect of tree species mixture in tropical or subtropical forests.

The ecological mechanisms that explain the enhanced insect resistance of species-rich forests (Jactel, Moreira and Castagneyrol, 2021) provide clues for better design and management of mixed-species plantations.

The first mechanism involves the relationships between host and non-host tree species for pests. In mixed forests, the presence of non-host trees makes it more difficult for insects to locate and colonize their host trees because the non-host trees may hide them or emit repellent volatile compounds: this is the semiochemical diversity hypothesis (Zhang and Schlyter, 2004). These effects are all the stronger when the non-host trees are phylogenetically distant from the host trees, which is notably obtained in mixtures with conifers and broadleaved trees or deciduous and evergreen trees (Jactel and Brockerhoff, 2007). They also increase with the proportion of non-host species, which suggests designing mixed plantations with a relative proportion of about two-thirds of production species and one-third of companion species (Jactel, Moreira and Castagneyrol, 2021). These diversion or repellent effects on insect pests can be achieved either by intimate tree species mixing or by planting hedgerows with non-host tree species around the plantation to be protected.

A second mechanism is the enhanced biological control of insect pests by their natural enemies in mixed forests: this is the natural enemy hypothesis. Forests rich in tree species harbour a greater diversity of generalist predators, such as insectivorous birds or bats, and predatory arthropods, which are also more abundant and more active (Stemmelen *et al.*, 2022) because they have more niches for shelter, rest or reproduction. This diversification of insect predators can be achieved by increasing the diversity of composition or complexity of structure in the stand and complementing this by improving the heterogeneity of the surrounding forest landscape.

Increasing the diversity of forests to make them more resistant to insect attacks is not a method that is 100 percent effective as it depends on the species composition of the tree mixture, but it often allows a significant reduction in forest damage and, above all, it works preventively and generically. In addition, forest diversity can have other benefits, such as resistance to natural disturbances (Jactel *et al.*, 2017), better productivity in many cases (Feng *et al.*, 2022) and greater associated biodiversity (Ampoorter *et al.*, 2020) compared to tree monocultures. Although more complicated to manage, mixed-species plantations should therefore be further implemented to ensure better resistance, multifunctionality and provision of ecosystem services (Messier *et al.*, 2022).

Box tree moth caterpillar

FAO's work on forest health

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Miranda Wadham Smith, Communications Specialist, Forestry Division, FAO

FAO works to mitigate and protect against national, regional and global forest health issues through projects, the development of awareness-raising tools and capacity building. This includes:

- Providing direct technical assistance to countries on specific pest problems affecting forests and food security, offering assistance not only in response to pest outbreaks and emergencies but also in establishing long-term prevention and forest protection strategies. Currently, FAO is working to improve the resilience of forests in Azerbaijan, Belarus, Ethiopia, Indonesia, Myanmar, Tunisia and Ukraine, ensuring that they continue to contribute to national economies and provide livelihoods for rural populations.
- Facilitating regional forest invasive species networks, which are platforms for the exchange of information and mobilization of resources. These networks raise regional awareness and act as a link between and among experts, institutions and other groups and stakeholders concerned with forest invasive species.
- Publishing documents and guidelines. For example, FAO is currently developing a "Guide to the development and implementation of national forest biosecurity strategies, systems and processes," which will support countries in developing national forest biosecurity strategies focusing on prevention, early detection and rapid response to incursions of pests and diseases, as well as on control of pests to reduce their impacts. Biosecurity is defined by FAO as "a strategic and integrated approach to analysing and managing relevant risks to human, animal and plant life and health, and associated risks to the environment." *

Note: * See glossary on p. 95 in: **FAO**. 2007. *FAO Biosecurity Toolkit*. Rome.

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Increasing diversity for improved provision of ecosystem services

Hikers in Telluride, Colorado, USA with autumn gold aspen trees

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Rita Sousa-Silva, Assistant Professor, Institute of Environmental Sciences, Leiden University

Highlights

- There is strong evidence that increasing tree species diversity in forests can enhance biodiversity, productivity and multifunctionality while mitigating risks and decreasing vulnerability to environmental change.
- Mixed-species planted forests also provide more options for adapting to ongoing societal changes.
- More resources are needed for designing guidelines and best management practices for mixed-species planted forests.

Why and where do we want mixed-species forests?

Encouraging the development of mixed-species forests over monocultures has a long-standing history. As early as 1886, Karl Gayer, a professor of silviculture at the University of Munich, Germany, contended that mixed forests are the only forests that can handle the uncertainty of future developments and environmental risks. The adoption of his ideas by forest owners and managers is more urgent than ever. Forest dieback due to massive bark beetle infestations (Gandhi *et al.*, 2022) and the combination of drought and warming (Allen *et al.*, 2010) serve as poignant reminders of the vulnerability of monospecific forests to increased disturbances associated with climate change. Therefore, concerns over the stability and sustainability of ecosystem services provided by forests in the face of expected future stress and disturbances have grown more urgent than ever. Moreover, societal changes, such as the desire for more diverse and natural landscapes, and the recognition that mixed-species forests have the potential to provide multiple benefits, are increasing demand for these forests.

©Jürgen Bauhus

Germany | Dead spruce trees stand destroyed by bark beetle in the Harz National Park

Where do we most need diversity and structural complexity?

To enhance the adaptability and resilience of forests to environmental and societal changes, species diversity and structural complexity are needed at both the stand and landscape level. This is particularly important for forests managed on long production cycles because many risks increase with tree age and height. In addition, societal expectations create uncertainty because it is impossible to predict which ecosystem services future generations may want from forests and at what level. Uncertainty in the face of new and unpredictable disturbance events further underscores the need for species-diverse forests that can spread the risks, adapt and deliver multiple ecosystem services (Bauhus *et al.*, 2017). By promoting mixed-species forests, we can enhance the capacity of forests to deliver a mix of ecosystem services while ensuring their sustainability for future generations and keeping open the option of fulfilling new services in the future. In contrast, this is less important for forests managed on short-rotations, where landowners' goals can be adjusted between production cycles (e.g. from wood production to the provision of public goods like recreation or nature conservation)(Bauhus *et al.*, 2017; Krott, 2008).

Evidence for benefits of mixed-species forests

A growing body of scientific literature and empirical studies has demonstrated the benefits of including a greater diversity of tree species in planted forests. One of the key advantages of mixed-species forests is their multifunctional nature, also referred to as the "jack-of-all-trades" effect, as different species with different functional traits provide a broader range of ecosystem services simultaneously (van der Plas *et al.*, 2016). Yet, this multifunctionality often prevents them from achieving the highest levels of any single function, making them versatile "masters-of-none". For instance, observations of transgressive overyielding, where the productivity of mixed-species forests is greater than the highest-performing monoculture, are limited, but mixtures exhibiting overyielding are more common. For example, Huang *et al.* (2018) reported significant increases in forest productivity from monocultures to multispecies mixtures in subtropical China. After 8 years of growth, the stand-scale productivity of 16 species mixtures was 80 percent greater than the average monocultures in terms of annual volume increment but not higher than in two monocultures of commercially cultivated species. Moreover, mixed-species forests provide a higher level of other ecosystem functions and services than timber alone, including higher biodiversity and improved risk management, improved soil conditions and water quality, and aesthetic and recreational values; and they may be more socially acceptable than monospecific forests (Felton *et al.*, 2010; Messier *et al.*, 2021).

The benefits of species diversity for enhancing ecosystem stability, productivity and resilience are explained by two main concepts: the portfolio effect and the mixing effect. The portfolio effect refers to the insurance effect of biodiversity on maintaining ecosystem functioning in case of risks. When multiple species perform similar ecological functions, stress or damage to one or more species can be compensated by other, more resilient ones that maintain ecosystem functions. The mixing effect, on the other hand, refers to changes in species performance in mixture when compared to monospecific stands; this can enhance species productivity and resilience in mixtures through mechanisms such as facilitation, competitive reduction and complementary resource use (see article on mixed planted forests experiments on p. 40). For example, species with different rooting depths or water-use strategies might use resources more efficiently and complement each other during droughts (Grossiord *et al.*, 2014; Schnabel *et al.*, 2021). However, the relative importance of these effects may depend on the specific stressors and disturbances affecting a given forest system, as well as on species proportions and their spatial arrangements in mixture.

Are mixed-species forests more resistant and resilient to biotic and abiotic disturbances?

There is solid evidence that mixed-species stands decrease the likelihood of host-specific pest and pathogen outbreaks compared to monocultures (Bauhus *et al.*, 2017; Jactel *et al.*, 2017). Several mechanisms contribute to this increased resistance: (i) higher tree diversity can lead to chemical or physical interference that prevents pest insects from locating host plants, thereby reducing damage; (ii) tree diversity increases the number of natural enemies of pest insects; and (iii) in addition, reducing or diluting host-plant densities may result in less insect damage. However, the existence and importance of associational resistance vary by forest type and tree and insect species, and there may also be associational susceptibility in the case of polyphagous insects. For instance, Berthelot *et al.* (2021) found that while tree diversity can reduce the risk of infestation for preferred conifer species, such as larch and spruce, it can increase the risk for less preferred species, such as pine or exotic trees, as beetles, once attracted, also attack these trees. Understanding these dynamics is important for the effective management of mixed-species forests.

There is also increasing evidence that mixed forests are more resistant and resilient to abiotic disturbances. For instance, mixtures consisting of conifers and broadleaves often have trees of varying heights and crown shapes, which can reduce wind damage propagation during windstorms. Additionally, they have a greater diversity of root systems, which can improve anchoring of trees in soil and reduce the risk of uprooting. There is less evidence regarding reduced fire risk. That would be the case if mixtures had lower fuel loads, lower vertical and horizontal fuel continuity, and higher moisture content, all of which would reduce fire severity and spread. At the landscape level, scattered patches of fire-resistant trees can act as a physical barrier that limits flame spread, thus preventing ignition of neighbouring patches of less-resistant trees (Azevedo *et al.*, 2013).

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Cultivating poplars (*Populus x canadensis*) with oak (*Quercus robur*) clusters increases biodiversity and options for future use in planted floodplain forests

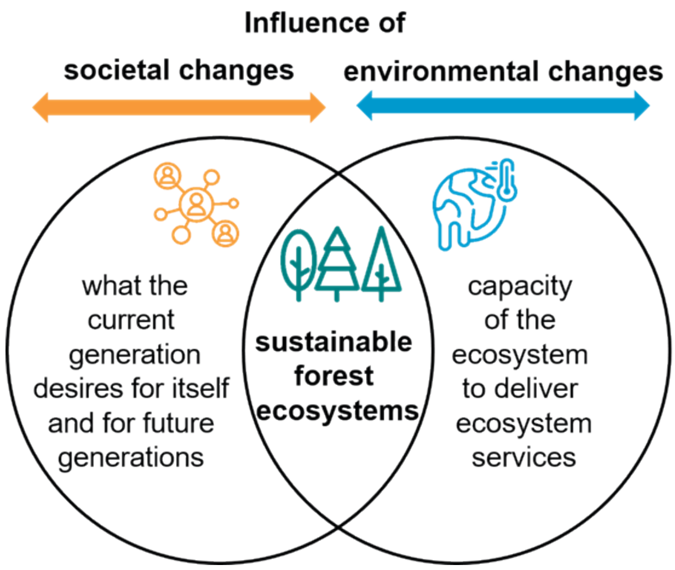

Figure 1. Sustainability at the intersection between societal expectations and the capacity of forest ecosystems to deliver ecosystem services

Note: When faced with changing societal and environmental conditions, mixed-species forests will likely provide for a larger overlap between societal demands (left sphere) and the capacity of forest ecosystems to deliver ecosystem services (right sphere).

Major knowledge gaps and challenges to increase tree-species diversity in forests

Several knowledge gaps have impeded the implementation of more diverse planted forests. One of the main challenges is the increasing complexity of management as tree species composition and structural diversity increase. For instance, mixtures may require different management practices than monocultures, such as different thinning regimes or pruning practices. Managing diverse forests also requires knowledge of the ecological interactions between species and their effects on ecosystem functions (Bauhus *et al.*, 2017). For instance, adding a new tree species requires additional knowledge, such as on its propagation and growth requirements, wood properties, potential pests and diseases, and interactions with existing species. These factors contribute to operational complexity, which can deter forest managers from adopting mixed-species systems. Moreover, ecological research has not been adequately accompanied by applied research and studies at an operational scale.

To encourage forest owners to adopt mixed-species forests, it is also crucial to address financial limitations and provide appropriate incentives. Embracing mixed-species stands entails not only acquiring the necessary knowledge, but also making additional investments associated with planting and managing mixtures (Nichols, Bristow and Vanclay, 2006). These requirements can deter forest managers from adopting mixed-species systems unless they receive financial incentives for the ecosystem services provided by diverse forests (see article on new "natural capital" assets on p. 87). However, markets have historically favoured a limited number of tree species for their high productivity, the products that they provide and their commercial value. In addition, many ecosystem services that are provided at a higher level by more diverse planted forests, especially those with less common species, including soil protection, biodiversity conservation or cultural services, are not easily quantifiable or marketable.

Finally, the relationship between tree diversity and ecosystem functioning depends on the environmental context, as mixing effects are site-specific and change with forest development, further complicating management. Therefore, the actual outcomes of mixing a certain combination of species are still difficult to predict, even for common tree species combinations. Addressing these knowledge gaps and challenges is crucial to facilitate the wider implementation of mixed-species planted forests.

Conclusion

Rapidly changing societal aspirations and environmental conditions underscore the need for mixed-species forests that are resilient and adaptable but still maintain more options for future use (Figure 1). Solid evidence supports the idea that increasing tree species diversity can lead to greater multifunctionality, biodiversity and productivity. Mixtures also play a critical role in spreading risks and reducing vulnerability. As the importance of ecosystem services beyond timber production increases, so does the opportunity for establishing more mixed-species planted forests. Consequently, greater attention and resources should be dedicated to designing clear guidelines and best management practices that forest managers and landowners can easily follow to overcome operational complexity. By doing so, we can ensure the long-term sustainability of our forests while maximizing their potential to provide a wide range of ecosystem services.

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Democratic Republic of the Congo | Forest view in Yangambi

Establishing mixed-species planted forests for restoration and production in Brazil

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Figure 1 | An experimental mixed plantation of eucalypts and native species (right) contrasting with a monoculture eucalypt plantation (left, mature trees on top left of the picture and a recently planted stand on the bottom left of the picture)

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Highlights

- Mixed-species planted forests have considerable untapped potential in Brazil for the restoration of degraded conservation areas and legal reserves and in agroforestry.
- Although increased management complexity might limit the adoption of mixed-species configurations in industrial plantations, clone mixtures might be viable.
- Various economic, ecological and legal constraints must be overcome to upscale deployment of mixed-species planted forests in Brazil.

Introduction

Tree plantations have considerable importance for the Brazilian forest sector today. Brazil harbours the largest area of forest plantations in Latin America. Most of these plantations are industrial monospecific tree plantations with short rotations (6–8 years). They cover about 9.93 million hectares (ha), of which 7.53 million ha are planted with eucalypt (representing about 30 percent of the global area of eucalypt plantations), 1.93 million ha with pine and 0.475 million ha with other species (mostly rubber, acacia, teak and parica). Wood consumption from forest plantations in Brazil was 273 million cubic metres (m^3) in 2021, and it is steadily growing, mirroring the global trend (IBÁ, 2022). Current evidence suggests that sustainable management of natural tropical forests will not meet this increasing timber demand, which indicates that plantations and other tree-based systems, such as agroforestry, will be increasingly important in the future. Moreover, the current international momentum towards forest restoration has resulted in very ambitious targets for reforestation and restoration in various biomes of Brazil, which often involve tree planting in all or part of the areas concerned.

As described in other chapters of this issue, mixed-species forestry is a promising alternative to monocultures for both production and conservation purposes, as monocultures have a lower capacity to provide diverse ecosystem goods and services than multispecies (mixed) plantations. Yet, this potential remains overlooked in Brazil. On the other hand, very few native tropical tree species are used in commercial plantations, which means that the potential represented by the wealth of Brazilian tropical tree species is not being exploited for production. The reason for this is twofold. Rapidly growing, homogeneous plantations dominate supply for industrial uses while illegal logging in forest remnants in the Amazon supplies the market with hardwood. The increasing frequency and intensity of disturbances associated with climate change, and the growing demand for wood and timber may result in wider adoption of mixed plantation systems in the future.

This article describes some important types of mixed-species plantations currently found in Brazil and their potential to contribute to restoration goals as well as production needs. Using Brazil as a case study, we show how mixed plantations can be used in permanent conservation areas and legal reserves, for forest restoration, agroforestry systems and industrial tree plantations.

Regulatory frameworks and mixed tree plantations

The main piece of legislation guiding forest conservation, restoration and production in Brazil is the Native Vegetation Protection Law, also known as the new Forest Code, which was adopted in 2012. This law established three main land-use classes in private landholdings: (i) permanent preservation areas (APPs), which are established on farms and other areas to protect vulnerable ecosystems, such as riparian buffers, springs, steep slopes and mountain tops (e.g. within a 50 m radius for riparian buffers, 30 m wide riparian buffers along water courses less than 10 m wide, and all areas with a slope greater than 45 degrees); (ii) legal reserves (LRs) established to safeguard a minimum cover and the sustainable use of native ecosystems within farms, on areas ranging from 80 percent of the farm area in the Amazon to 20 percent in other regions of Brazil; and (iii) production areas, which represent the areas not covered by APPs or LRs, where alternative land uses (e.g. cropland, pastureland, infrastructure) are allowed (for more details on APP and LR regulations, see Brancalion *et al.* [2016]). Understanding this regulatory framework is critical for planning forest plantations. In APPs, only mixed plantations of several native species are allowed, as the forests established in these areas cannot be commercially exploited and must be exclusively used for restoring native ecosystems. In LRs, mixed plantations of native and exotic species are allowed, as forest plantations in these areas combine promoting the recovery of native ecosystems with commercial forest use. However, to be legally accepted, mixed plantations in LRs must have no more than half of the area covered in exotic trees and cannot be clearfelled; both exotic and native trees can be harvested and replanted for further exploitation. Similarly, agroforestry systems, which are land-use systems that integrate woody perennial species with agricultural crops or livestock, or both, in spatial and temporal arrangements (IBGE, 2019), are permitted in LRs. In production areas, all types of forest plantations are allowed, including industrial monoculture plantations.

Mixed tree plantations for the restoration of legal reserves

Brazilian LRs can be restored and exploited using both natural regeneration and tree planting. Tree plantations are usually managed with strips of two to four contiguous rows of valuable, slow-growing native species, interspersed with the same number of strips planted with fast-growing pioneer species (Figure 1). Fast-growing exotic species have been preferred as pioneers, as this may help offset restoration costs and provide an income and wood for farmers while initiating regeneration processes (Brancalion *et al.*, 2020). Eucalypt has been the commercial pioneer species most used because of its versatility (e.g. for cellulose, coal, fuelwood, mooring and construction) and rapid growth, resistance to pests and diseases, ability to adapt to different site conditions and good economic returns. Amazonas *et al.* (2018) examined three main experiments in the south of the State of Bahia and northern Espírito Santo to evaluate the development of stands planted in strips with a high diversity of forest species (23–30 species) native to the Atlantic Forest, interspersed with eucalypt strips. The mixed plantations were beneficial to the growth of the eucalypts, which produced almost 75 percent of the basal area of monocultures from only 50 percent of the trees. Although the eucalypts slowed the growth of the native species, this effect was not strong enough to jeopardize their survival. The slower growth of the native species was not considered a major concern in the short term because after the eucalypt harvest, the native species were able to make up for lost growth. According to these authors, the mixed planting of native species with eucalypt is technically and economically viable, and represents an important alternative for establishing multipurpose plantations, especially in the context of forest and landscape restoration (Brancalion *et al.*, 2020). Moreover, small and medium-sized producers have shown interest in mixed plantations for obtaining multiple forest products and increasing ecosystem services on their landholdings. Tree species of the Fabaceae, Myrtaceae, Arecaceae and Lecythidaceae families appear to be the most promising for use in mixed plantations for wood production and as a food source for fauna (Paula *et al.*, 2020). Science-based sylvicultural guidelines for this type of plantation are lacking and should be developed in the future, as these mixed plantations are emerging as an important option for meeting the combined goals of livelihoods, production and environmental protection, both within and outside LRs.

Mixed tree plantations in agroforestry systems

Agroforestry systems (AFS) are usually associated with a high diversity of tree species, in most cases not arranged in rows. Agroforestry systems are mostly used in small and medium-sized landholdings, with low to medium intensification. In 2006, 8.3 million ha managed in agroforestry were classified on 306 000 farms. Of late, this cultivation system has benefited from public policies supporting environmental protection, food security and climate mitigation. For example, AFS were included as one of the proposed technologies of the Brazilian Programme for Low Greenhouse Gas Emissions in Agriculture (ABC Programme), ratified under the Paris Agreement. Agroforesty systems have commonly been used as an alternative for agricultural and forest cultivation to increase crop resilience in regions with a humid tropical climate, such as the Amazon Forest region, or a subhumid tropical climate, such as the Atlantic Forest region, where the risk of pests and diseases is high. Agroforestry systems are considered to be more resistant to these disturbances than monocultures, and thus have expanded over the last decades.

For example, the Mixed Agricultural Cooperative of Tomé-Açu, formed by Japanese immigrants in the State of Pará in the Amazon after a period of prosperity and decline of black pepper (*Piper nigrum* L.) monocultures, began agroforestry in the 1970s, intercropping forest species typical of the region with cocoa, black pepper and other species that provide noble vegetable oils and pulp from 15 tropical fruits. They were motivated by the success in pest and disease control achieved by small landowners on the banks of Amazon River tributaries. Currently, approximately 17 000 ha are managed by 172 cooperative members and 1 800 farmer suppliers, directly and indirectly supporting 10 000 jobs in the region (CAMTA, n.d.). The southern State of Bahia has the largest cocoa plantation area in Brazil over 700 000 ha in the central corridor of the Atlantic Forest. There are two typical cocoa production systems used both by smallholders (5–8 ha) and larger farmers (approximately 300 ha). In the traditional cultivation system known as *cabruca*, cocoa plantations are established under native forest cover. The total area is approximately 400 000 ha, with a stocking of 600 cocoa trees/ha (Fontes *et al.*, 2014). In the other system, all native forest is removed, and cocoa plantations are established with a stocking of 1 100 cocoa trees/ha shaded with banana and *Erythrina glauca*, a nitrogen-fixing tree (Müller and Gama-Rodrigues, 2012). These cacao agroforestry systems generally accumulate large amounts of soil organic carbon (Monroe *et al.*, 2016).

Industrial mixed tree plantations

Most of the mixed tree plantations managed for industrial production that were studied in Brazil combined nitrogen-fixing and other species. In particular, mixtures of fast-growing *Eucalyptus* with *Acacia mangium* received considerable attention (Figure 2). Eucalypt–acacia mixtures can offer a wider range of products from the same plot compared to monoculture stands. They also maximize the provision of ecosystem services, for example by reducing surface runoff, and increasing carbon sequestration and biological nitrogen fixation (Paula *et al.*, 2020). In the last two decades, Brazil has developed a network of experimentation sites mixing *Eucalyptus* with *A. mangium*. A body of evidence suggests that there are gains of biomass to be had in mixed plantations compared to eucalyptus monocultures under favourable climatic conditions (i.e. hot and humid) for the development of *A. mangium*, as well as low soil fertility and reduced water availability. Such plantations can be more productive than monospecific plantations when established at sites with low productive capacity. Positive interactions are expected to prevail at poor sites (Marron and Epron, 2019), whereas intraspecific competition among fast-growing species dominates over facilitative interactions at more productive sites (Bouillet *et al.*, 2013; Forrester *et al.*, 2006). Zoning the productive capacity of the managed forest area is therefore a prerequisite for identifying sites where mixed plantations should be implemented.

Figure 2. An experimental mixed plantation of *Eucalyptus grandis* and *Acacia mangium* in Itatinga in São Paulo State, southern Brazil

Note: The two species are planted in alternating rows. In this picture, eucalypts largely dominate an understory of acacia, resulting in strong crown complementarity in canopy space.

However, management of mixed plantations, including eucalypt for commercial purposes in Brazil faces strong technical and economic limitations, which preclude their adoption on a large scale. The main silvicultural limitation stems from mechanization and automation of field operations and practices. Because each species planted in a mixture requires specific management in the establishment and maintenance phases, mixed plantations often have lower operational yield and increased production costs. In addition, harvesting and wood transport are more complex. In the wood processing phase, either for pulp, steel (charcoal) or panel production, there are similar limitations, as standardized, high-quality raw materials are required to optimize industrial processes. In addition, the invasive potential of acacia species may restrict their use in mixed plantations in climatic regions where this species thrives.

Another option towards increased diversity in industrial plantations that is currently being explored in Brazil is the mixture of eucalyptus clones (Rezende *et al.*, 2019). Results suggest that clone mixtures exhibit better growth stability (i.e. yield predictability) than monocultures and lower vulnerability to biotic or abiotic damage agents while being more compatible with industrial plantation management. Whether clone mixtures are economically viable (i.e. with stable production costs) and can provide a wider array of ecosystem services and greater biodiversity than monocultures deserves further scrutiny.

Conclusion

By reviewing current practices and successful examples of mixed plantations as well as economical and legal barriers to their adoption in Brazil, we hope to increase the current momentum towards adaptation of forest plantations to climate change. Our review suggests that the greatest potential for mixed-species plantations in Brazil is in agroforestry and restoration areas. In productive plantations, especially when the objective is production of a very calibrated product such as cellulose from monoclonal eucalyptus stands, increased management complexity remains a challenge for large adoption of mixed-species guidelines. Intermediate systems with mixed eucalyptus clones or where eucalyptus is mixed with native species are an interesting way forward. Future efforts should be directed towards the development of science-based silvicultural guidelines for mixed plantations in the different Brazilian biomes, using species of commercial interest and which are resilient to biotic and abiotic stress. Large field trials will help demonstrate the benefits of this new sylviculture and prove its relevance for large-scale management. In addition, sylviculture of native tree species – from breeding programmes to nursery techniques to field management – needs to be further developed to better exploit the huge potential of Brazilian trees for the supply of wood and other products and services under climate change.

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Demonstrating the benefits of planted-forest diversity through economic risk assessment

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Highlights

- Risks to forests are increasing under climate change, with potential impacts on entire forest supply chains.
- Mixed-species forests are more likely than monocultures to be resilient, thereby lowering risk, but many managers are reluctant to explore this option.
- It is essential, therefore, to improve bioeconomic modelling to better measure the economic advantages of mixed-species forests and encourage greater uptake.

Mixed versus monospecific stands – a historical perspective

The challenges and benefits associated with managing mixed and monospecific forest stands have been discussed since the nineteenth century (Scherer-Lorenzen, Körner and Schulze, 2005). At that time, the vast forests of Central Europe had been under pressure for many centuries. A growing population led to an increasing demand for timber and wood (Hasel and Schwartz, 2006). Profound societal changes at the time and associated overuse of forest resources promoted the development of forest plans focused on timber production. It was then believed that mixed stands would represent a loss in productivity compared to monospecific stands, and that transitioning any natural mixed stands into pure stands would therefore be beneficial (Hartig, 1975). However, it was also argued that mixed forests might enhance other forest functions and reduce the risk of economic losses (Cota, 1828). Today, over 200 years later, the debate on the benefits of mixed versus monospecific forests is still highly relevant. Growing societal demands and increasing uncertainties require a closer look to fully comprehend and utilize the dynamics of mixed forests, their ecology and the impact that forest management activities have on them.

Ecological benefits of mixed-species stands and forests

Carefully designed mixed-species stands and forests can provide a wide range of ecosystem services, at a lower risk of suffering losses from disturbances and without negatively affecting wood production compared to monospecific stands and forests (see article on TreeDivNet on p. 40). In addition, research at various scales has shown potential ecological benefits of transitioning from pure planted forest to different types of mixed forest.

In the past, it was believed that focusing on biomass production with one particular species was enough to promote a variety of ecosystem services. Today, however, we know that stands with a higher diversity of tree species provide a more diverse set of ecosystem services, and that they provide those services in larger quantities than those achieved by monospecific stands (Gamfeldt *et al.*, 2013). Some studies even show that, in certain instances, the full potential of various economically, ecologically and culturally valuable ecosystem services can only be achieved with multispecies management. Mixed-species stands also offer a broader gradient of ecological conditions, creating a variety of habitats that allow the coexistence of a larger number of species, thereby promoting biodiversity. Tree species diversity positively affects tree productivity at different spatial scales (Paquette and Messier, 2011). This is particularly relevant given the growing societal demands for products and services from forest ecosystems (Foley *et al.*, 2011).

Finally, given what we know about climate change today, all management decisions have to take into consideration the role of tree diversity when evaluating forest vulnerability to changing conditions. With increasing pressure from natural disturbances (see article on increasing diversity to boost provision of ecosystem services on p. 50), promoting mixed-species stands is a particularly promising alternative for adapting forest ecosystems to a new reality.

With the research-based knowledge that has been developed in the past 200 years in support of the debate on the benefits of mixed versus monospecific forests, today we can confidently say that mixed-species stands can have better growth performance and are less susceptible, for example, to wind or pests compared to monospecies stands (Griess and Knoke, 2011). While other impacts, such as those caused by drought events are not yet fully understood (Steckel *et al.*, 2020), pointing at the importance of developing very detailed site- and species-specific information and knowledge, the question remains why monospecific stands are still so frequent, particularly in plantations and production forests, focusing on growing timber and wood.

Why homogeneity might seem preferable in plantation management

Although the ecological benefits of mixed forests have led to their promotion in forest management strategies globally (Bolte *et al.*, 2009), homogeneous forests still appear to be a preferred option in many plantation management discourses. There are several reasons why homogeneity might seem preferable. First, standardized timber provision in terms of dimensions and properties may be advantageous for specific timber markets, where a homogeneous forest with a focus on selected species may be seen as more convenient for certain production systems and products. This has been the case with the widely spread monocultures of Norway spruce (*Picea abies*) in Europe, which were strongly preferred in the past due to their economic efficiency, high productivity and ability to grow well outside their natural range (Spiecker, 2003). Second, it may appear more complicated to assess the economic benefits of mixed forests, as their ecological dynamics are more complex, and tree species interactions have to be considered, both of which are still poorly understood (Knoke *et al.*, 2008). Therefore, it may seem easier to assess the benefits of species for which an extensive research and knowledge base exists (e.g. regarding plant nutrition, associated pests and pathogens, propagation, genetics, growth and yield, or response to silvicultural treatment) (Pretzsch, Forrester and Bauhus, 2017). Increasing species diversity may be believed to increase the complexity of silviculture treatments and management strategies, potentially leading to higher costs.

The link between ecological and economic benefits: the importance of considering risks

Mixed forests are well known to have many advantages from an ecological perspective. However, when it comes to the details of these advantages, and how to benefit from them, things become more difficult (Knoke *et al.*, 2008; Pretzsch, Forrester and Bauhus, 2017). In terms of the economic benefits of mixed forests, if a forest owner asks, "What should I do with my forest, what should I plant, and how?", the answer has to be "It depends," as there are numerous factors influencing the de facto forest ecology and therefore forest economics at any given site. However, one thing remains constant across forests worldwide, independent of species, mixture or growing conditions: forests are exposed to risks (Box 1).

Increasing risks to forests under climate change affect forest production and tree survival, impacting the entire forest supply chain. Management favouring mixed forests usually leads to greater stand resistance and resilience in the face of natural disturbances, reducing losses in revenue compared with monocultures. Mixed forests perform better in mitigating the negative impacts of changing environmental conditions via the growth and survival of the trees (Pukkala, 2017). They also provide the possibility of growing a more diverse product assortment, which might be an advantage in changing markets. While these details also depend on the types of mixed forests that are promoted (Box 2), the moment we include risk in our forecasts and consider the risk reduction associated with mixing tree

Box 1

Defining risk in relation to forests

Like financial stocks, the economic returns from forest investments are volatile. Just like any other asset, forests are exposed to risks and uncertainties, such as the possibility of damage from storms, fire, insect infestations, disease, invasive plants or drought. Additionally, the economic value of forests is influenced by fluctuations in product market prices and production costs. We can define risk as the probability that an adverse event will occur. Therefore, risk management is the process of making decisions, considering risk and implementing actions that reduce (or do not reduce) the probability or the magnitude of the adverse event. Considering risk is key when assessing the economics of mixed versus pure planted forests. In the context of climate change, risks result from the interaction between climate-related hazards, such as an increased intensity and frequency of natural disturbances, and the exposure and vulnerability of forests. However, not every potential mis-assessment in forest projections should be described as a "risk". There is also uncertainty in any projection into the future, meaning that context and comparability matter.

Uncertainty leads to different attitudes towards risk prevention and reduction. If the risk is perceived as imminent, it is more likely that the need for action will be accepted than if the risk is seen as unlikely or further away in time. Forest managers' attitudes towards risks play a crucial role in forest management decision-making, in particular regarding species composition and whether mixed forest structures are implemented. Even though we know that mixed forests are more likely to be more resistant and resilient against risks, managers are often reluctant to act because they do not perceive the risk as imminent. The manager's risk preference also plays a critical role; it is therefore fundamental to accurately assess the economic advantage of mixed forests and management actions over a range of risk aversion alternatives. Doing so helps to guide forest policies and define financial assistance programmes to improve the adoption of management actions towards mixed forests.

species, mixed stands economically outperform monospecific plantations. It is therefore clear that any unbiased economic assessment must quantify and consider risks.

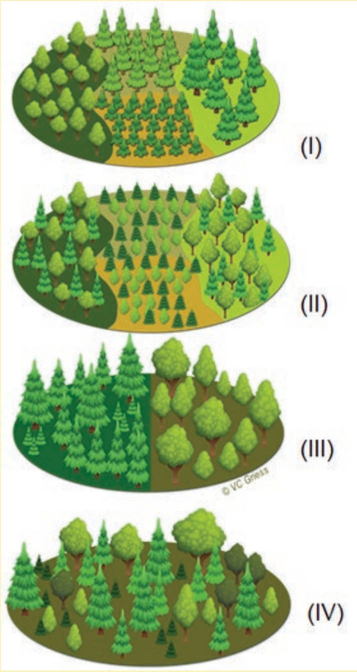
If we want to include risks related to production in our economic assessments, such as losses due to natural disturbances or market changes – for example, drops in timber prices, or disruptions of forest continuity – we must quantify them. This is where tools from financial mathematics (e.g. Monte-Carlo simulation) come into play, enabling the quantification of risks using the variance or standard deviation of a return. Another option is to simulate forest dynamics, including risk, as the probability of suffering damage (e.g. stochastically) and finding optimal management strategies to maximize the desired forest products and services considering risks. However, every projection of forest development into the future is associated with uncertainty. These uncertainties can stem from the way ecological processes are defined in our models, or from the unknowns of market demand or societal needs. It is therefore also vital to assess the uncertainty of our projections.

Models of forest dynamics are tools developed to assess future forests under changing conditions, such as climate change, greater societal demands and increasing risks. Modelling dynamics in mixed forests is challenging, due to the complex interactions among species. Specifically, it is difficult for bioeconomic models to include different species interactions because these models have traditionally used data resources based on monospecific forests and have involved a somewhat simplified approach. In many instances, these models can only be improved by collecting data from long-term experiments considering mixed forests. Simple bioeconomic models might make sense for computational and methodological reasons, but they fail to correctly capture mixture dynamics in which species interactions and their impacts on yield and resistance are fundamental. Furthermore, bioeconomic models must consider projections under different management strategies and assess their effects on timber production and multiple ecosystem services, integrating the costs of implementing and managing mixed forests. Without considering all these aspects, it is impossible to provide sound answers to questions about the economic attractiveness of mixed forests.

Conclusion

- Mixed-species forests have economic benefits.
- Risks are of increasing relevance and must be considered.
- When risks are considered, species mixtures (all of them) are economically (and ecologically) favourable compared to monospecific even-aged forests.
- Many challenges to improving bioeconomic modelling still exist. Most of these can only be addressed by collecting data from long-term experiments.

Box 2



Types of mixed forests from an economic perspective

(I) A portfolio of tree species mixed at the enterprise or forest estate level. Here, the enterprise/estate comprises pure forest stands of various species. No – or very limited – interactions between tree species occur.

(II) Tree species are mixed at the stand level, forming mixed-species stands. Here, the various species influence each other, e.g. regarding resilience, growth and timber quality.

(III) A mixture of age classes forms an uneven-aged forest, but different species grow in different areas of the enterprise/estate. Here, various tree sizes/ages are mixed, leading to the opportunity for continuous harvesting (single-tree selection).

(IV) Both age classes and species are mixed throughout the enterprise/estate. This situation is known as a plenter forest and is associated with the same benefits as (II) and (III).

- Species interactions and relationships between variables relating to different planning periods need to be included in models.

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Enhancing the role of planted forests in biodiversity conservation

Rubber plantation ("jungle rubber") in Indonesia supporting significant biodiversity

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Adapted from: **Harrison, R.D., Shono, K., Gitz, V., Meybeck, A., Hofer, T. & Wertz-Kanounnikoff, S.** 2022. *Mainstreaming biodiversity in forestry*. FAO Forestry Paper, No. 188. Rome, FAO and Bogor, Indonesia, CIFOR. https://doi.org/10.4060/cc2229en

Highlights

- Depending on several key factors, such as tree-species selection and landscape context, planted forests can help restore and maintain biodiversity while providing socioeconomic benefits.
- The biodiversity value of planted forests can be increased by integrating biodiversity conservation strategies into planted-forest planning and management.
- For long-term biodiversity conservation, well-planned and -managed planted forests should be complemented by sustainably managed natural forests.

Biodiversity is critical to the maintenance of planetary health. Forests are host to most of the Earth's terrestrial biodiversity. Thus, the conservation of the world's biodiversity is utterly dependent on the way in which we interact with and use the world's forests. Planted forests accounted for 7 percent (290 million hectares [ha]) of the forest area worldwide in 2020, an increase of 123 million ha since 1990 (FAO, 2020). Considering the current global movement on ecosystem restoration, which often involves tree planting in terrestrial ecosystems, and the recognition of biodiversity conservation as a global priority, it is important to consider ways in which the contribution of planted forests to the conservation and sustainable use of biodiversity can be enhanced.

Impact of planted forests on biodiversity

Planted forests vary widely in their structure, species composition, management objectives and combination of services provided, ranging from monoculture plantation forests managed on a short rotation for biomass production, to mixed planting of diverse native species managed for non-productive services.

Accordingly, the biodiversity impact of planted forests, which can be positive or negative, varies depending on several key factors:

1) Tree species selection: The choice of tree species in planted forests can significantly affect biodiversity. Monoculture plantations, especially of exotic species, host limited biodiversity. In contrast, planted forests that are more similar to natural forests in species composition and structure can provide a more diverse habitat and support a broader range of native plant and animal species (Quine and Humphrey, 2010; Brockerhoff *et al.*, 2008).

2) Landscape context: The location and surrounding landscape of planted forests play a crucial role in determining their biodiversity value. Planted forests established in areas adjacent to natural forests can serve as buffer zones, connecting fragmented habitats and allowing for species movement. This connectivity enhances biodiversity by facilitating gene flow and providing corridors for wildlife.

3) Ecosystem services: Planted forests can provide environmental services such as soil protection, water regulation and carbon storage depending on the choice of species and management practices. These functions can indirectly benefit biodiversity by maintaining habitats for a wide range of native forest plants and animals (Brockerhoff *et al.*, 2008).

4) Management practices: The quality and intensity of forest management strongly influence the forest's ability to support biodiversity. Sustainable forest management practices implemented to a high standard can enhance habitat quality and maintain key biodiversity resources for a wider array of species. More intensive management practices (e.g. the use of pesticides or clearcutting on short rotations) may negatively impact biodiversity (Brockerhoff *et al.*, 2008). In general, increasing rotation lengths, managing uneven-aged stands and retaining some large trees contribute to enhanced biodiversity

Blocks of forest plantation in Brazil managed by Klabin S.A., interspersed with native forests set aside for biodiversity conservation

©Zig Koch/Klabin

outcomes in planted forests (Brockerhoff *et al.*, 2017).

Plantation forests and biodiversity

Plantation forests are often perceived as being detrimental to conservation of biodiversity. This is because forest plantations under short-rotation, even-aged monoculture management, especially of exotic species, generally support only a small proportion of native biodiversity (Bremer and Farley, 2010).

Conversion of natural forests, even if degraded, to plantation forests will almost certainly result in a negative outcome for biodiversity. Therefore, forest plantation development should be carried out on degraded lands that have limited biodiversity value so that the plantation establishment does not come at a cost to biodiversity. This may require removing perverse incentives that promote forest plantation expansion at the expense of natural forests and aligning incentive structures with the sustainable use and conservation of biodiversity.

Nevertheless, plantation forests provide important productive functions and may reduce pressure on natural forests by providing alternative supplies of fuelwood, timber and other forest products. Furthermore, plantations may produce timber that replaces steel and concrete in construction, reducing overall greenhouse gas emissions and biodiversity impacts of these materials, hence contributing to a more sustainable society (Girardin *et al.*, 2021).

Furthermore, depending on the landscape context, forest plantations can reduce edge effects through providing a soft edge, and thereby increase the effective size and biodiversity value of natural forest patches (Brockerhoff *et al.*, 2008; Arroyo-Rodríguez *et al.*, 2020). Similarly, forest plantations can facilitate the dispersal of species that avoid open areas, thereby increasing connectivity for this sensitive group of species (Barlow *et al.*, 2007). When appropriately situated, plantation forests can also serve as buffer zones between natural habitats and human settlements to reduce human-wildlife conflicts.

Mainstreaming biodiversity in planted forest management

The biodiversity value of planted forests can considerably be improved through appropriate design and management (Brockerhoff *et al.*, 2008; Pawson *et al.*, 2013). This requires the integration of biodiversity conservation strategies into planted forest planning and management. Key approaches for mainstreaming biodiversity in planted forest management include the following:

Assessing and managing risks of forest operations to biodiversity. During planning and before initiating any major operations, forest managers should undertake biodiversity risk assessments, and implement measures to mitigate identified risks. The high conservation value (HCV) approach[19] provides a robust framework for identifying and managing the ecological, environmental and social impacts of forest operations with the engagement of relevant stakeholders.

Establishing and managing set-aside areas. Biodiversity outcomes in planted forests can be improved by delineating and preserving judiciously located areas set aside to protect old-growth forest and vulnerable habitats, and maintain habitat connectivity. While standards vary among countries, a minimum of around 15 percent set aside is often required within a managed forest. These set-asides not only protect threatened habitats and the species they harbour, but also their contribution to local livelihoods and the cultural values they represent.

Protecting critical biodiversity resources. The impacts of forest management on biodiversity can be further mitigated by retaining and protecting key biodiversity resources within production stands, such as large trees that serve as nest sites (e.g. *Koompasia* spp. in Southeast Asia which are often retained within a forest plantation for bee nests) and seed sources for the maintenance of tree genetic diversity.

Sustainable management of forest genetic resources. The conservation of genetic diversity and sustainable management of genetic resources in production forests is an often-overlooked aspect of forest biodiversity conservation. Intraspecific diversity is likely to be essential for climate change resilience. Steps that can be taken to maintain and enhance genetic diversity of tree resources include: establishing set-aside areas; maintaining forest connectivity; and integrating genetic diversity considerations in tree planting.

Conclusion

While planted forests cannot fully replicate the biodiversity of undisturbed native forest ecosystems, they can play an important role in restoring and maintaining biodiversity while providing socioeconomic benefits at the landscape level. Maintaining and sustainably managing natural forests, alongside well-planned and managed planted forests, are crucial for long-term biodiversity conservation. A key consideration in integrating biodiversity conservation in planted forest management is how to combine wood production and biodiversity values at the stand, forest and landscape scales. Creating mosaics of well-managed planted forests and natural habitats through a landscape approach can provide for sustainable wood production and long-term biodiversity conservation. Such an approach must be applied from the beginning of planted forest planning.

[19] https://www.hcvnetwork.org/

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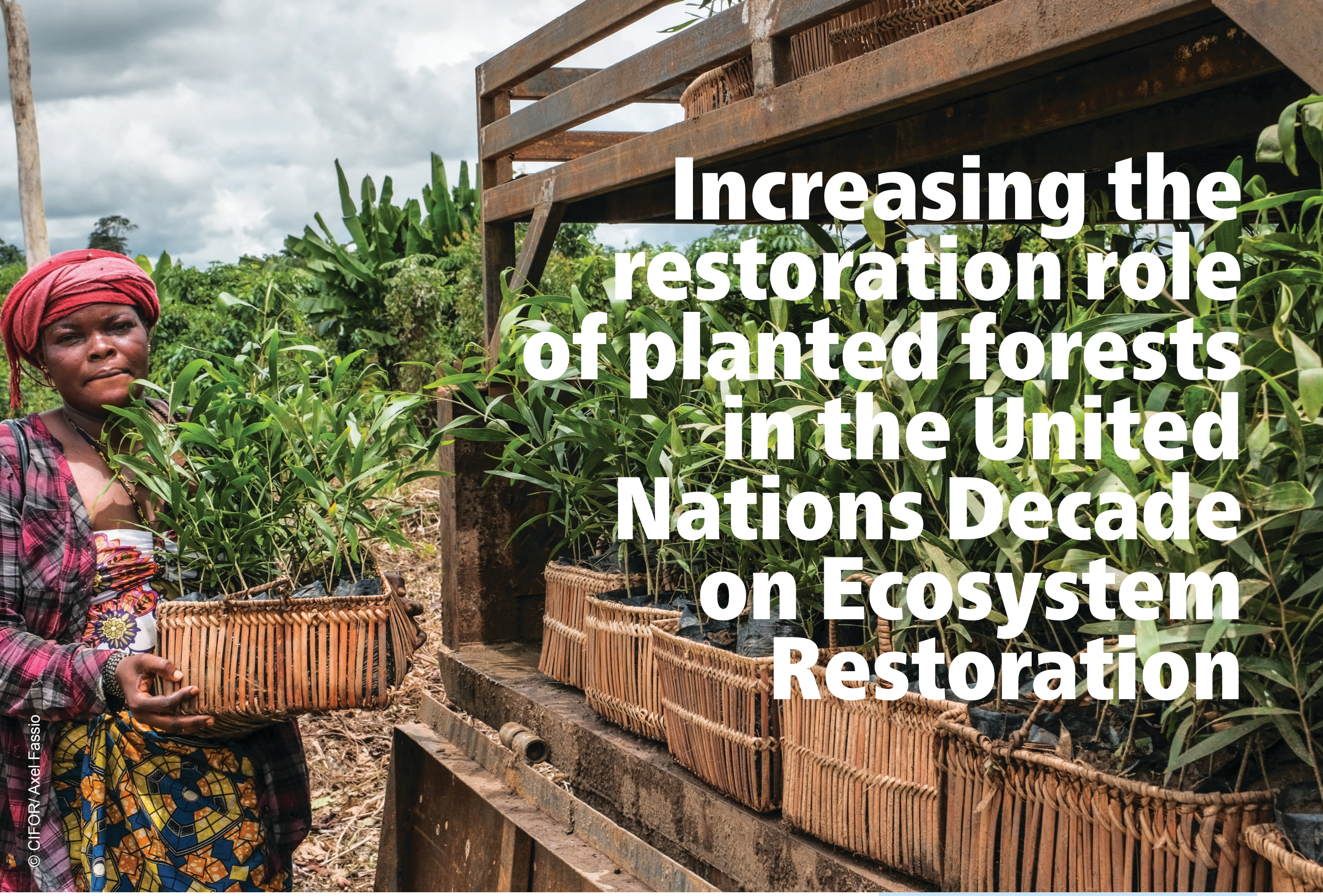
Democratic Republic of the Congo | Afrormosia seedlings at the tree nursery



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Increasing the restoration role of planted forests in the United Nations Decade on Ecosystem Restoration

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Highlights

- The United Nations Decade on Ecosystem Restoration is a global restoration movement to catalyse restorative ground-level action.
- Planted forests can deliver on multiple objectives, including wood production and the UN Decade's mission of preventing, halting and reversing ecosystem degradation.
- The UN Decade provides a platform for sharing knowledge to enhance the contributions of planted forests to restoration worldwide.

The need and opportunity to combine restoration and sustainable wood production

Facing the urgency of reversing ecosystem degradation, countries worldwide have made ambitious pledges to restore an area amounting to more than 1 billion hectares (ha) (UNEP, 2021). This political momentum led to declaring 2021–2030 the United Nations Decade on Ecosystem Restoration (hereafter, the "UN Decade"), a global restoration movement catalysing action on the ground and from all society (see box on Youth in the UN Decade). Within the scope of the UN Decade, ecosystem restoration encompasses a wide range of restorative activities that contribute to different objectives, from reducing societal impacts, improving ecosystem management, rehabilitating ecosystem functions and services, to fully recovering native ecosystems (FAO, SER and IUCN CEM, 2023). In terrestrial ecosystems, forest and landscape restoration (FLR), defined by the Global Partnership on Forest and Landscape Restoration (GPFLR) as "an active process that brings people together to identify, negotiate and implement practices that restore an agreed optimal balance of the ecological, social and economic benefits of forests and trees within a broader pattern of land uses" (GPFLR, n.d.), is a widely adopted approach for ecosystem restoration in degraded forest and deforested landscapes.

Meeting FLR commitments is expected to lead to large-scale restoration of degraded forests through a combination of several types of restorative activities, including afforestation, reforestation and sustainable forest management throughout the world. With a global demand for primary processed wood products expected to increase by 37 percent by 2050 compared to 2020 (FAO, 2022), the major forest area expansion foreseen through FLR could be the springboard towards sustainably increasing wood production globally. Planted forests include a wide diversity of systems and management intensities – from monoculture plantations to multipurpose, diverse plantings – and can supply timber (including woodfuel), non-wood forest products and other environmental services for commercial and non-commercial use (FAO, 2016). This article explores how planted forests can successfully contribute to meeting the growing demand for wood and other products and services, as well as restoration commitments on a global scale.

Youth in the UN Decade

Francis Asamoah, Wildlife Ecologist, Member of the Youth Taskforce of the UN Decade on Ecosystem Restoration

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Across cultures, people have said, "Plant a tree not for yourself, but for your children's children to one day sit under its shade." As the Youth Taskforce (YTF) for the United Nations Decade on Ecosystem Restoration, we speak for our generation and the following ones when we stress the intergenerational nature of reforestation and the importance of youth engagement in ecosystem restoration, forest management and policymaking. Youth involvement in forestry historically dates back to the early 1800s, but recognition for youth actions in the sector has only come in recent years.

The YTF is a youth-led movement demonstrating the power of an environmentally conscious generation taking concrete action towards #GenerationRestoration to protect a healthy planet. Young people are already taking steps towards restoring today's environment, and we will continue, with or without recognition. It is often said that there is time, well, this is the time, we cannot fail, this is our planet!

Source: **Kaiser, F**. 2021. A new generation of young people is putting the planet first. Here's everything you need to know. In: *World Economic Forum*. Cited 9 August 2023. https://www.weforum.org/agenda/2021/04/generation-restoration-everything-you-need-to-know/

The contributions of planted forests to the restoration of mosaic landscapes

Planted forests are primarily established for productive purposes (FAO, 2006). Seventy-six percent of planted forests globally are managed for the production of essential goods such as wood products, pulp and fibre, and fuel or bioenergy (Evans, 2009). Planted forests are also increasingly established to sequester carbon. Although they accounted for only 7 percent[20] of the global forest area in 2015, planted forests contributed around 46 percent of global industrial roundwood supply (Nepal, 2019). Plantations,[21] which are intensively managed planted forests, are especially successful in meeting the demand for wood production because they are designed to meet a single management objective (Bauhus *et al.*, 2010). Globally, the area of plantation forest composed of introduced species is 49.7 million ha, which represents 1.4 percent of the total forest area of the reporting countries. Introduced species account for 44 percent of the total area of plantation forest in these countries.

[20] Or 291 million ha according to the Global Forest Resources Assessment (FRA) 2015 (FAO, 2015). Note that according to FRA 2020 (FAO, 2020), the global planted forest area has increased to 294 million ha, which still amounts to 7 percent of the global forest area.

[21] According to FAO (2020), plantations are intensively managed and include only one or two species, even-aged classes and regular spacing. This definition includes short-rotation plantations for wood, fibre and energy but excludes forest planted for protection or ecosystem restoration, and forest established through planting or seeding that at stand maturity resembles or will resemble naturally regenerating forest.

Planted forests can also directly provide a range of other ecosystem services that contribute to the UN Decade's mission of preventing, halting and reversing ecosystem degradation. About one-third of planted forests globally are established with the primary objective of protecting natural resources (Evans, 2009). When well designed and managed, planted forests contribute to regulating climate, recovering and maintaining soil structure and quality, and improving water quality. They can provide habitat for animal and plant species and corridors for wildlife. Tree planting is also a strategy to fight desertification, protect watersheds from erosion and for phytoremediation (Isebrands and Richardson, 2013).

Despite multiple trade-offs across production, profitability, social acceptability and environmental benefits such as carbon storage, water provisioning, soil erosion control and biodiversity (Hua *et al.*, 2022), planted forests have the potential to deliver on multiple objectives. They can play a role in enhancing productive capacity, ecological connectivity, livelihoods and food security. In some cases, planted forests provide the enabling environment for the establishment of native vegetation and can also help prevent further degradation of natural forests (Maginnis and Jackson, 2003). By reducing pressure on natural forests, they can contribute to strategies to combat forest degradation and deforestation (as an example, see the Makala Project box). Including planted forests as part of the mix of restoration options at the landscape level has the potential to provide balanced packages of ecosystem services and goods. Although intensively managed tree monocultures can hardly be considered as restored stands, they may be considered as a relevant FLR option in specific landscapes. Successful examples exist, where large-scale tree plantings with native species play a key role in the restoration of mosaic landscapes combined with a mix of other interventions, such as in The Atlantic Forest Restoration Pact "PACTO" (Rodrigues *et al.*, 2011). By optimizing spatial arrangements and balancing trade-offs between land uses and between productive and protective functions of forests, expansion of the planted forests area can meaningfully contribute to achieving global restoration goals.

The Makala Project: sustainably managing woodfuel resources

In the Congo and in the Democratic Republic of the Congo, a major part of domestic energy comes from wood. Urban sprawl takes a hard toll on natural peri-urban forests. The Makala ("charcoal" in lingala) Project implemented from 2009 to 2013 under the coordination of the French International Cooperation Centre of Agricultural Research for Development (CIRAD), was designed to address the degradation of wood resources while meeting energy needs in the cities of Kinshasa and Kisangani, Democratic Republic of the Congo, and Brazzaville, Congo. Building on lessons learned from pre-existing high productivity plantations, the project contributed to increasing wood resources through planted forests. It adapted technical itineraries for planted forests, with the priority objective of sustainable production of wood for energy purposes; supported the establishment and management of woodfuel plantations by small private growers and communities; and integrated planted forests for energy purposes into an agroforestry dynamic.* In areas of second-growth forest where biodiversity was still high, the project favoured assisted natural regeneration to protect species useful to farmers.* In contrast, in the most degraded areas where only invasive grasses or shrubs remained, planting fast-growing leguminous trees was the most appropriate solution for restoring soil fertility, while producing woodfuel and non-timber forest products.**

Sources: *** Peltier, R., Dubiez, E., Diowo, S., Gigaud, M., Marien, J.-N., Marquant, B., Peroches, A., Proces, P. & Vermeulen, C.** 2014. Assisted Natural Regeneration in slash-and-burn agriculture: Results in the Democratic Republic of the Congo. *Bois et forêts des tropiques*, 321: 67–79.

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Implementing afforestation and reforestation as restoration interventions

The variety of tools and approaches already used in restoration initiatives worldwide can be mobilized towards effective restoration with planted forests. As for all restoration interventions, the ten principles for ecosystem restoration (FAO, IUCN CEM and SER, 2021) and standards of practice (FAO, SER and IUCN CEM, 2023) developed under the UN Decade provide a useful guiding framework and key recommendations, which can apply to afforestation and reforestation initiatives, from assessment, planning and design, to implementation, ongoing management, and monitoring and evaluation. It is important to highlight that, to be considered restorative activities, afforestation and reforestation must result in improvements for biodiversity, ecosystem integrity and human well-being, and should enhance natural recovery processes and not generate additional degradation (FAO, IUCN CEM and SER, 2021). Aligned with the guiding framework, the ten golden rules for reforestation developed by Di Sacco *et al.* (2021) offer relevant recommendations for conducting reforestation within forest restoration initiatives in a way that maximizes benefits for nature and people.

From an assessment and planning standpoint, careful landscape- and stand-level assessment, planning and mapping of restoration interventions, are needed. The widely used Restoration Opportunities Assessment Methodology (ROAM) (IUCN and WRI, 2014) offers a good starting point, but tools tailored to informing restoration planning while linking to forest value chains and especially wood production potential, and taking into account a variety of factors such as opportunity costs of land, infrastructure and wood prices, are much needed. Some organizations have started developing tools and approaches towards better consideration of these dimensions (Caradine *et al.*, 2023). The contribution of a wide range of planted forest management systems can be explored. On the one hand, establishing highly productive plantations to meet the industrial roundwood demand increase by 2050 would be needed over at least 33 million ha (FAO, 2022). On the other hand, models of multifunctional planted forests, including mixed-species planted forests, which produce diverse packages of ecosystem goods besides wood, such as non-timber forest products for food or medicinal use, fibre, biofuels or fuelwood, or closer-to-nature forest management – a new concept of nature-based forest management (NBFM) proposed in the EU Forest Strategy for 2030 – should be operationalized on a larger scale (Messier *et al.*, 2022).

In a restoration context, the quality of planting material is essential to ensuring successful outcomes. High-quality tree seed or other propagation material are needed in sufficient amounts. The lack of tree seed and forest reproductive material undermines the success of restoration. Guidelines, including FAO's recently launched publication on "Delivering tree genetic resources in forest landscape restoration: A guide for practitioners and stakeholders to ensure local and global restoration outcomes" (FAO, forthcoming), training materials (FAO e-learning) and tools are being developed to improve the use and benefits of genetic resources in restoration. To enhance the role of planted forests in restoration as well as the biodiversity benefits derived from their establishment, industrial roundwood production with commercial exotic (not invasive) and indigenous species should be better explored.

Finally, lack of ownership from local populations is often quoted as a reason for failure of restoration efforts. To successfully integrate planted forests as a restoration option at the landscape level, buy-in of local communities is paramount. This entails engaging all stakeholders from the onset of the process to ensure that the proposed interventions are acceptable, the species selected are suitable and mechanisms are set up to grant their rights and benefits (Maginnis and Jackson, 2003). Some initiatives, such as New Generation Plantations, are working actively towards that end (refer to the article on the contribution of properly governed plantations on p. 91). As planted forests often involve economic interests, it is paramount to ensure responsible investments in restoration. Guidelines and principles developed in the context of forestry investments apply to reforestation programmes (FAO and Landesa, forthcoming). Other tools, such as certification, can be implemented to ensure the quality of restoration outcomes.

Moving forward

A vast body of knowledge focused on major challenges posed by the large-scale restoration movement, such as monitoring or finance, and on specific restoration approaches, such as assisted natural regeneration, has been consolidated. There is much evidence and experience from both science and practice about planted forests in FLR, but relatively limited capitalization and experience sharing on the topic. Knowledge on planted forests for restoration needs to be strengthened and widely disseminated. The UN Decade, through its Taskforce on Best Practices, provides a unique platform for sharing knowledge and good practices and engaging with a wide range of stakeholders, and to leverage science and practice, which could potentially enhance the role and contributions of planted forests to FLR and the global restoration movement.

Whereas national restoration assessments and strategies recognize planted forests as one of the options for restoration, successful examples and best practices remain isolated. Partners have a role to play in encouraging the implementation of sound productive restoration interventions that deliver on multiple benefits across the landscape. Testing and promoting sound approaches in mosaic landscapes with planted forests, implemented through coalitions of partners, would help build the case required to meet the concomitant needs for restoration and production in the coming decades.

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The contributions of fast-growing trees to restoration

Interview with Martin Weih,

Chair, International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment

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Highlights

- Fast-growing trees (FGTs) can supply ecosystem services while providing local people with income.
- The mandate of the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment expanded recently to include all FGTs.
- A focus of the commission's future work will be the role of FGTs in increasing resilience and the provision of ecosystem services.

Fast-growing trees (FGTs) such as poplars, willows or acacias, are well known for wood production. Which other ecosystem services can they provide?

MW: These trees can provide additional ecosystem services such as healthy soils, clean water and carbon sequestration, while providing alternative livelihoods to local communities. Especially when these trees are grown in mixed-species or agroforestry settings, they also can increase biodiversity and enhance resilience of livelihoods.

Can you give us examples of how FGTs have successfully contributed to restoration?

MW: Due to their fast growth rates along with their high capacity to take up water and nutrients, these trees provide excellent opportunities for the fast establishment of green belts and ecological restoration of mining areas and landfills, for example, while providing biomass and enhancing soil health and carbon sequestration. There are many examples of phytoremediation applications using poplars and willows across Europe and the United States of America.

Agroforestry is often cited as an approach that can simultaneously provide a wide range of ecosystem goods – including timber – and services, while generating alternative livelihood opportunities. Can you give us examples of the successful inclusion of FGTs in agroforestry systems?

MW: As their name implies, FGTs have rapid growth, and many species are amazingly resilient and can be grown in many different ways, including in combination with other agricultural species. A good example of a successful agroforestry concept with FGTs is a cooperative partnership between Italy and China, initiated in the 1970s, where the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC) facilitated the transfer of germplasm (poplar clones), scientific knowledge and technology from Italy into a new agroforestry context in China. This partnership increased the tree cover in Siyang County from 7 percent to 47 percent and supported smallholder farms by providing enhanced food security and alternative livelihoods. Other examples include poplars grown with cereals or horticultural crops in China and India, where the poplars function as shelters for the agricultural crops.

How has the IPC supported the expansion and sustainable management of forests throughout the world since its creation? What can we expect from the IPC's new mandate?

MW: The IPC offers fantastic possibilities to help implement FGT stands as part of FAO's work while at the same time supporting global sustainability goals by acting as a science–policy implementation platform and a proven model for international technical cooperation in forestry. One example of such technical cooperation is the Italy–China partnership for the application of poplars in an agroforestry context mentioned above. Traditionally, the IPC focused on poplars and willows, but in 2019, it broadened its scope and received a new mandate to include other FGTs with the potential to sustain people and the environment. This new mandate supports the sustainable provision of wood and ecosystem services through sharing of experiences and lessons learned on FGTs in forestry and agroforestry systems in various countries. It also aims to strengthen the contribution of plantations with FGTs to food security, and sustainable livelihoods and land use in rural areas. Key ingredients of the new mandate are thus new species, new geographies and a strong alignment with strategies of the 2030 Agenda and the Global Forest Goals, the United Nations Decade on Family Farming and the United Nations Decade on Ecosystem Restoration. Due to their fast-growth rates including in the juvenile stage, cultivation systems of FGTs can also serve as excellent model systems for testing hypotheses on the relationships between tree diversity, management and productivity. A particular focus of the IPC's future work will therefore be on further development and implementation of FGT species in different contexts, including mixed-tree and agroforestry settings, to enhance resilience and provision of essential ecosystem services.

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The Sawlog Production Grant Scheme: Uganda's flagship programme for inclusive commercial forestry

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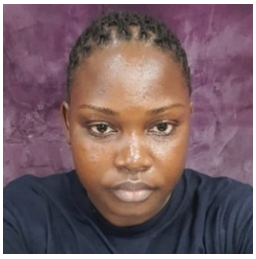

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Highlights

- The Sawlog Production Grant Scheme (SPGS) is a public-private partnership in Uganda to encourage mostly small- and medium-scale landholders to grow trees commercially.
- Investors are attracted by the SPGS incentives package and the availability of long-term tree-planting permits on government land.
- Since 2004, the SPGS has supported establishment of 70 000+ hectares of plantations and created 12 000+ jobs.

Introduction

In Uganda, commercial tree planting started many years ago. Despite government involvement, it faced several challenges, including lack of improved planting material, skills and information, and matching finance for continued forest management. As the government plantations matured, they were harvested to meet the nation's demand for timber, but the Uganda Forest Department failed to replant the harvested areas in the early 1970s.

Initiated in 1998, the Ugandan forest sector reforms resulted in a policy that states that "the private sector will play the major role in developing and managing commercial forest plantations," and that "the government will create a positive investment climate to encourage private investment in commercial forest plantations" (MWLE, 2001). Although the Government of Uganda provided incentives under the 1991 Uganda Investment Code and its 1997 revision, this did not stimulate investment in commercial forestry, largely because incentives favoured short-term investment cycles of 3 to 5 years while long-term commercial forestry has a longer gestation period of 15–30 years. The banking industry in Uganda was not (and is still not) offering long-term financing. It is these gaps that the Sawlog Production Grant Scheme (SPGS) was formed to fill.

The SPGS[22] is an initiative of the Government of Uganda through the Ministry of Water and Environment (MWE) that provides a good example of a successful public-private partnership. It was funded by the European Union and the Governments of Norway and Uganda. The project supported private-sector entrepreneurs, who were mostly small- and medium-scale landowners interested in growing trees commercially for timber, poles and woodfuel. The project started in 2004, and its remarkable achievements resulted in close to 20 years of funding by the European Union (for more information on the lessons of SPGS, see Kazoora [2007]). Because of its remarkable achievements, the government secured additional funding from the World Bank under the Investing in Forests and Protected Areas for Climate-Smart Development (IFPA-CD) project, which is expected to contribute an additional 36 500 hectares (ha) of commercial plantations in the country over 2022–2026.

The SPGS supports private investors in forestry both financially and technically. By providing an alternative source of timber and other forest products, the pressure on the remaining natural forests in Uganda is reduced, leading to conservation of biologically diverse native forests.

The scheme provides an incentive for the private sector to establish long-term commercial forestry, which they would not easily attempt otherwise. The SPGS stands out today as a flagship forestry project in Uganda and the rest of sub-Saharan Africa, demonstrating good practice regarding how to justify, plan for and implement an incentive-based, community tree-planting scheme.

The SPGS model in Uganda

The SPGS model takes a holistic approach to commercial forestry, whereby small-, medium- and large-scale landowners in the community are all involved. In this model, the tree growers have been categorized as community tree planters (0.5–5 ha), woodlot planters (5–25 ha) and commercial growers (25–500 ha and 501–3 000 ha), as reflected in Figure 1.

This approach created a conducive environment for commercial forestry investment. The small-scale community and woodlot planters were a source of skilled labour to the medium- and large-scale growers, which created a sense of ownership and reduced community-induced risks and threats to plantation forestry. In addition, the small-scale growers adopted improved practices and standards, and marketed their products more effectively through the large-scale planters, who had established national, regional and international timber market networks.

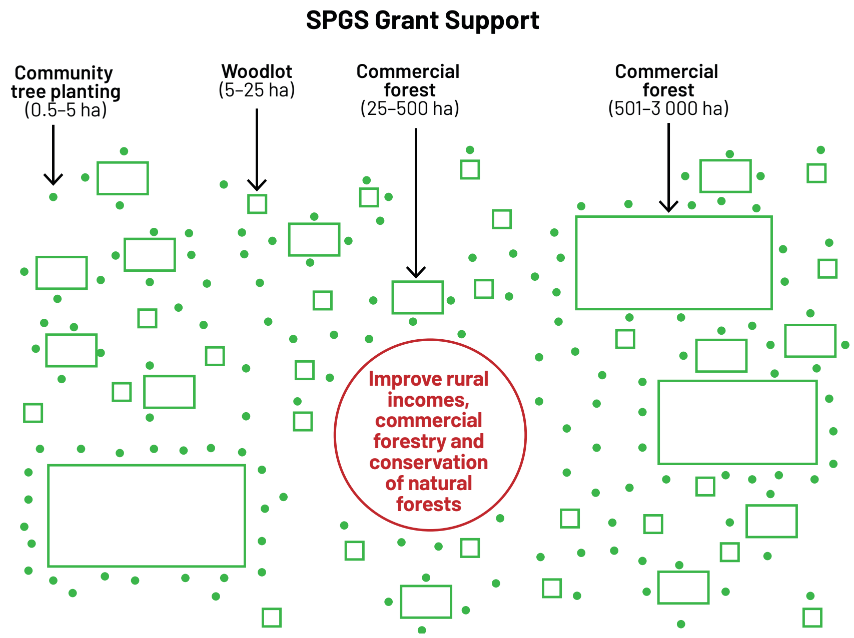

Figure 1. Pictorial representation of the SPGS model

SPGS incentives and their impact

According to Jacovelli *et al.* (2009), the SPGS incentives package and availability of long-term tree-planting permits in specific central forest reserves throughout the country were the two main factors that attracted private investors to the commercial forest sector in Uganda.

Close to 80 percent of the tree plantations were established on government land leased by private tree growers for an average ground rent fee of USD 4–13/ha per year depending on the distance from the capital city Kampala. The lease remained valid as long as the land use was kept as forestry. This arrangement where the government provided land, the donor

[22] See https://spgs.mwe.go.ug/

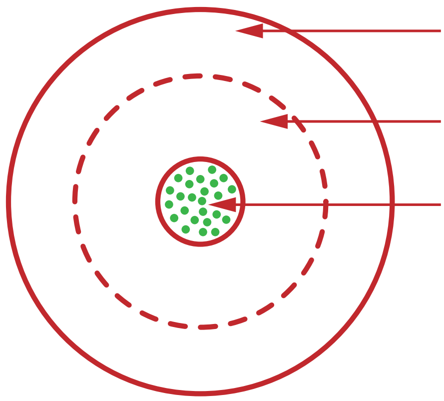

Figure 2. SPGS training in relation to other training providers

Source: SPGS II News Issue No. 39, Oct.- Nov. 2014

provided the conditional grant, and the private sector co-invested in tree planting functioned as a public-private partnership.

The tree-planting and maintenance incentive package was delivered in several forms:

- **Conditional, retrospective establishment grant** at an average of 40 percent of the establishment cost (USD 1 200/ha). The grant reimbursement was staggered over 2 to 3 years to ensure that the crop was out of danger by the time payments were completed, and to avoid the risk of funds diversion at tree-grower level. In addition, a plantation maintenance grant incentivized the execution of non-commercial, yet quality-impacting operations, particularly first thinning.
- **Direct seedlings support to community tree planters (0.5–5 ha) and in addition, basic forestry tools** and community exchange programmes encouraged the creation of standards-inclined community groups and collaborative forest management groups, which have planted close to 30 percent of the current timber resource in Uganda.
- Other monetary incentives were offered through **funded applied research projects** for studies on emerging challenges to tree growing.

Overall, the SPGS grants have supported direct plantation establishment and maintenance of close to 70 percent of the planted forest resource in Uganda, estimated at 105 000 ha to date (Howard, 2019). These were largely monocultural plantations, which excluded taungya practices, except at community level (0.5–5 ha).

Table 1 shows the achievement of the SPGS between 2004 and 2021.

The seedlings that were used for commercial tree planting and direct support to the communities came from certified private tree nurseries. The nursery certification scheme increased seedling quality and quantity for the major commercial tree species. In addition, the certification initiated by the project was eventually institutionalized by the Government of Uganda.

However, there was limited availability of germplasm to promote plantation resource diversification.

SPGS capacity-development programme

The capacity development consisted of 90 percent practical sessions and 10 percent theory to impart skills and standards on best and modern forestry practices. Figure 2 shows the SPGS approach to training on best practices and standards.

The SPGS courses were based on a commercial forestry training curriculum developed by the project, which complemented trainings by national colleges and universities to deliver the skill sets required by the industry. The project subsidized the training cost by up to 70 percent, and the private sector met only 30 percent of this cost.

The capacity development was delivered in three ways:

- **Field-based practical training** targeted forest supervisors and managers, contractors and nursery operators.
- **Regular growers field days** informed and demonstrated research findings, latest technologies and allowed learning and sharing of experiences among the growers.
- **Annual exposure trips** to other countries were undertaken to change the growers' negative perception of commercial forestry. A lot of benchmarking was done with countries in southern Africa with an edge on timber industry development. The project put in place a certification system to ensure that consumers are receiving quality services and products from contractors and nursery operators.

Acceptable industry standards in forestry practices

Best operating practices (BOPs), standards and procedures were introduced and enforced. Four well-illustrated sets of operational guidelines were developed, on tree planting

Table 1. SPGS project achievements in 2004–2021

Project phase	Year of implementation	Plantation area achieved (ha)
Phase I	2004–2009	11 000
Phase II	2009–2015	32 000
Phase III	2016–2021	28 000

Source: SPGS Phase I-III project reports, unpublished.

(Jacovelli *et al.*, 2009), teak planting (Rance *et al.*, 2013), community tree planting (SPGS, 2011) and pests and diseases (SPGS, undated). These publications have served as the main reference material on commercial forestry practices in Uganda.

Socioeconomic impact of the SPGS

According to the National Forest Plan (MWE, 2013), it was expected that by 2025, 100 000 jobs would be created from forest plantations alone. Since its launch in 2004 and until its end in 2021, the SPGS has created over 12 000 jobs in plantation management, nurseries, forest contracting and other support services (SPGS, 2021).

In addition, the project has ensured sustainability of actions by the private sector through establishment of the Uganda Timber Growers Association (UTGA) in 2006. UTGA is a tree growers members' organization that promotes collective access to inputs and services cost-effectively and provides a platform for a collective voice to continually lobby and advocate for an enabling climate for investment and favourable government policies. Currently, UTGA has 670 members and holds a Forest Stewardship Council (FSC) group certification. UTGA's objectives also include increasing the competitiveness of commercial forestry, and attracting and engaging in strategic partnerships.

Environmental benefits attributed to the SPGS

Enforcement of environmental standards has resulted in mosaics of mixed conservation areas (e.g. wetlands, riverine areas and intact forests) and planted forests using a variety of pine species, including *Pinus caribaea* (seed from Brazil and Australia), *Pinus Oocarpa* (seed from Brazil), *Pinus Patula* and five eucalyptus clones, which were planted in different parts of Uganda. Some areas were planted with pure stands of *Eucalyptus grandis* (Uganda seed and South Africa seed) and *Tectona grandis* (seed from the United Republic of Tanzania and South Sudan), *Maesopsis eminii* and *Terminalia* spp. This also improved the species diversity in plantations. Close to 80 percent of the SPGS-supported plantation area was established in degraded gazetted central forest reserves, which has contributed to increasing the national forest cover to 15 percent in 2023, according to the National Forestry Authority (NFA, 2023). Approximately 44 000 ha of forest in Uganda are FSC-certified for economic, environmental and social sustainability, and 75 percent of this area belongs to SPGS-affiliated growers.

Conclusion

The SPGS model provides a classic example of how to structure a private sector-led approach to tree planting with marked social and environmental dimensions. It combines profitable investment, sustainable land use and forest conservation for biodiversity.

The model was piloted and scaled up successfully in Uganda and has high potential for replication across the globe.

The sustainability of the commercial forestry investments will depend on continued government support, efficient value addition to the timber, and the development of premium markets to motivate tree growers to reinvest.

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Enhancing the engagement of forest-based industries in ecosystem restoration

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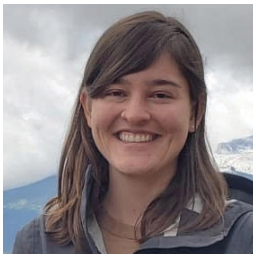

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Highlights

- The forest-based industries are uniquely positioned to contribute to global ecosystem restoration ambitions.
- A wide range of challenges needs to be addressed, and strategies must be crafted to optimize the participation of these industries in restoration efforts.
- The global ecosystem restoration movement is working to engage the private forest sector, including through the Advisory Committee on Sustainable Forest-Based Industries (ACSFI).

Introduction

Among a suite of alternatives, ecosystem restoration has the potential to contribute up to one-third of the total climate change mitigation needed (Griscom *et al.*, 2017). Restoration interventions can also promote climate change adaptation and resilience, sustainable use and conservation of biodiversity, food and water security, and economic prosperity (Gann *et al.*, 2019). The potential benefits of ecosystem restoration have motivated several global ambitions to restore more than 2 billion hectares (ha) of degraded and deforested lands across the globe by 2030 (United Nations General Assembly, 2019).

Mobilizing the forest-based industries' knowledge and expertise to support ecosystem restoration at scale

The forest-based industries have been identified among other key players as being able to help achieve global restoration targets. Forest-based industries are investing in restoration, given its potential for risk mitigation. As many governments are planning to introduce new regulations to address nature loss and climate change, investing in forests offers an opportunity for businesses to stay ahead of these policy shifts. In addition, forest conservation and restoration can indirectly increase core business profits, through lower costs of capital and equity, while increasing customer loyalty associated with sustainability attributes (World Economic Forum, 2021).

The forest-based industries also have the land, expertise and reputational need to invest in restoration activities. Globally, production forests cover approximately 1.15 billion ha (FAO, 2020). In addition to managing production forests, the forest-based industries have experience and knowledge about how to manage both conservation and restoration activities in different parts of the world. For example, in Tasmania, Australia, Forico manages approximately 173 000 ha of forest. Of these, 89 000 ha are used to produce wood fibre, while 77 000 ha are managed for their conservation and biodiversity values (Forico, 2023). In Brazil, some companies are expanding their conservation activities beyond the targets required by the Forest Code. For example, Veracel, one of the largest forest-based companies, has dedicated more than 50 percent of its forestland to conservation and restoration activities, such as the Monte Pascoal-Pau Brasil Ecological Corridor project (Veracel, 2023). The forest-based industries have also developed expertise in engaging with local communities while balancing the economic challenges associated with the implementation of restoration activities (Bloomfield *et al.*, 2018; Mansourian *et al.*, 2022).

Enhancing the engagement of the forest-based industries in restoration initiatives

While some forest-based companies are already active in restoration, opportunities exist to upscale the industry's engagement in ecosystem restoration initiatives. These opportunities may include operational engagement with restoration – for example, companies pursuing restoration on their land – and financial indirect engagement – for example, companies issuing green bonds or selling carbon offset credits.

Recognizing these opportunities, FAO's Advisory Committee on Sustainable Forest-Based Industries (ACSFI),[23] in collaboration with The Forests Dialogue (TFD),[24] convened a round table in October 2022 on "Enhancing the Forest Sector's Engagement in Ecosystem Restoration" as a satellite event of the twenty-sixth session of FAO's Committee on Forestry (COFO). The round table's objectives were to: (1) build trust and increase the forest-based industries' understanding of ecosystem restoration; (2) discuss a plan to enhance their engagement in ecosystem restoration; and (3) identify scoping opportunities and needs for driving restoration understanding and actions both globally and in specific contexts (ACSFI and TFD, 2022a).

The round table also identified a series of actions to operationalize strategies for enhancing engagement of the forest-based industries in ecosystem restoration. These included: (1) building unity within the forest sector through a shared ecosystem restoration vision and exchange learnings; (2) developing suitable metrics to facilitate goal setting and monitoring of restoration activities; (3) increasing multistakeholder collaboration; (4) increasing understanding of how degraded land and forest-sector capacity align geographically; (5) establishing new business cases for ecosystem restoration based on research and practice to better understand and demonstrate the value proposition of the private sector; and (6) identifying and building understanding about business and financial models that enhance shared value and deliver multiple outcomes in support of ecosystem restoration (ACSFI and TFD, 2022b).

Following the round table, in February 2023, The Forests Dialogue, based at Yale University, convened a scoping dialogue to explore a broader range of stakeholder perspectives and better understand the opportunities and challenges for the forest sector to contribute to global restoration efforts. To accomplish this, three frames of analysis were used based respectively on the spectrum of restoration activities, restoration spheres, and restoration incentives and disincentives. The multistakeholder group then sought to better understand the role of the private forest sector in ecosystem restoration. Participants identified the need for a broad continuum of interventions and spectrum of delivery of potential benefits. The relevance of bridging local-level learnings to the regional and global scales and the need to build landscape and societal resilience were also discussed. Finally, participants emphasized the importance of engaging with different stakeholders to ensure that restoration practices consider local communities' needs, knowledge and rights, and also that restoration and conservation activities are complementary (Panwar and Toro, 2023; TFD, 2023).

[23] The ACSFI is a FAO statutory body composed of senior executives from the forest-based industries worldwide. Its main objective is to provide guidance on activities and the work programme of FAO's Forestry Division on issues relevant to the paper and forest-products industry, in support of Members' efforts to progress towards sustainable development.

[24] TFD is a platform and process for multistakeholder discussion and collaboration on the most pressing local and global issues facing forests and people.

It was agreed at both the round table and the scoping dialogue that greater involvement of the forest-based industries can significantly augment ecosystem restoration initiatives while also creating opportunities for the companies and other stakeholders. For example, the 2022 State of Finance for Nature Report (UNEP, 2022) indicates that finance flows to nature-based solutions are only a third of the investment that is required to 2030 to limit climate change to below 1.5 °C, halt biodiversity loss and abate land degradation. This report also calls for increasing private-sector investments in nature-based solutions by several orders of magnitude. By integrating restoration into their suite of land-management activities, the private forest sector increases opportunities for use of innovative financing tools, particularly those that include carbon and biodiversity markets, such as carbon credits, agroforestry and biodiversity corridors.

Cautions and caveats

Accessing forest-based carbon and biodiversity markets and capital is, however, not a trivial matter. It requires an organization to understand and apply appropriate accounting frameworks to avoid issues such as double accounting. Implementation of financial safeguards to oversee the process will be necessary. Similarly, while forest-sector companies own large land bases and have expertise in restoration, the financial feasibility of pursuing large-scale restoration initiatives is ambiguous. Moreover, their involvement in restoration efforts is influenced by national and local policies, land tenure, land-use history, local communities' needs and capacities, interests of other landscape stakeholders and rights holders, company capacities and the geographic location of areas most in need of restoration. The degree and nature of this influence need to be better understood. As such, to significantly scale up restoration activities by forest-based companies, financial, social and environmental impact assessments are needed, all of which entail investment in research (e.g. seed quality, seedling propagation, insect management, wildfires and tree-species mixing) and the development of a business case.

It is critical to increase efforts for restoration, but it is also essential to ensure that native forests are conserved, forestry practices are sustainable, and due efforts are made to halt deforestation and land conversion. Ensuring that restoring an area will not lead to deforestation in another is critical. Encouraging the public to adopt sustainable consumption patterns is key to ensuring that conservation and restoration practices do not compete for resources.

Effective restoration requires the need for collaboration with a wide range of actors, including non-governmental organizations (NGOs), academia, government agencies, local communities, international governmental organizations (IGOs), multilateral organizations, private-sector actors and multistakeholder engagement platforms. Effective and meaningful collaboration, even if a slow process, is essential for durable and effective restoration outcomes.

Conclusion

If humanity is to meet its ambitious restoration targets, it will be necessary to engage all stakeholders in the landscape. The forest-based industries are an important manager of forests and other ecosystems around the world. Catalysed by the work of the ACSFI, FAO is actively engaging with the forest-based industries, including through planned dialogues, in collaboration with The Forests Dialogue, to continue to enhance their contributions to ecosystem restoration.

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A mosaic of plantations and forest restoration on formerly degraded land in Brazil's Atlantic Forest

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The Forests Dialogue

Interview with Gary Dunning,

Executive Director of The Forests Dialogue and The Forest School at the Yale School of the Environment

Highlights

- The Forests Dialogue (TFD) convenes round tables to engage forest stakeholders on high-conflict forest-related issues.
- Dialogue can help create sustainable, locally driven solutions, such as for conflicts between forest companies and local communities.
- A recent webinar series convened by TFD, FAO and the Yale Forest School explored the needs, challenges and opportunities for smallholder involvement in planted forests.

What are the objectives of The Forests Dialogue (TFD)? How does your approach work and what makes it unique?

GD: TFD is a platform specifically set up to bring together stakeholders to discuss issues related to sustainable forest management and conservation. It organizes "dialogues", which are in-person round table and field-based events whose purpose is to provide stakeholders in the forest sector with an opportunity for high-quality, facilitated engagement around high-conflict, forest-related issues. Since our founding 23 years ago, TFD has engaged over 3 000 individuals in more than 100 dialogues covering more than 20 key topics.

Despite their essential contribution to the global provision of wood and other products and services, planted forests remain controversial. What challenges and constraints are associated with planted forests?

GD: Planted forests are as important as ever, and they also continue to be controversial for some. We are focused on where *challenges* exist surrounding planted forests. This involves working on social challenges, like tenure and access rights for Indigenous Peoples and local communities. Despite marked regional differences, one of the most persistent issues that we see is the conflict between companies managing concessions and local communities. For example, land tenure was central to the dialogue we organized in Indonesia in June 2023. Environmental challenges are also central to our work. In this context, plantation establishment on peatland, which can cause both ecosystem degradation and release of carbon in the atmosphere, is a critical issue. We also engage in dialogues looking at the involvement of planted forest companies in mandated or voluntary conservation and restoration on their forest estate. For instance, there is a substantial amount of restoration work happening with companies and non-governmental organizations (NGOs) operating in the Atlantic Forest in Brazil.

How can we reimagine the design and implementation of planted forests through integrated landscape approaches? What is key to successfully negotiating trade-offs across conflicting objectives?

GD: We advocate specifically for considering planted forests within the context of a broader landscape approach. Integrated landscape approaches are defined as "a basic framework for balancing competing demands and integrating policies for multiple land uses within a given area" (Reed, Deakin and Sunderland, 2015). We call our initiative the Land-Use Dialogues (or LUDs for short) based on this approach. The LUDs are dialogue processes that support collaborative and inclusive multistakeholder decision-making around key socioenvironmental and ecological issues across sectors at the landscape or jurisdictional level.

The LUDs are founded on the premise that through dialogue, people and institutions can create more sustainable, locally driven and durable solutions to landscape challenges as part of a landscape approach. While each LUD process is unique and based in the specific landscape context and needs of landscape actors, they share the following overarching aims, to:

- support a social learning process across sectors;
- generate a landscape vision shared among an inclusive set of landscape actors; and
- identify prioritized actions that feed into planned or ongoing activities or processes on the ground.

Examples of LUDs can be found on the TFD website.

For more information on the approach, principles and process of the LUDs, see the Land-Use Dialogue Guide (TFD, 2020).

Talking about multistakeholder engagement, what challenges and opportunities exist for smallholders to engage in tree growing?

GD: It is a *real* challenge to involve smallholders in the tree-growing enterprise. Many companies have outgrower schemes and work directly with smallholders. But usually, it is almost a simple rent system where the companies essentially "rent" smallholder land to grow trees. Most smallholders need a large company or another access point to a market to make it viable. If the access point is a large pulp and paper company or a timber company, smallholders are not usually deeply involved in the production process. The point is that the companies thus have access to smallholder land.

One of the challenges is that companies are only interested in working with smallholders within the catchment area of pulp and paper mills. Smallholders without a big company nearby, therefore, generally do not have access to global markets.

Another challenge is that, for example, in Indonesia, smallholders who plant pulp species, like acacia, typically earn less than the smallholders who plant oil palm. Oil palm is much more economically lucrative for smallholders, creating a relatively stable annual income for up to 25 years (or when the palms need to be replanted). If there is not a big company, the incentive for smallholders to plant trees is limited given the other options that they have.

To maximize opportunities for smallholders, it is important for them to try to collectively organize into associations or cooperatives, which gives

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them leverage. The associations then need to try to expand their reach to more smallholders, thus growing their collective power. These associations play a vital role, not only economically in helping to negotiate prices but also in learning best practices and what works for smallholders. Organizations like FAO and others supporting these associations and smallholders are also hugely important.

Recently, we had a successful collaboration between TFD, the Forest School at the Yale School of the Environment and FAO in an effort to better understand the needs, challenges and opportunities facing smallholders. We created a webinar series where we talked to a variety of actors, including forest smallholder associations, organizations supporting smallholders and investors in smallholder enterprises. We heard from a lot of different individuals and organizations, which had great ideas on how to encourage and support smallholders in diverse ways to participate in planting trees. Some of the key challenges I mentioned are lessons learned from the webinar series. It is important to continue to shine a spotlight on the need for smallholders to enter the field of planted forests, and to enable them to do so. Co-hosting the webinar series with FAO helped us highlight issues again and share some key challenges and some of the ways that those challenges are being addressed. The recordings of the webinar series are available here.

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Forestry and land-use investment – Transitioning to a new "natural capital" asset class

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Highlights

- Professional institutional investors hold about USD 100 billion in forestry assets, and this could grow to USD 400 billion in coming years.
- Forestry, agriculture and conservation are collectively being absorbed into a new "natural capital" asset class.
- This is creating the opportunity for a more granular approach to land management as a means for generating higher returns and greater social and environmental benefits.

Introduction

Private forestry investment has long been based on owning forests for the income produced from timber harvesting and sales. Over recent decades, an increasing emphasis has been placed on efficient, productive plantation forestry assets. While there are many different investors in forestry including governments, Indigenous Peoples, rural communities, forest industry firms, and individuals and families, in this paper I will focus on professional institutional investors. Institutional investors, including pension funds, insurance and reinsurance firms, foundations, endowments and sovereign wealth funds, control close to USD 100 trillion in diversified portfolios of assets. Over the past 25–30 years, portfolio allocation has trended towards an increasing proportion of private real assets. These real assets now commonly represent about 10 percent of investment portfolios and include real estate, infrastructure, forestry and farmland.

Traditional fundamentals of forestry investment

From an investment perspective, forestry assets have traditionally been seen as an attractive diversifier. Forests are unique in having capital appreciation over time as forests grow, and trees become larger and more valuable. When trees are harvested, income is generated. Trees do not have

a fixed maturity point, so the value of a forest, calculated using a discounted cash flow model, is less volatile than the market price of timber. With much of the return from forestry coming from the process of biological growth, there is little or no correlation between the returns from forestry and the returns from the stock market, government bonds or other assets. Investors seek a diversified portfolio with uncorrelated assets to optimize the overall portfolio investment return while reducing risk (measured as volatility). Forestry assets have also been generally demonstrated to be positively correlated with inflation, thus providing another benefit to investors.

As a result of these positive investment fundamentals, forestry investment has been increasingly popular and has today risen to USD 100 billion, including private forestry investments and listed timber real estate investment trusts (T-REITs). Of course, USD 100 billion is only one-tenth of 1 percent of institutional capital, but the amount of capital invested in forestry is rising every year. It is estimated that forestry assets that could be suitable for investment in the coming years might represent USD 300–400 billion. Most of these assets are timber plantations on privately owned land or land leased from governments or communities (New Forests, 2022).

Evolution in the forestry asset class as climate change and biodiversity increase in importance

The perspective of investors towards the forestry asset class is shifting. The rising recognition that the global economy must be rapidly decarbonized to avoid the worst effects of global climate change has led investors to seek assets that can contribute positively to the net zero emissions transition (Busby and Jun, 2022; UNEPFI, 2022). Forestry has been recognized as having two important roles to play. The first is by removing carbon dioxide from the atmosphere and storing it in forests and long-lived wood products. The second is the role of forestry in the transition to a circular bioeconomy where timber, wood fibre and biomass replace fossil fuel-based and high embodied energy materials. Large institutional investors are invested across the entire global economy and see threats like climate change or the loss of biodiversity as systemic risks. They are therefore motivated to invest in ways that align with reducing those risks. It also makes good commercial sense, as many forests are now exposed to carbon markets, and demand for new engineered wood products, paper-based packaging, cellulosic fabrics and other products is rising steadily.

From a land-use perspective, the dual challenges of climate change mitigation and biodiversity conservation are morphing together. Not only are the Conferences of the Parties to the United Nations Framework Convention on Climate Change and Convention on Biological Diversity setting parallel intergovernmental targets for emissions reductions and biodiversity conservation, but businesses are being urged to report on their climate change risk via the Taskforce on Climate-Related Finance Disclosures[25] and their biodiversity-related risks via the Taskforce on Nature-Related Financial

[25] See https://www.fsb-tcfd.org/

Disclosures.[26] Researchers suggest that there are three major priorities in the land-use sector that could contribute approximately 25 percent of the emissions reductions needed to reach net zero. The first is to protect all remaining natural ecosystems from conversion to other land uses; the second is to manage working lands including forestry and agriculture to reduce emissions and remove carbon dioxide from the atmosphere; and the third is to restore degraded land. Collectively, it is estimated that these natural climate solutions could represent 11 billion tonnes of carbon dioxide-equivalent emissions reductions and removals annually in the coming decades (Griscom *et al.*, 2017).

Several emissions trading schemes have been implemented that reward forest owners for undertaking reforestation of marginal land, extending forestry rotation ages or putting areas under conservation management. Government-regulated carbon markets in California, New Zealand and Australia have set prices of USD 25–50 per tonne of carbon dioxide absorbed and stored in forestry assets. After 10–15 years of experience with these regulatory instruments, it is possible to make some general assessment of the implications for investors. First, it is clear that a rising carbon price acts as an economic margin phenomenon. As carbon prices rise, more marginal land becomes economically attractive for reforestation, and more marginal forestry areas shift from timber harvesting to conservation management. Land prices can rise as the net present value of future carbon value becomes capitalized into land value.

In addition to these regulated markets, there are also voluntary or verified carbon markets, which provide financial support for forest conservation, improved forest management and reforestation projects outside of areas with regulated markets. Investors in some cases seek accurate carbon accounting systems alongside their financial accounts to help them transparently assess their overall portfolio emissions profile over time. There has been considerable interest recently in standardizing carbon accounting and potentially wider natural capital accounting to create much greater capacity for investors to understand their ecological impacts – both positive and negative.

Forestry investors now face a rising range of opportunities that are collectively referred to as option value. Land that might have been solely valued based on future timber prices and production rates, now could also be managed for carbon markets, biodiversity conservation payments or easements, freshwater regulation, wind farms and solar farms, in addition to timber production. The rising importance of this range of option value is both changing the management of existing forestry assets, but also expanding the boundaries of what is considered the forestry asset class and bringing new investment structures like blended finance to bear on forestry investments. For example, New Forests is currently implementing a blended finance structure in a Southeast Asian forestry fund that will have classes of investors who seek conventional forestry returns, and those who seek high climate, community and biodiversity impacts. By bringing the two sources of capital together, the fund investments can create greater social and environmental benefits alongside the conventional forestry returns.

This evolution of forestry investment needs to be aligned with the interests of rural communities as well as Indigenous Peoples' communities. Alignment can occur when long-term institutional capital takes long-term risks but provides near-term benefits to local farmers and forest-dependent communities. For example, long-term

[26] See https://tnfd.global/

forestry investors can lease marginal farmland at attractive rates, providing income diversification to farm families. Forestry investors can also support outgrower schemes, de-risking future timber markets and ensuring that smallholder timber will receive a fair price on the market.

It is interesting to note that most forestry investment remains based on monoculture plantations. What seems to be evolving is not a transition to multispecies plantations, but a reorganization of landscapes to accommodate and enhance both sustainable intensification of production systems (for both timber and agriculture) and increased conservation and biodiversity enhancement. Investors may now be able to invest across a spectrum of timber plantations, agriculture, and the conservation and restoration of ecosystems. The multiple markets and price signals create complex management regimes and the need for sophisticated geospatial modelling tools to optimize the allocation of land use across space and over time. The term granularity refers to making land allocations at a smaller and smaller scale. Individual farms or properties may have cropping, grazing, commercial forestry, conservation and ecosystem restoration projects, wind turbines and many other options to consider. Being able to consider how these various land uses can coexist or evolve over time will create better returns for investors and better outcomes for social and environmental impact objectives.

The emergence of a natural capital asset class

This is a very different model from the way investors operated in the past. Specific forestry funds, agriculture funds, infrastructure funds and even climate change mitigation funds would invest in their specific silos. This is becoming inefficient and economically suboptimal. New Forests' funds now often incorporate broader mandates to invest across landscapes and seek unrealized option value as a key driver of returns. Our current fund for Australia and New Zealand for example is called a landscape investment strategy rather than a forestry investment strategy. Our African investment programme is called the African Forestry Impact Platform, which can invest across plantation forestry, forest conservation, ecosystem restoration and community forestry. Different types of capital can be invested in an integrated way, creating more positive social and environmental impacts.

This may be challenging for investors given that modern portfolio allocation theory seeks to blend together very specific asset classes, each with a historical track record of correlations and risk return profiles. However, this must be balanced with the imperative of making a series of transitions in the global economy towards sustainability. Transitions by definition do not have a long-term track record. But investors seem to be comfortable with this rising complexity of land management so long as the core returns are still coming from conventional markets like agriculture, forestry and rural land values.

This new asset class is attracting a new name – natural capital. The concept of natural capital as an asset class is that land-based production systems, biodiversity conservation and climate mitigation objectives, and new forms of option value have superseded the prior concept of segregated land uses in agriculture, forestry and conservation areas. This starts to point towards a super asset class that may have high social and environmental impact objectives and flexibility to operate landscapes in the most commercially optimal fashion via a continual tinkering and fine tuning of land-use allocation over time as multiple market prices and sources of option value play out. What may have been static niche asset classes like forestry and agriculture may also expand substantially in the coming years.

Expectations for the growth of a natural capital asset class are leading major asset management businesses and investors to expand their capability in this area. There is a fresh exploration of new business models and development of sophisticated technologies and analytical tools to execute on the investment opportunity. It is also providing opportunities for access to capital in emerging markets where important and valuable conservation and climate mitigation opportunities exist that were previously considered uninteresting from an investment perspective.

Conclusion

In this paper, I have argued that the context of forestry investment is evolving and being superseded by an overarching natural capital asset class concept. Forestry, agriculture, climate solutions and biodiversity conservation are all coming together in sophisticated landscape investment concepts. While this does not seem to be fundamentally changing how forestry plantations are grown, it does set a different, broader context within which forestry will operate. This type of large-scale transition in land-use investment and management will be challenging and will need active engagement with stakeholders and benefit sharing with rural communities and farmers. However, if the transition succeeds, it will provide globally significant contributions to climate change mitigation, biodiversity conservation and economic opportunities for rural communities as well as new materials for the circular bioeconomy.

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Contributing to sustainable landscapes and biodiversity goals through well-managed and properly governed planted forests

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Highlights

- Novel landscape-scale models such as those developed by New Generation Plantations can integrate planted forests and other land uses to increase local support, economic returns and raw material supply and improve biodiversity conservation.
- New modes of multistakeholder governance are needed to institute such integrated landscape approaches.
- Achieving sustainable multiple-use landscapes requires dialogue, compromise and a willingness among stakeholders to experiment.

Introduction

The world is facing unprecedented rates of biodiversity loss with approximately 1 million animal and plant species threatened with extinction

(IPBES, 2019). Besides the intrinsic value of biodiversity and our ethical duty to conserve it, biodiversity underpins human health and well-being and generates the products and services on which all humankind depends. Forest ecosystems, for example, harbour over 50 percent of terrestrial vertebrate species and provide wood, fibre, food and other essential ecosystem services, such as carbon sequestration or regulation of the water cycle (Pillay *et al.*, 2022). Yet, global demands for food, fibre, water and energy are increasing. By 2050, food production must grow by 70 percent to feed an estimated 9.7 billion people (UN DESA, 2019), while wood supply may need to grow three- or even fourfold to meet increasing demands for wood products and bioenergy (Hetemäki, Palahí and Nasi, 2020). We argue that well-managed and appropriately governed forest plantations, in the right locations, can contribute to more economically and ecologically sustainable landscapes. With the right design and planning, integrated with other land uses, forest plantations can contribute to meeting the growing demand for forest products, supporting biodiversity and providing for other human needs, including food security.

How can forest plantations contribute to biodiversity conservation?

Nature reserves, national parks and other protected areas now extend over approximately 16 percent of the Earth's land surface (Protected Planet, 2023). Despite their crucial role in preserving biodiversity, these areas alone are insufficient to meet conservation goals, as biodiversity continues to decline globally (IPBES, 2019).

While more protected areas are desirable, restoration of degraded landscapes is also required to meet ecological objectives including biodiversity conservation and socio-economic objectives, such as food security and improving livelihoods. Meeting these goals can be achieved by integrating land uses and the flow of ecosystem services that they provide at the landscape scale (Kremen and Merenlender, 2018). Land used and managed sustainably to supply food, wood and other provisioning ecosystem services, can generate economic returns, which can be channelled to finance biodiversity conservation programmes, including the conservation and restoration of native forests, and other ecosystem restoration programmes. Conservation and restoration, in turn, generate the supporting and regulating ecosystem services that underpin productive land uses. For example, pollination and pest control services contribute to more sustainable farming and forestry systems (Ulyshen *et al.*, 2023 and see article on resilience of mixtures to pests and diseases on p. 46). At the landscape level, a mosaic of different land uses and forms of land cover, with multiple stakeholder governance, can generate a diversity of interrelated services that can contribute to long-term sustainability of both production and conservation activities (Figure 1).

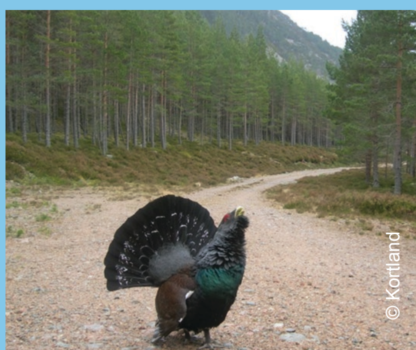
In these landscapes, trees and forests may be spatially integrated in fine-scale mosaics, such as integrated belts and tree woodlots in agroforestry systems, or at larger scales, making up more intensive, landscape-level agricultural and forestry mixes integrated with areas allocated for biodiversity conservation along riparian zones, on ridges or steep terrain, or other connecting areas of native vegetation. Forest plantations in such land-use mosaics, managed over varying rotation times, can generate production benefits and provide wildlife habitat as the trees go through the cycle of establishment, growth, harvest and regeneration (Brancalion *et al.*, 2020).

Planted forests, that is, forests predominantly composed of trees established through planting and/or deliberate seeding (FAO, 2020), include the intensively managed forest plantations used for commercial production of timber, pulp or biomass.

Box 1

Forestry and Land Scotland

The capercaillie (*Tetrao urogallus*), the world's largest species of grouse, is one of the UK's most endangered birds. Fewer than 500 male capercaillies exist in the country, and the species is largely restricted to pine forests in the Strathspey area of Scotland. Forests managed for timber production can provide habitat for the species. Public funding and management of publicly owned planted forests in Strathspey by Forestry and Land Scotland (FLS), one of the UK's governmental forest agencies and New Generation Plantations (NGP) partners, have enabled an increase in the local capercaillie population from 6 displaying males in 2002 to 45 in 2019.



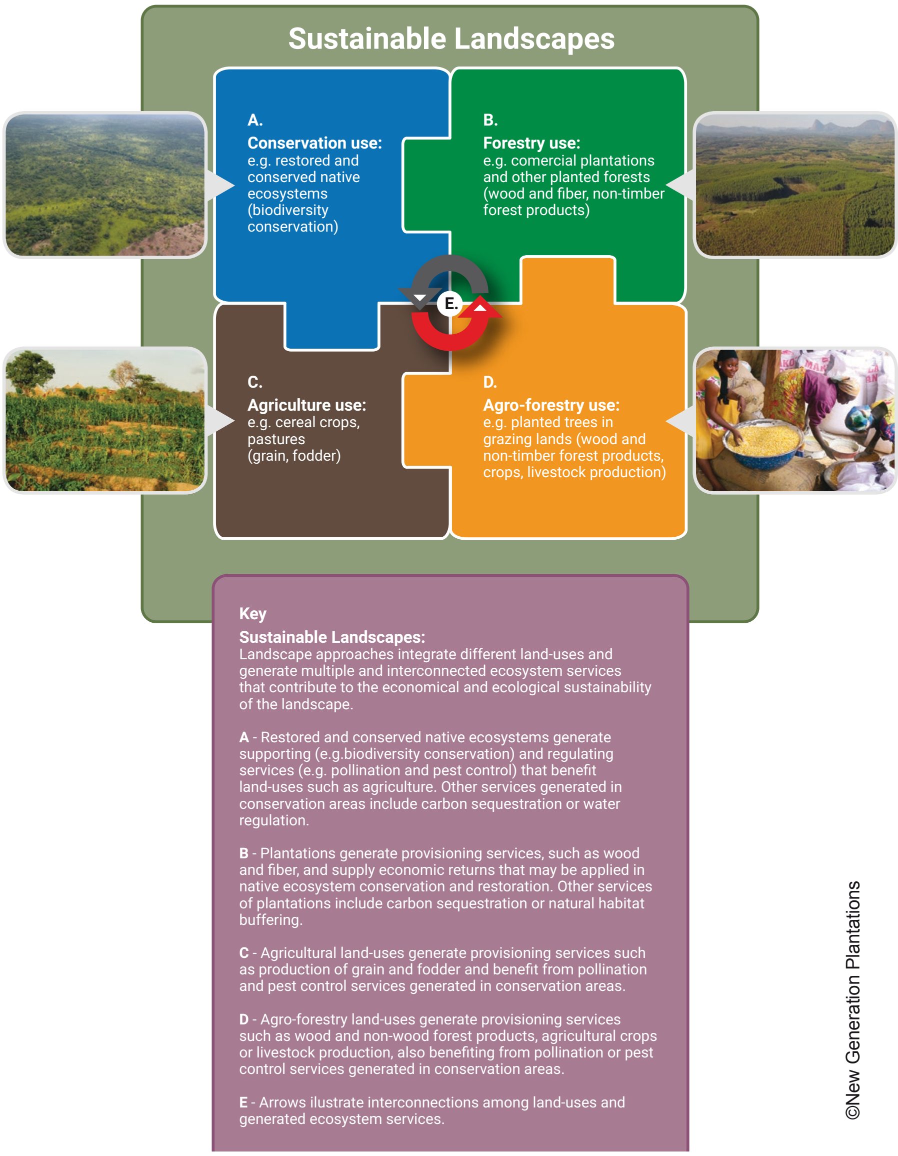


Figure 1. Diverse and interconnected services offered by sustainable landscapes

Other forms of planted forests include planted native species, mixed-species planted forests and trees grown as part of farming systems. Planted forests are estimated to represent 7 percent of the total forest area globally, which includes 3 percent of plantations managed intensively for wood production (FAO, 2020). Yet, this area supplies one-third of the global demand for industrial roundwood (Jürgensen, Kollert and Lebedys, 2014). Such efficient wood production in commercial plantations reduces resource extraction pressures on native forests and their biodiversity (Ghazoul, Bugalho and Keenan, 2019).

While commercial monoculture plantations of fast-growing (often exotic) tree species have often been described as "green deserts", they can nonetheless provide habitats for a variety of mammals, birds, reptiles and invertebrates (Bremer and Farley, 2010). When integrated with other land uses such as cropping and grazing, commercial plantations can increase landscape heterogeneity and enhance biodiversity since the resulting landscapes provide a wider range of habitats and microclimates (Brancalion *et al.*, 2020). In areas where native forests have been heavily depleted, commercial plantations around native forest remnants can also buffer adverse edge effects and improve their functioning (Bremer and Farley, 2010). Forest plantations established on degraded lands also often have higher stand-level biodiversity than surrounding land uses and can provide favourable habitat for rare or threatened species (Brancalion *et al.*, 2020).

Expansion of plantation land requires better planning and governance

Before establishing new forest plantations, regional conservation assessments and local-level planning must be undertaken to ensure that valuable natural ecosystems are not destroyed. Additionally, customary land tenures and land uses must be recognized. In other words, plantations can only contribute to broad sustainability goals if they are located in the right places. For example, biodiversity-rich native grasslands and savannahs should not be replaced by forest plantations due to misclassification of the former as "degraded lands" (Bond *et al.*, 2019). Multistakeholder planning processes can also provide a strong basis of public support for plantation activity. These processes provide conditions ensuring that all involved in the land-allocation process benefit fairly and that conservation and cultural values are being recognized and protected (Jansen and Kalas, 2020). Principles such as those of free, prior and informed consent (IPBES, 2019) should apply in the planning of plantations that will affect local communities.

Voluntary schemes such as forest certification can also help ensure that plantations contribute to biodiversity conservation goals. These third-party audited voluntary mechanisms assess compliance with forest management standards and provide assurance to buyers of forest products that these have been produced according to adequate environmental and socioeconomic criteria (Auld, Gulbrandsen and McDermott, 2008). Forest certification schemes place clear restrictions on conversion of natural ecosystems to plantations and include measures to protect native forests and other ecosystems of high conservation value. Such schemes frequently require forest managers to dedicate parts of their estate to ecosystem conservation and restoration. For example, the Forest Stewardship Council (FSC) certification scheme requires 5 percent of the area dedicated to plantations to be native forest. Some countries and state jurisdictions (such as some states in Brazil) have higher requirements for minimum areas of native forest (which can vary between 10 percent and 50 percent). However, these figures are arbitrary. An improved approach would be to develop and adopt standards based on clear, transparent and verifiable criteria for identifying vulnerable habitats and ensuring their protection and management. While in some regions, this would preclude the development of any plantations, in others there would be more flexibility for establishing those plantations. More importantly, such criteria, based on evidence and data, would have more relevance to conservation and biodiversity than arbitrary percentages of land cover. These criteria, however, would be more challenging to verify and monitor, although the advent of new technologies for biodiversity and habitat assessment is making this easier and potentially applicable in the near future (Haneda *et al.*, 2023).

Plantations, biodiversity and climate objectives

Integrating biodiversity conservation in forest plantations can contribute to net zero emissions objectives (IPBES, 2019). When established on degraded lands, plantations are a "natural climate solution" within the broader toolkit of forest restoration (Griscom *et al.*, 2017). By taking an integrated approach, forest plantations can contribute to international forest restoration goals, such as the New York Declaration on Forests, which aims to restore 350 million ha of degraded landscapes and forests worldwide by 2030 (IPBES, 2019; Temperton *et al.*, 2019). Debates about whether naturally regenerated forests offer a "better" carbon sequestration option than forest plantations (Lewis *et al.*, 2019) present a false dichotomy, as both planted and natural regenerated forests in suitable locations contribute to climate change mitigation, conservation and Sustainable Development Goals.

When used in construction, timber from forest plantations can also

Box 2

Forest and landscape restoration in southern Bahia, Brazil

The New Generation Plantations (NGP) and Forum Florestal da Bahia have a 15-year-old partnership with landscape stakeholders in southern Bahia. The partnership brings together forestry companies and local communities to protect and restore areas of the Atlantic Forest while simultaneously promoting socioeconomic benefits. The partnership has led to the creation of a fund – Fundo Ambiental do Sul da Bahia (FASB) – dedicated to financing local community projects, such as the "Organic Barn" initiative, which develops and promotes certified organic farming techniques with families who grow their own food, thereby helping improve livelihoods and food security at the local level. In 2 years, FASB has funded 23 projects worth EUR 1.18 million, which have led to the preservation of 1 890 hectares (ha) of Atlantic Forest fragments and 235 ha of restored forest area. Additionally, FASB has promoted 151 ha of sustainable agriculture initiatives so far out of a target of 750 ha, prioritizing the use of native trees species, fruit trees and traditional food crops. The social impact of these projects includes direct and indirect involvement of local families, the engagement of community schools and financial education. FASB's next goal is to attract external investment and market the goods and ecosystem services produced to ensure the self-sustainability of the supported projects going forward.

replace high carbon-footprint materials such as steel and cement (Silva, Freer-Smith and Madsen, 2019). New types of engineered wood products offer possibilities for scaling up timber construction, thereby significantly reducing emissions from the building industry (Ahn *et al.*, 2022). More plantations will be needed to meet this demand and avoid impacts on natural forests (Nepal, Johnston and Ganguly, 2021). Excluding plantations from global forest restoration targets is therefore likely to lead to increased pressures on natural forests, undermining the climate and conservation goals of forest restoration (Ghazoul, Bugalho and Keenan, 2019).

New governance approaches are needed for next generation plantations

Novel landscape-scale models can integrate forest plantations with other land uses, including naturally regenerated or restored natural forests, agriculture, agroforestry or other land uses (Boerstler, Kalas and Rezende, 2022). The resulting land-use mosaics can generate wider local support, economic returns for local landholders and governments, and raw materials for local industries (Metternicht, 2017). Such innovative integrated landscape approaches require new modes of multiple stakeholder governance to enable landscape transformation. Achieving sustainable multiple-use landscapes necessitates dialogue, compromise and a willingness among the forest industry, conservation groups and local stakeholders to experiment (Kremen and Merenlender, 2018).

A successful example of such dialogue and social learning is the New Generation Plantations initiative (NGP) (Silva, Freer-Smith and Madsen, 2019) led by the World Wide Fund for Nature (WWF). The initiative brings together businesses and communities from across the world that share ideas for innovation in plantation design and management that meet the needs of people, industry and the environment, with the aim of promoting more sustainable landscapes. This includes integrating restoration and protection of native forests in sustainable business models that benefit nature and people while also producing economic benefits (see Boxes 1 and 2 for examples of two case studies). To avoid risk of exclusion and marginalization, tenure issues are part of NGP's integrated landscape approach through multistakeholder engagement processes. NGP addresses biodiversity conservation by showcasing and supporting a portfolio of projects at local, regional and cross-regional scales. These projects include biodiversity monitoring in partnership with universities and environmental non-governmental organizations (NGOs), and assessment of management outputs using a range of performance indicators.

NGP also facilitates dialogue and experience sharing between public- and private-sector forestry organizations, local communities and smallholders, and the initiative catalyses donor investments for forest restoration and conservation projects. The approach aims to promote better landscape governance by integrating a variety of land uses and generating a wide range of ecosystem services.

Conclusion

The present global biodiversity crisis must be tackled in the context of increasing global demand for food, fibre and energy, and climate change. Sustainable landscapes that integrate complementary land uses and ecosystem services, accommodating both production and biodiversity conservation, are better equipped to respond to forecasted global-change scenarios. Well-managed forestry plantations, in the right places, can play a crucial role in the sustainability of such landscapes and in achieving biodiversity conservation goals. Failure to recognize this will seriously undermine the effectiveness of global conservation efforts. It is critical to stop neglecting tree plantations as "green deserts" and start working on feasible landscape-level solutions in which well-managed, appropriately governed and rightly located forest plantations, are integrated with other land uses, to simultaneously meet production, conservation and restoration goals and achieve overall landscape sustainability.

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Author contributions

M.N.B., J.A. and J.G. led paper writing-up. L.N.S. is the WWF coordinator of the NGP platform. L.N.S., M.N.B., J.A., J.G., F.D. and R.K. all participated in the manuscript writing.

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Responsible land-based investments in forestry

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The forest industry has a key role to play in achieving restoration goals. The efficacy and sustainability of its intervention often depend on how these goals are adapted to the local context and the extent to which they contribute to the Sustainable Development Goals. A typical challenge for the forest industry is that a significant percentage of lands granted by governments to companies as concessions are already inhabited, thus adversely affecting existing land users who may lose lands and livelihoods.[i, ii] The problems are even more complex where local land- and resource-use rights are unrecognized in law or undocumented, land governance is weak, or decision-making processes lack transparency. Small-scale farmers may be particularly vulnerable if tenure systems are not well defined or implemented.[iii] Likewise, business entities also face significant operational, financial and reputational risks.[iv] Disputes between business entities and local stakeholders can lead to delays in launching projects and rolling out operations, or disrupt ongoing operations, leading to significant financial losses for the business entities. Conflicts with local stakeholders at times can result in cancellation of agreements before the start of operations. Such disputes and conflicts can be several times the average cost of implementing measures to mitigate social risks.[v]

Useful global instruments now exist to make land-based investments more responsible, which is achieved by recognizing the rights of local stakeholders, improving local livelihoods, being inclusive of smallholders and their enterprises, developing local skills and promoting meaningful collaboration, and innovative and transformative multistakeholder governance models,[vi] while mitigating risks to multinationals and large-scale business entities. These instruments include the Committee on World Food Security (CFS) Principles for Responsible Investments in Agriculture and Food Systems (RAI);[vii] and the voluntary guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGT), which promote secure tenure rights and equitable access to land, fisheries and forests with respect to all forms of tenure: public, private, communal, Indigenous, customary and informal.[viii] The United Nations Principles for Responsible Investment, the United Nations Global Compact,[x] and *Making forest concessions in the tropics work to achieve the 2030 Agenda: voluntary guidelines*[xi] also provide useful guidance. The publication by FAO and Landesa, *Applying responsible land-based investment models in forestry: promoting the use of global instruments*[xii] provides further information on global instruments and examples of how these are being applied on the ground, and identifies practical steps that governments and non-governmental stakeholders, including investors and business entities, can take to make such investments more responsible.

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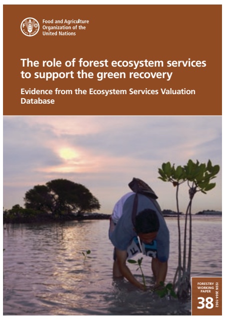
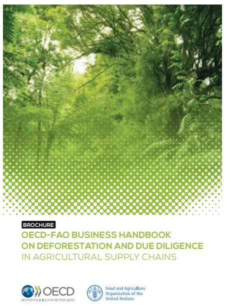
Key FAO publications

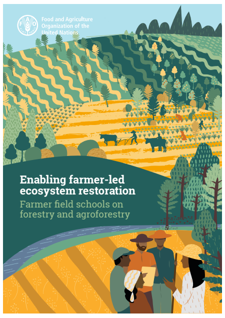
The world's mangroves 2000–2020
This report provides global and regional estimates of the area covered by mangrove forests, including area changes between 2000 and 2020. It analyses the drivers of global, regional and subregional changes for the periods 2000–2010 and 2010–2020 with the aim of improving understanding of these drivers, their interactions and how their relative importance has shifted over time. This is the first global study of mangrove area to provide information on land use rather than land cover.



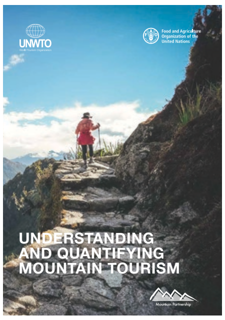
The role of forest ecosystem services to support the green recovery
Forests are an important component of natural capital and deliver a broad range of ecosystem services that underpin human well-being. The extent and condition of forests in many parts of the world, however, have declined dramatically during the preceding decades due to unsustainable harvesting of timber, forest fires, urbanisation, and conversion to agriculture. This paper is a background document developed for FAO's flagship report, The State of the World's Forests (SOFO) 2022. It reflects the results of a collaboration between FAO and the Foundation for Sustainable Development (FSD) to update the Ecosystem Services Valuation Database (ESVD).



OECD-FAO Business Handbook on Deforestation and Due Diligence in Agricultural Supply Chains
This handbook on Deforestation and Due Diligence in Agricultural Supply Chains aims to help companies incorporate deforestation and forest degradation considerations in their supply chain due diligence and responsible sourcing efforts and adopt a holistic approach to deforestation risk and forest-positive outcomes. It builds on the risk-based due diligence framework of the OECD-FAO Guidance for Responsible Agricultural Supply Chains, the leading international framework on responsible business conduct and risk-based due diligence in the agri-food sector.



Enabling farmer-led ecosystem restoration - Farmer field schools on forestry and agroforestry
With agricultural expansion being responsible for almost 90 percent of deforestation worldwide, it is being coined as a leading driver of biodiversity and habitat loss around the globe. This situation presents a critical question: How can agriculture continue to feed growing populations while contributing to the urgent restoration of the planet's ecosystems? This paper presents farmer field schools (FFS) as a valid response for answering the growing international call for a much-needed re-direction in agriculture.



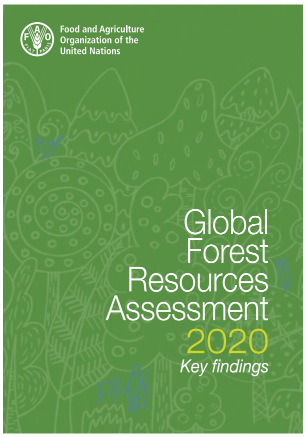
Understanding and quantifying mountain tourism
All around the world, mountain tourism is driven by the human desire to experience nature in unique settings. In turn, tourism has proved to be a lifeline for many communities in mountain regions, and it can play a leading role in sustaining systems that contribute to protect these fragile ecosystems from overexploitation and support their adaptation to climate change. This study, jointly developed by the Mountain Partnership Secretariat of FAO and the World Tourism Organization (UNWTO), addresses the current lack of relevant data and so improves our understanding of mountain tourism.

FAO bookshelf

The State of the World's Forests 2022

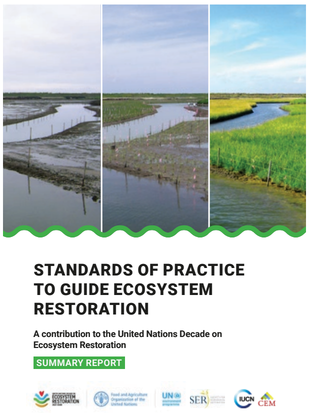
Forest pathways for green recovery and building inclusive, resilient and sustainable economies

Against the backdrop of the Glasgow Leaders' Declaration on Forests and Land Use and the pledge of 140 countries to eliminate forest loss by 2030 and to support restoration and sustainable forestry, the 2022 edition of The State of the World's Forests (SOFO) explores the potential of three forest pathways for achieving green recovery and tackling multidimensional planetary crises, including climate change and biodiversity loss. The State of the World's Forests 2022 presents evidence on the feasibility and value of these pathways and outlines initial steps that could be taken to further pursue them. There is no time to lose – action is needed now to keep the global temperature increase below 1.5 °C, reduce the risk of future pandemics, ensure food security and nutrition for all, eliminate poverty, conserve the planet's biodiversity and offer young people hope of a better world and a better future for all.



Global Forest Resources Assessment (FRA) 2020 Key findings

FAO Global Forest Resources Assessment (FRA) provides essential information for understanding the extent of forest resources, their condition, management and uses. The FRA 2020 Key Findings reports present a synoptic view of the world's forests and the ways in which the resources have changed in the period 1990-2020.



Standards of practice to guide ecosystem restoration: A contribution to the United Nations Decade on Ecosystem Restoration - Summary report

Effective restoration of degraded ecosystems is of paramount importance for recovering biodiversity, ecosystem health and integrity, ecosystem goods and services, climate-change mitigation and human health and well-being. UN Decade partners, through a consultative process, offered ten principles for ecosystem restoration to create a shared vision and increase the likelihood of achieving the highest level of recovery possible. The goal of this document is to provide an overview of the standards of practice to guide ecosystem restoration and present the recommendations for the entire restoration process.

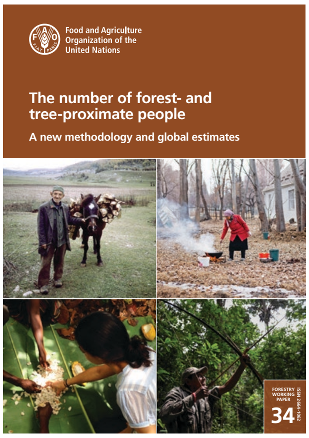
Unasylva No. 253: Forests for a better world

To coincide with the 50th anniversary of FAO's Committee on Forestry (COFO), this edition of *Unasylva* showcases the ways in which forests are delivering the "four betters" and underscores how forests are crucial for resilient and sustainable agrifood systems in a changing climate. As FAO's longest running periodical, *Unasylva* focuses on issues and themes relevant to forestry and forest industries and aims to bring globally significant developments in forestry to policymakers, forest managers, technicians, researchers, students and teachers around the globe.

FAO bookshelf

Global forest sector outlook 2050: Assessing future demand and sources of timber for a sustainable economy.

The global threats to climate, biodiversity and a healthy environment are mainly caused by the excessive use of non-renewable materials. The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Tropical Timber Organization (ITTO) and Unique Consultancy, elaborated a Global Forest Sector Outlook 2050 to assess the capacity of wood supply to support a sustainable bioeconomy. The report presents a business-as-usual scenario, based on the Global Forest Products Model (GFPM), and a bioeconomy scenario based on the impact of increased consumption of two wood products consolidated in the market: mass timber and manufactured cellulose fibre.



The number of forest- and tree-proximate people - A new methodology and global estimates

Mapping the spatial relationship between forests, trees and the people that live in and around them is key to understanding human-environment interactions. First, quantifying spatial relationships between humans and forests and trees outside forests can help decision-makers develop spatially explicit conservation and sustainable development indicators and policies to target priority areas. This study combined tree cover and human population density data to map the spatial relationship between forests, trees and people on a global scale providing estimates of the number of forest-proximate people and tree-proximate people for 2019.

Principles for ecosystem restoration to guide the United Nations Decade 2021–2030

To support the implementation of the UN Decade on Ecosystem Restoration and help achieve its goals, there is a need for a shared vision of ecosystem restoration. A key step in creating a shared vision of ecosystem restoration is to adopt principles that underpin the full set of ecosystem restoration activities. To this end, this brochure presents ten principles for ecosystem restoration including a first principle that orients restoration in the context of the UN Decade, followed by nine best-practice principles. These best-practice principles detail the essential tenets of ecosystem restoration that should be followed to maximize net gain for native biodiversity, ecosystem health and integrity, and human health and well-being, across all biomes, sectors and regions.

FAO Yearbook of Forest Products (Multilingual)

The FAO Yearbook of Forest Products is a compilation of statistical data on basic forest products for all countries and territories of the world. The yearbook contains annual data on the production and trade in forest products for the years 2016-2020. This is the 74th issue of the FAO Yearbook of Forest Products, and all forest product data - including time series starting in 1961 - are available at: http://www.fao.org/forestry/statistics.

Collective tenure rights for REDD+ implementation and sustainable development

This technical paper emphasizes the opportunity that REDD+ and the global climate agenda represent for countries to engage more actively in securing land and resource rights for Indigenous Peoples and local communities. At the same time, it stresses how collective tenure rights represent a key element to achieve long-lasting and successful results for REDD+, contributing to addressing global climate change.

Wildcheck – Assessing the risks and opportunities of trade in wild plant ingredients

Thousands of consumer products around the world contain ingredients obtained from wild plants. While these products have global markets and provide critical sources of income, they can also have deep ties to particular cultures and places. Along with a broader update on the state of the wild plants trade, the report provides a "profile" on each of the Wild Dozen species, summarizing key facts on production and trade. The information is aimed at industry, consumers, policymakers, investors, and practitioners, concluding with a summary of what these various stakeholders can do to contribute to a sectoral shift towards responsible sourcing of wild plant ingredients.

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