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Foreword

Forests are host to most of Earth's terrestrial biodiversity. The conservation of the world's biodiversity is thus utterly dependent on the way in which we interact with and use the world's forests. The role of forests in maintaining biodiversity is also explicitly recognized by the United Nations Strategic Plan for Forests 2017–2030 and in the ongoing discussions around the forthcoming post-2020 global biodiversity framework under the Convention on Biological Diversity (CBD).

In December 2019, the Food and Agricultural Organization of the United Nations (FAO) adopted the Strategy on Mainstreaming Biodiversity across Agricultural Sectors. In October 2020, at its twenty-fifth session, the Committee on Forestry (COFO) requested FAO to conduct a review of biodiversity mainstreaming in forestry and share good practices on solutions that balance conservation and sustainable use of forest biodiversity.

This publication results from a partnership between FAO and the Center for International Forestry Research (CIFOR), lead centre of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). The study was initiated at the occasion of the Global Landscapes Forum (GLF) Biodiversity Digital Conference: One World – One Health held on 28 October 2020. It involved experts from FAO, CIFOR, FTA and other organizations around the world in a collaborative process. It is enriched by eight country case studies from the Democratic Republic of the Congo, Ethiopia, Finland, Japan, Malaysia, Mexico, Peru, and the United Kingdom of Great Britain and Northern Ireland (case from Scotland).

This study has the following objectives: assess the state of mainstreaming biodiversity in the forest sector; take stock of existing concepts and tools for integrating biodiversity in forest management; review the range of policy instruments that, beyond legal protection, can enhance biodiversity conservation; and recommend actions to advance biodiversity mainstreaming in the forest sector.

Protected areas play a central role in biodiversity conservation covering 18 percent of the world's forests. A much larger extent (30 percent of the global forest area) is managed primarily for the production of timber or non-wood forest products. Often, protected areas are established in remote and inaccessible places, leaving critical habitats in more accessible areas vulnerable to pressures from competing land uses. Weak governance and law enforcement often undermine biodiversity conservation even in protected areas. For these reasons, mainstreaming biodiversity in production forests is of paramount importance to stem biodiversity loss. Sustainable management of production forests can also provide the much-needed finance and incentives for biodiversity conservation. Therefore, this study focuses on mainstreaming biodiversity in production forests by integrating biodiversity concerns into everyday forest management practices and striking the right balance across multiple objectives, including productive economic benefits, as well as maintaining or enhancing ecosystem services and biodiversity conservation.

The country case studies illustrate in various contexts the progress made in mainstreaming biodiversity in forest policies and forest management. Based on the identification and assessment of strengths and weaknesses, these case studies provide lessons learned that can help other countries to improve biodiversity mainstreaming in their own forest sector.

We hope that the wealth of information and suggestions included in this study will inspire relevant actors in the forest sector to further strengthen management of forests for conservation and sustainable use of biodiversity. Building upon the main findings and recommendations of this study, strategies for mainstreaming biodiversity in the forest sector could be elaborated at different scales (from the regional, national to the local level), involving broad stakeholder consultations, and strengthening the voice of Indigenous Peoples and local communities as custodians of forests and biodiversity.

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List of abbreviations and acronyms

CBD	United Nations Convention on Biological Diversity
CIFOR	Center for International Forestry Research
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CSR	corporate social responsibility
EIA	environmental impact assessment
FAO	Food and Agriculture Organization of the United Nations
FLEGT	Forest Law Enforcement, Governance and Trade
FMU	forest management unit
FSC	Forest Stewardship Council
GHG	greenhouse gas
GPFLR	Global Partnership on Forest Landscape Restoration
HCV	high conservation value
ICRAF	International Centre for Research in Agroforestry (now CIFOR-ICRAF)
IUCN	International Union for the Conservation of Nature
METSO	Forest Biodiversity Programme for Southern Finland
NBSAP	National Biodiversity Strategy and Action Plan
NDC	nationally determined contributions
NGO	non-governmental organization
NTFP	non-timber forest product
NWFP	non-wood forest product
ODA	official development assistance
OECD	Organisation for Economic Co-operation and Development
OECM	other effective area-based conservation measures
PEFC	Programme for the Endorsement of Forest Certification
PES	payments for ecosystem services
REDD+	reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RIL	reduced impact logging
SDG	Sustainable Development Goals
SFM	sustainable forest management
SOP	standard operating procedures
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
VPA	Voluntary Partnership Agreement

Executive summary

Forests harbour most of the Earth's terrestrial biodiversity. Tropical rainforests alone harbour over 50 percent of terrestrial species. Forests and their biodiversity serve as a safety net for humanity, providing clean air, regulating water cycles, sequestering atmospheric carbon, mitigating natural disasters, and bolstering livelihoods. Forests also have an important role in maintaining human health and psychological well-being, as well as in sustaining our economies. A large proportion of the world's poorest people are dependent on forest resources, although all people in the world benefit from forests and the products of their biodiversity.

Even though biodiversity conservation has been an important global agenda for at least three decades, forest biodiversity continues to be lost at an alarming rate. Deforestation is the single most important driver of forest biodiversity loss. Approximately 10 million ha of forest are cleared for other land uses every year, with agricultural conversion being the primary driver. The global commitment taken during the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow to halt and reverse forest loss and land degradation by 2030 will be critical to stem global biodiversity loss, as well as contribute to achieving the +1.5 °C climate target of the Paris Agreement. Furthermore, the Abidjan Call adopted at the 15th Session of the Conference of the Parties of the United Nations Convention to Combat Desertification (UNCCD) reaffirmed the commitment of the international community to combat desertification, halt biodiversity loss and mitigate climate change in an integrated manner. Forest biodiversity is also being eroded over enormous areas through forest degradation, in particular by overharvesting of timber species, other valuable plants and wildlife, as well as from invasive species, fires, pests and diseases. Biodiversity loss compromises the ecological functioning and stability of forests, therefore undermining the provision of ecosystem services to humanity. Ample scientific evidence shows that sustainable forest management (SFM) can help stem biodiversity losses and secure sustainable benefits. The juxtaposition of high biodiversity in forests and severe pressures from deforestation and degradation driving biodiversity loss means that forest management has a central and critical role to play in addressing the global biodiversity crisis.

Globally, 18 percent of the world's forest area (726 million ha) is in legally established protected areas, exceeding the Aichi Biodiversity Target 11 to protect at least 17 percent of the terrestrial area by 2020. A much larger percentage of the global forest area (30 percent or 1.15 billion ha) are managed primarily for the production of timber and non-wood forest products. The remaining forest area may be managed for multiple purposes, including the provision of ecosystem services, or is being used primarily for production without being officially designated as such. There is abundant evidence that well-managed forests can support significant biodiversity and underpin valuable ecosystem services. Therefore, the sustainable management of forests managed for production and other ecosystem services has a critical role in biodiversity conservation. Furthermore, whereas the management of protected areas is often constrained by insufficient funds, production forests generate resources to invest in quality forest management and biodiversity conservation.

Mainstreaming biodiversity is "the process of embedding biodiversity considerations into policies, strategies and practices of key public and private actors to promote conservation and sustainable use of natural resources" (Huntley and Redford, 2014). Mainstreaming biodiversity in forestry involves prioritizing forest policies, plans, programmes, projects and investments that have a positive impact on biodiversity at the ecosystem, species and genetic levels. It is about integrating biodiversity concerns into everyday forest management practice and finding optimal outcomes across multiple objectives, including productive economic benefits, maintaining or enhancing ecosystem services and biodiversity conservation.

This study is divided into four main parts. The first part sets the scene and frames the study. The second part is a review of biodiversity mainstreaming in forest policy and forest management, focusing on forests managed for productive benefits, including ecosystem services. The third part summarizes the progress made on mainstreaming biodiversity in the forest sector through eight country case studies, identifying the remaining gaps and possible solutions. The last part presents the recommendations emerging from this study including the associated case studies.

Mainstreaming biodiversity in forest policies, strategies and programmes

National Biodiversity Strategies and Action Plans (NBSAPs) are an important starting point for mainstreaming biodiversity. They provide the basis for developing specific sectoral policies to support the sustainable use and conservation of biodiversity. A recent review highlighted the increasing importance of biodiversity mainstreaming in national planning and policy-making. The potential productive benefits arising from sustainable management of biodiversity were recognized in 90 percent of NBSAPs for at least one sector.

The Paris Agreement noted "the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity, recognized by some cultures as Mother Earth", encouraging synergies between climate action and biodiversity protection. Nationally determined contributions (NDCs) offer an opportunity to mainstream biodiversity in climate policies, as the critical role of forests in mitigating and adapting to climate change is well recognized. The global movement on restoration also provides an important opportunity to enhance biodiversity conservation by improving degraded habitats, bringing back native ecosystems, enhancing habitat connectivity and creating a sustainably managed productive landscape that supports improved management of protected areas.

Forest governance is notably complex and fragmented, involving multiple levels of government, different ministries and institutions, and multiplicity of other actors, such as Indigenous Peoples and local communities, environmental non-governmental organizations (NGOs), research and training institutions, forest owners and private enterprises. Hence, biodiversity mainstreaming in the forest sector requires integrated multi-stakeholder approaches that cross sectoral boundaries.

Approaches and tools for biodiversity mainstreaming

Mainstreaming biodiversity requires both regulation and steering, and there should be a strong focus on landscape approaches including SFM. There is a wide variety of approaches and instruments for mainstreaming biodiversity in forestry, including spatial planning-based approaches, species-based approaches, regulatory instruments, economic instruments, market-based instruments, participatory forest management, and support for knowledge and capacity development.

Spatial planning-based approaches

Large-scale spatial land use planning is a critical tool for implementing government policy on biodiversity. By acknowledging trade-offs in outcomes for different land use objectives, multiple objectives can be met through a well-considered spatial plan. Considering biodiversity objectives in spatial planning can greatly enhance biodiversity outcomes and is a commitment under the Convention on Biological Diversity (CBD). Large-scale spatial planning must also consider the effects of other sectors, especially agriculture and infrastructure, on forest biodiversity.

The suite of spatial-based approaches for conserving forest biodiversity include the designation of multiple-use protected areas, including other effective area-based conservation measures (OECMs), protecting threatened habitats, spatial planning to optimize ecosystem services provisioning, and increasing forest cover through restoration and forest plantation establishment.

Species-based approaches

Species management is an important tool to promote sustainable use and conservation of biodiversity. This approach enables governments, often in partnership with NGOs and civil society organizations, to harmonize efforts across sectors and levels of government to manage species that interact strongly with human activities. The main targets of this approach include: 1) species threatened by human activities; 2) migratory species; 3) species causing human–wildlife conflict; 4) invasive species; 5) overabundant native species; and 6) harvested species.

Putting in place national strategies on species management, with appropriate supporting legislation covering each of these categories, sets clear objectives and helps facilitate cross-sectoral cooperation. Biodiversity conservation in forests plays a key role in managing all of these categories of species. Hence, it is important that forest sector policies support, and forest management planning reflects, national species management strategies.

Regulatory instruments

Forest regulations are an indispensable tool for governments to ensure that forest management contributes to the successful implementation of national biodiversity management strategies. Regulatory instruments include quotas, permits and licenses designed to regulate the exploitation of forest resources, as well as legal provisions for environmental governance, including environmental impact assessments. Policies and regulations that support SFM are particularly important. Regulations are also needed to enforce species management requirements, ensure incorporation of biodiversity considerations in spatial planning, and provide a legal basis for the various economic and market-based instruments, as well as to establish a mechanism for participatory forest management.

Regulatory approaches are effective when the process is transparent, information concerning regulations and management requirements is well documented and readily available, permits can be obtained efficiently, monitoring is comprehensive and timely, and transgressions can be effectively and efficiently identified and dealt with.

Economic instruments

Economic instruments, including taxes, subsidies and grants, can be leveraged to incentivize forest owners and managers to advance SFM and improve biodiversity outcomes. As a part of national biodiversity mainstreaming, governments should review taxes and subsidies to identify perverse incentives, such as subsidies for agricultural inputs or forest conversion, and align incentive structures with the sustainable use and conservation of forest biodiversity.

Biodiversity offsetting is unlikely to be of direct benefit to forest managers, but it is a relevant economic instrument that can generate income for expanding and improving protected area management, and for generating funds for forest restoration.

Market-based instruments

Payments for ecosystem services (PES) schemes generate income that can support SFM and biodiversity conservation. However, ensuring that benefits from PES schemes trickle down to those that are most in need, who often bear the largest opportunity costs, can be challenging. High transaction costs, limited resources and insecure land tenure have been identified among the main barriers impeding participation in PES schemes. Nevertheless, REDD+ and other carbon-based PES schemes offer tremendous potential for supporting SFM and biodiversity conservation.

There has been rapid growth in forest certification, which has become an important tool for promoting and ensuring SFM, including biodiversity conservation in production forests. However, forest certification remains strongly biased towards boreal and temperate forests and has made negligible progress in tropical low-income countries. High costs of achieving certification and the low levels of price premium on certified forest products are key barriers to entry.

Governments can encourage certification by providing incentives (e.g. reduced license fees) and through purchasing policies that require the use of certified timber. Many countries and private sector companies have put in place procurement policies to ensure the purchase of forest products from legal and responsible sources.

Participatory forest management
Recognizing the rights of Indigenous Peoples and local communities, ensuring their participation and integrating their knowledge in forest management is critical to achieving SFM. Furthermore, equitable sharing of the benefits of biodiversity is one of the central pillars of the CBD.

One of the most tried and tested approaches to improving the rights of Indigenous Peoples and local communities, specifically their right to access and benefit from forest resources, is community-based forest management. Community-based forest management can also confer benefits for biodiversity conservation by reducing illegal activities and empowering the community to defend their forests against external threats. Further benefits accrue when communities implement SFM and focus on business models that have better biodiversity outcomes. Similarly, it has been shown that lands traditionally owned, managed, used or occupied by Indigenous Peoples perform better in resisting deforestation compared to unprotected, or sometimes even protected, areas. Challenges associated with community-based forest management include potential conflicts among neighbouring communities, the need for capacity among the institutions supporting the process, the requirements of business acumen and social capital to establish and operate viable community-based forest enterprises, and the need for quality monitoring.

Supporting instruments
High quality biodiversity management requires knowledge on biodiversity and capacity among a wide range of actors from government agencies to local communities, civil society organizations, forest owners and forestry corporations. Governments can promote improved biodiversity management through support for research and training on biodiversity and forest management, provision of information on biodiversity, and the production of guidelines and standards.

Barriers and threats to biodiversity mainstreaming
Critical barriers to biodiversity mainstreaming relate to the lack of (or inadequate) use of the regulatory, financial or supporting instruments mentioned above. The most serious barriers and threats to biodiversity mainstreaming in forestry include the following.

1) **Deforestation** – This is the single most important driver of forest biodiversity loss. Although the rate of forest loss is slowing, deforestation continues at an alarming rate of 10 million ha per year especially in lower income tropical countries, primarily driven by agricultural expansion.

2) **Illegal forest activities and corruption** – Illegal timber harvesting is estimated to account for 15–30 percent of global timber production and 50–90 percent of forest harvesting in many tropical countries. These activities not only directly impact forest biodiversity through forest degradation and deforestation but undermine efforts towards SFM.
3) **Low profile of conservation outside protected areas** – Management of biodiversity outside protected areas is critical in efforts to stem biodiversity losses given the limited and uneven coverage of protected areas. Furthermore, the effectiveness of protection often depends on the management of productive landscapes that surround protected areas. However, biodiversity conservation often receives little attention outside protected areas.
4) **Insufficient capacity, financing and regulatory oversight** – Many developing countries struggle to enforce forest and biodiversity regulations because of insufficient capacity and resources, especially at sub-national levels. Monitoring biodiversity management also requires financial investment over the long term, which is often inadequate.
5) **Lack of Indigenous Peoples and local community participation** – The interests of Indigenous Peoples and local communities are often not given sufficient consideration in national forest policy and in the development of forest management plans. Not only is this counter to social justice objectives and the equitable sharing of the benefits derived from biodiversity, but it also increases the threats to biodiversity through undermining management authority.

Integrating biodiversity in forest management

Actively managed forests, including those that have been selectively and repeatedly logged, often support significant levels of biodiversity. These managed and often degraded natural forests play a key role in biodiversity conservation by acting as corridors and refuges for native biodiversity. The quality of forest management has a critical role in determining the value of production forests for a range of values, including biodiversity. In forest plantations, particularly those under monoculture short-rotation management, the success of biodiversity integration depends mostly on the appropriate identification and protection of vulnerable habitats and the spatial configuration of natural vegetation managed as set-asides. However, in the management of natural forests, protection of biodiversity within the production forest stands is also important. The volume of harvest is generally the most significant determinant of the impact of forest operations, and longer harvesting rotations enable a greater degree of biodiversity recovery between harvests.

Biodiversity conservation in production forest can be enhanced through the following measures:

1) **Assessing and managing risks of forest operations to biodiversity**. All forest operations have at least some impact on forest biodiversity. During planning and before initiating any major operations, forest managers

should undertake biodiversity risks assessments, and implement measures to mitigate identified risks. The high conservation value (HCV) approach provides a robust framework for identifying and managing the ecological, environmental and social impacts of forest operations with the engagement of relevant stakeholders. The implementation of reduced impact logging techniques has been shown to greatly improve biodiversity and environmental outcomes.

2) **Establishing and managing set-aside areas**. Biodiversity outcomes in production forests can be improved by delineating and preserving judiciously located set-aside areas to protect old-growth forest and vulnerable habitats, as well as to 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. The HCV approach serves as a valuable tool for prioritizing areas for set-aside.
3) **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 rare plants, nest sites, large trees, hollow trees, dead wood, fruit trees and seed sources for the maintenance of tree genetic diversity.
4) **Sustainable management of timber resources.** Timber harvesting is a major threat affecting a huge number of tree species. The biggest determinant of the impact of timber harvesting is the volume of timber extracted. Therefore, lower harvesting volume combined with a longer rotation period would result in higher time-averaged biodiversity value overall. In order to ensure long-term viability of commercial timber species, carefully implemented harvesting operations with appropriate limits need to be combined with appropriate silvicultural treatments.
5) **Regulating non-wood forest product (NWFP) harvest.** Harvesting of NWFPs, including plant resources and animals, has substantial impact on biodiversity. Therefore, appropriate regulation of NWFP harvest and sustainable management of these species are required to ensure their sustainability. NWFPs come from a diverse range of species, and each species requires case specific management.
6) **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; reducing damage to residual stands and the understorey during forest operations; maintaining forest connectivity; and integrating genetic diversity considerations in tree planting.

7) **Managing and controlling invasive species**. Some forest management activities can increase the risk of invasive species. Invasive species may arrest natural regeneration or dominate naturally open habitats, increasing fire risks and negatively impacting biodiversity. Thus, forest managers should implement an invasive species management plan, including the monitoring and eradication of invasive species that enter the forest area and controlling already-established invasive species that pose a threat to the forest ecosystem.
8) **Protecting forests from illegal and unauthorized activities**. Production forests are often susceptible to encroachment as well as unauthorized and unsustainable harvesting of NWFPs, which is a major cause of biodiversity loss. To address this issue, forest managers should put in place forest enforcement teams to prevent and monitor illegal activities. Cooperation with local communities, including co-management of NWFP resources, is essential to building a social fence for forest protection.

Tree planting and restoration

Globally, 29 percent of forest mosaics are degraded, negatively affecting the livelihoods of an estimated 3 billion people. Land degradation is a major driver of food insecurity, extreme poverty and biodiversity loss. Recognizing the potential of well-designed restoration to address multiple societal and environmental goals, countries, development organizations and the private sector have come together to work towards achieving ambitious restoration targets.

These restoration commitments, including the UN Decade on Ecosystem Restoration (2021–2030), present an enormous opportunity to enhance landscape biodiversity values while meeting multiple environmental and development objectives.

The impact of forest restoration on biodiversity and local communities will depend on the initial conditions of the land to be restored and the desired future condition of the restored forest, as well as on the restoration methods applied. Assisted natural regeneration is cost-efficient and locks in biodiversity benefits early on, but planting may be required where seed sources are not available in the local landscape or where soil remediation is required for seedlings to establish. Between planted forest establishment and natural regeneration, a wide panoply of restoration options exists. Restoration also often involves the control of invasive species.

Despite the potential of restoration to provide a wide range of benefits to society, there are also some risks. These include the potential for the focus on restoration to divert attention away from addressing ongoing deforestation and forest degradation, insufficient focus on local needs and livelihoods, and falling short of expectations due to poor selection of restoration approaches or the use of inferior planting materials.

To minimize these risks, several initiatives and authors have developed guiding principles on forest and landscape restoration. The common elements identified include:

1) maintaining and enhancing existing natural forests;
2) engaging multiple stakeholders and focusing on governance;
3) restoring for multiple benefits with a focus on maximizing biodiversity recovery;
4) tailoring interventions to the local ecological, cultural and socioeconomic contexts;
5) adaptive management for long-term resilience; and
6) ensuring long-term sustainability, including economic sustainability.

Biodiversity monitoring in forests

Defining the biodiversity objectives is the most important step in developing a biodiversity management plan, and this should also be an integral part of the forest planning process. This process should be guided by relevant national legislation and involve a broad range of stakeholders, including local communities and conservation organizations. Once the objectives and targets are defined and agreed, an appropriate set of biodiversity indicators, with corresponding management responses, can be selected for application at different scales. Five criteria to guide the selection of biodiversity indicators have been identified: i) scientific merit; ii) ecological breadth; iii) practicality; iv) utility; and v) relevance. Application of local knowledge in the selection and implementation of indicators is crucial for their local relevance and can often substantially reduce costs.

Biodiversity indicators can include: species community data (presence/absence, abundance, or genetic diversity); information on rare and threatened species; measures of habitat quality, extent and connectedness; metrics reflecting the levels of threats; and the level of compliance with regulations and management prescriptions. Biodiversity indicators often follow a pressure–state–response framework. Biodiversity indicators should support management for improved biodiversity outcomes by providing timely information on performance, but not become so onerous that monitoring detracts from implementing actions to protect biodiversity. Efficiencies can be achieved by embracing modern technologies, such as remote sensing, DNA meta-barcoding, trail cameras and soundscapes, and by developing data pipelines that, for example, enable field information collected on tablets to flow to an online dashboard that generates alerts as required.

Case studies

Eight country case studies were conducted to identify success factors and assess progress made on mainstreaming biodiversity in the forest sector in a variety of national contexts. The countries selected for study were the Democratic Republic of the Congo, Ethiopia, Finland, Japan, Malaysia, Mexico, Peru and the United Kingdom of Great Britain and Northern Ireland (case from Scotland). The studies were conducted through a combination of stakeholder consultations and literature review, while focusing on nationally relevant documents, such as government policy statements and laws.

These country case studies show that, on the one hand, much progress has been made towards mainstreaming biodiversity in production forest management. The principles of SFM ensure that, when implemented well, the interests of Indigenous Peoples and local communities are incorporated, and biodiversity values are protected or enhanced. The advantages of community-based forest management for social justice, as well as for community development, appear to be well appreciated and are being actively promoted by several governments.

On the other hand, biodiversity continues to decline globally. Factors driving this decline vary in importance among countries, but include ongoing deforestation, failure to prevent or sustainably manage hunting, illegal and unregulated timber and NWFP harvesting, conversion of natural forest into monospecific plantations, and landscape scale impacts occurring outside of the forest sector. Several of the case studies drew attention to poorly defined, impractical and overly complex laws and regulations, as well as institutional conflicts among different agencies and levels of government, as factors hindering biodiversity mainstreaming in the forest sector. A substantial capacity gap for both SFM and biodiversity management was identified. Nonetheless, opportunities for improved biodiversity management through REDD+, product certification including for NWFPs, and multi-stakeholder partnerships between environmental NGOs and local communities were also noted. A challenge exists in scaling up local scale success stories to the national scale.

Recommendations

There are a number of measures and actions that governments and development partners can take to facilitate biodiversity mainstreaming in forestry. The following recommendations were identified as the most urgent and impactful priorities.

1. Halting and reversing deforestation

Commitments and efforts in halting and reversing deforestation should be further promoted and strengthened as a critical step to protecting biodiversity in forests. A focus on sustainable agricultural intensification, confining future expansion of agriculture to already deforested areas, removing perverse incentives and increasing penalties for deforestation is required. Corporate efforts to ensure their commodity supply chains do not embed deforestation can also contribute to reducing natural forest loss and should be encouraged. To maintain forest land use, forest management must become a financially viable land use option through the various regulatory, economic and market-based mechanisms described in this report.

2. Combating illegal and unregulated forest activities

Illegal and unregulated forest activities undermine SFM and are a key driver of biodiversity loss in managed forests. Overly complicated and poorly harmonized regulations with conflicting institutional roles contribute to the prevalence of illegal forest activities. Where such issues exist, countries should simplify laws and regulations, focusing on their practical implementation, and clarifying institutional roles across relevant ministries and departments. Investments are also required for implementation and capacity development in law enforcement. Information pertaining to laws, regulations and licenses should be made readily available and implemented through transparent processes. Finally, forest managers should be required to protect the forest under their management against external threats.

3. Recognizing forest tenure of Indigenous Peoples and local communities
Devolving forest management authority through participatory forestry is often an effective strategy in combating illegal forest activities, especially where local communities are the de facto forest managers. In addition, other effective area-based conservation measures (OECMs) will likely prove to be a useful mechanism for engaging communities in forest management as they provide a flexible form of governance that allows existing use and traditional management to be recognized and to continue, so long as the agreed upon biodiversity objectives are met. Emphasis should be on enhancing the equitable sharing of benefits through the sustainable use and conservation of biodiversity.

4. Preventing conversion of natural forests into monospecific forest plantations
Forest policies and regulations should be updated to direct forest plantation development to degraded lands that have limited biodiversity value, so that increasing timber production through plantations does not come at a cost to biodiversity. If established on degraded land and managed to high sustainability standards, forest plantations can have a positive impact on biodiversity, as well as other ecosystem services such as recreation and water provisioning. There is also scope to improve biodiversity outcomes through silvicultural measures, such as managing uneven-aged stands and using a mix of native tree species.

5. Ensuring sustainable management of harvested species
Overharvesting of plants and wildlife is a serious issue driving widespread declines in biodiversity. Hunting by Indigenous Peoples and local communities should be managed through a transparent, negotiated process, based on best available science. Likewise, highly sought-after wild plants should be identified, and management plans put in place. In production forests, commercial species should be sustainably managed based on the best available data to ensure adequate regeneration and the maintenance of genetic diversity.

6. Managing invasive and overabundant species
Invasive species have caused enormous damage to forests and pose serious threats to biodiversity. To protect native biodiversity, it is important to control invasive species through nationally-coordinated plans. Information regarding invasive species should be made readily available, standard best practices developed, and forest management plans should include measures to monitor and control invasive

species. Creating an economic harvest around the species can be an effective approach to controlling an established invasive species.

Overabundance of native wild grazers and browsers is a widespread issue where predators have been functionally or literally extirpated. Reintroduction of predators, or more commonly control through fencing or culling, can be used to manage herbivore populations. Likewise, overgrazing by livestock can be managed through exclosures and reductions in livestock populations. Failure to control wild and domesticated herbivores often impedes forest regeneration and negates restoration efforts.

7. Leverage global momentum on restoration to enhance biodiversity conservation

The global momentum on restoration offers opportunities to enhance biodiversity management in forests and across wider landscapes. These include opportunities to improve habitat connectivity through restoration, ecological restoration of key biodiversity areas, expansion of habitats and threatened ecosystems, and promotion of biodiversity-friendly restoration approaches, such as assisted natural regeneration and mixed planting of native tree species. Adoption of the landscape approach will be key to ensure planning of a biologically-diverse productive landscape, where conservation and production needs are balanced at the landscape level. In order to ensure access to quality planting material and climate resilience of restored forests, a national level system for seed and seedling production needs to be established. Such systems should be designed to sustainably manage tree genetic diversity while matching planting materials to restoration sites.

8. Adopting a multisectoral perspective

As biodiversity is impacted by changes occurring outside of forests, it is important that biodiversity is mainstreamed across other land use sectors. Development of forest management plans should consider wider spatial planning objectives and strategies for biodiversity conservation. Cross-sectoral coordination and inclusion of the forest sector in national development strategies, as well as biodiversity mainstreaming within forestry, are of critical importance.

9. Providing economic incentives

Governments can play an important role in incentivizing SFM and high-quality forest biodiversity management through a variety of economic instruments, including: tax breaks for compliance with specific management objectives; issuing and renewing licenses and permits conditional on performance (and revoking them in cases of non-compliance); subsidies and investments for achieving biodiversity outcomes; compensation for reduced production to promote biodiversity benefits; and grants for forest managers and owners to shift management objectives towards biodiversity conservation.

10. Facilitating market-based instruments

Governments can facilitate biodiversity mainstreaming in forestry by steering practices through various market-based approaches. These include: promoting or requiring forest certification; facilitating PES schemes through government policy, regulations and public–private partnerships; supporting sustainable value chain development through green purchasing policies that reduce the environmental footprint of agricultural and forest products; and engaging in public–private partnerships to leverage corporate social responsibility commitments in support of SFM and biodiversity conservation.

11. Supporting knowledge and capacity development

Biodiversity outcomes can be improved through supporting research and training in forest management and biodiversity conservation at higher institutes of learning. Governments and institutions of higher learning can support biodiversity mainstreaming through developing national biodiversity databases, and digital tools for incorporating local knowledge and citizen science. These innovative technologies should be leveraged to improve forest law enforcement as well. Government, civil society organizations, private sector companies and development partners need to work together to enhance the capacity of forest managers to integrate biodiversity conservation into forest management through best practice guidelines and provision of training.

PART 1. SETTING THE SCENE

CANOPY OF INTACT TROPICAL RAINFOREST IN THE DEMOCRATIC REPUBLIC OF THE CONGO

1. Introduction

1.1. FORESTS AND BIODIVERSITY

Scientists debate about when the Anthropocene started. Some argue it began when modern humans spread out around the world over 60 000 years ago, altering fire regimes and driving megafaunal extinctions (Sandom *et al.*, 2014). A recent study found that rapid changes in global vegetation have been underway for 3–4 millennia, emphasizing the role of agriculture and expanding human populations (Mottl *et al.*, 2021). Others consider the start of the industrial revolution to be the most appropriate marker, as this denotes the point at which humans swapped biomass for fossil fuels as their primary energy source, thus uncoupling the economy from the limits of current solar radiation and altering atmospheric chemistry as a consequence (Lewis and Maslin, 2015). Regardless, there is overwhelming evidence that humans have had an enormous impact on the Earth's living systems; an impact that has accelerated through time and now surpassed safe planetary boundaries on several fronts (Rockström *et al.*, 2014), most notably for biodiversity (Newbold *et al.*, 2016).

Forests represent the apogee of terrestrial biodiversity. Forests grow naturally across most land areas of the globe where there is sufficient rainfall and soil to permit tree growth, and are the endpoint of natural succession. Forests comprise habitats with complex three-dimensional structures, producing strong gradients in sunlight, temperature, water and nutrient availability, and thus creating diverse niches for a wide range of taxa. When the forest canopy is opened, these gradients are simplified and niches disappear. Hence, forests not only support high biodiversity, but also play host to a large proportion of disturbance-intolerant species that are lost during clearance or negatively impacted by disturbance (Gibson *et al.*, 2011; Barlow *et al.*, 2016; Betts *et al.*, 2017).

Forests and their biodiversity serve as a safety net for humanity, providing clean air, regulating water cycles, sequestering carbon, mitigating natural disasters and bolstering livelihoods (FAO, 2018). Forests also have an important role in maintaining human health and psychological well-being (FAO, 2020b; Reyes-Riveros *et al.*, 2021). All people in the world benefit from forests and the products of their biodiversity, including the various ecosystem services that forests provide (FAO and UNEP, 2020).

Furthermore, forests sustain our economies, with the formal forest sector contributing approximately USD 580 billion in labour income to the global economy and employing 45 million people (FAO and UNEP, 2020). Moreover, if the informal sector is included, the number of people employed increases by 41 million with the contribution to the global economy being USD 730 billion

(OECD, 2018). It is important to note that these figures include only extractive forest uses and do not include the value of forests for other uses, such as recreation or ecosystem service provision. Overall, one third of humanity depends directly on forests to some extent for their livelihoods (FAO and UNEP, 2020; Fedele *et al.*, 2021), while 1 billion of 1.2 billion of the world's extremely poor rely on forests for their livelihoods (OECD, 2018). Forests are home to many Indigenous Peoples, and forest products are critical to the livelihoods of many rural communities (Shackleton and Pandey, 2013; FAO and UNEP, 2020).

Biodiversity conservation became a mainstream global agenda following the signing of the Convention on Biological Diversity in 1992. Protected areas have been a key strategy and a cornerstone of biodiversity conservation to date. Currently, 18 percent (726 million ha) of the world's forest area is managed specifically for conservation, while approximately 30 percent (1.15 billion ha) is officially designated for production of timber and non-wood forest products (NWFPs)[1] (FAO, 2020a). In addition, many forest areas without any designated management objectives are in fact being used informally or unofficially for economic purposes. Hence, forests that are managed primarily for economic benefits will be critical for biodiversity conservation (Cerullo and Edwards, 2019; Clark *et al.*, 2009; Gilroy *et al.*, 2014c; Harrison *et al.*, 2020).

Forests managed for production not only support significant biodiversity, but they are also essential components of landscapes in which protected areas are embedded, providing corridors and enhancing connectivity among reserves (Senior, Hill and Edwards, 2019; Brockerhoff *et al.*, 2008). Production forests tend to be located in accessible areas with favourable growing conditions as opposed to protected areas which are predominantly located in remote sites, on poor soils or at high elevation with historically less competition for other land uses (Joppa and Pfaff, 2009; Venter *et al.*, 2018). Thus, these forests managed for production can play a key role in the conservation of ecosystems and biodiversity that are under-represented within protected area networks, and have the potential to massively extend the area available for biodiversity conservation (Cerullo and Edwards, 2019; Harrison *et al.*, 2020).

Many developing countries struggle to adequately fund protected area management, leaving many reserves with little effective on-the-ground protection (Coad, Watson and Geldmann, 2019; Laurance *et al.*, 2012; Maxwell *et al.*, 2020). In many lower income countries, forests within protected areas suffer similar rates of deforestation as unprotected forests (Anderson and Mammides, 2020; Gaveau *et al.*, 2013; Geldmann *et al.*, 2019), and protected areas have been ineffective in reducing trade-driven wildlife declines in tropical and subtropical forests (Cardoso *et al.*, 2021; Morton *et al.*, 2021). In contrast, production forests generate income

[1] The terms non-timber forest product (NTFP) and non-wood forest product (NWFP) are sometimes used interchangeably, although there is a difference in the scope of forest products included under these two terms. The term NWFP excludes all woody raw materials. Consequently, timber, chips, charcoal and fuelwood, as well as small woods for use as tools, household equipment and carvings, are excluded. NTFP, in contrast, refers to all goods of biological origin produced in forests excluding timber. NTFP generally includes fuelwood and small woods.

for local communities, corporations and nations, making available human and financial resources to invest in protection and biodiversity management (Berry *et al.*, 2010; Edwards *et al.*, 2019; Harrison *et al.*, 2020).

Unlike strictly protected areas, managing biodiversity in production forests is a search for optimal outcomes across multiple objectives, including productive economic benefits, maintaining or enhancing ecosystem services, and biodiversity conservation. It is a complex balancing act, whereby biodiversity objectives need to be identified, and plans and actions put in place to maximise synergies and minimise trade-offs with other desired functions, such as production benefits. Ultimately, forest management represents a huge opportunity to contribute to positive biodiversity outcomes (Clark *et al*., 2009; Berry *et al.*, 2010), especially if forest management prevents forest loss or defaunation (Cerullo and Edwards, 2019; Edwards *et al.*, 2019; Harrison *et al.*, 2020).

Managing forests for economic benefits inevitably has consequences for biodiversity (Sheil, Nasi and Johnson, 2004). Harvesting of timber increases canopy openness, reduces structural diversity and depletes some resources. Even seemingly low impact activities have consequences. For example, collecting fruit or other NWFPs take away resources from the organisms that would otherwise use them, while altering plant communities (Shackleton, Ticktin and Cunningham, 2018). Likewise, recreational use affects animal behaviour and utilization of forest resources (Dertien, Larson and Reed, 2021; Lewis *et al.*, 2021). Moreover, organisms vary in their response to environmental change. For instance, selective logging may negatively impact understorey insectivorous birds, which are among the most disturbance-intolerant guilds (Powell, Cordeiro and Stratford, 2015). However, the same intervention may benefit species that browse on understorey plants (e.g. elephants), as increases in light reaching the forest floor promote the growth of understorey vegetation (Struhsaker, Lwanga and Kasenene, 1996). In some cases, traditional forest management practices have created habitats for certain species that are now rare, and restoration of these cultural ecosystems requires a return to former management (e.g. Buckley, 2020).

The international community has set ambitious targets for forest restoration, with the goals of providing sustainable local livelihoods, repairing ecosystem services, sequestering carbon and turning the tide on biodiversity loss (Edwards *et al.*, 2021a; Girardin *et al.*, 2021). Well planned and executed forest ecosystem restoration on deforested and degraded land can substantially improve biodiversity outcomes. Even relatively species-poor forest plantations can enhance the biodiversity of a degraded landscape, especially where SFM principles are applied and their design enhances habitat connectivity (Quine and Humphrey, 2010; Brockerhoff *et al.*, 2008). The global restoration movement offers an enormous opportunity for biodiversity conservation. However, there are some risks associated with these ambitious global targets, including the diversion of attention away from efforts to halt deforestation and forest degradation, failure to address the interests of Indigenous Peoples and local communities, and unfulfilled expectations due to application of inappropriate restoration approaches or use of inferior planting materials.

1.2. THREATS TO FORESTS AND BIODIVERSITY

Despite the recognition of the essential ecosystem services provided by forests and the global movement on restoration, forests and forest biodiversity continue to be threatened on multiple fronts. Forest loss is by far the most significant cause of terrestrial biodiversity loss, as natural forests continue to be cleared for agriculture, industrial plantations, and urban expansion (Hansen *et al.,* 2013; Curtis *et al.*, 2018). Deforestation, which results in the near-complete loss of forest biodiversity and ecosystem services, stands at 10 million ha annually (FAO, 2020a; Gibson *et al.*, 2011). An estimated 81 million ha of primary forests have been lost since 1990 (FAO, 2020a). Under current rates of forest loss, 121–219 vertebrate species will become threatened with extinction in the high-risk biodiversity hotspots in Borneo, the central Amazon and the Congo Basin within the next 30 years (Betts *et al.*, 2017).

Deforestation of biologically diverse native forest results in loss of biodiversity

In addition, forests and biodiversity are threatened by disturbances that do not necessarily result in deforestation, but nevertheless have devastating impacts on forest health and vitality, and subsequently their ability to provide a full range of goods and ecosystem services. For example, in 2015, insects, diseases and severe weather events damaged about 40 million ha of forests. Another 98 million ha of forest were affected by fire in 2015, primarily in the tropics (FAO, 2020b).

Forests also face more insidious threats. Outside of the largest rainforest blocks (i.e. Amazonia, Congo and New Guinea), there are few if any forests that are not impacted by unsustainable wildlife harvests, including in protected areas (Estes *et al.,* 2011; Dirzo *et al.*, 2014; Morton *et al.*, 2021). Defaunation has a major disruptive effect on the forest tree community, mainly by affecting seed dispersal and seedling recruitment (Galetti *et al.*, 2013; Harrison *et al.*, 2013). Although less documented, plants face similar threats (Margulies *et al.*, 2019). Indeed, BGCI (2021) reported that 30 percent of all tree species worldwide are threatened with extinction. Overexploitation of high-value timber species is a major threat impacting over 7 400 species (BGCI, 2021). In many countries, there is inadequate protection of forest wildlife, trees and other plants through effective regulation of hunting and harvesting. In addition, mismanagement of forests has substantially increased the risk of emergent zoonotic diseases, such as Ebola and COVID-19 (Morand and Lajaunie, 2021), as well as the prevalence of vector-borne diseases, such as malaria (Chaves *et al.*, 2020). Recent research has shown that climate change has driven a global decline in forest resilience, particularly in tropical, arid and temperate forests, with associated declines in primary productivity (Forzieri *et al.*, 2022).

In short, forest biodiversity continues to be rapidly eroded, compromising the ecological functioning of forests and undermining the services they provide to humanity (Cardinale *et al.*, 2012). The Millennium Ecosystem Assessment, carried out between 2001 and 2005, found that over 60 percent of global ecosystem services had been impaired over the previous 50 years (Millennium Ecosystem Assessment, 2005), and the situation continues to deteriorate (IPBES, 2019).

Degraded dryland forest suffering from drought

1.3. SUSTAINABLE FOREST MANAGEMENT FOR BIODIVERSITY

Sustainable forest management seeks to balance ecological, sociocultural and economic interests, and thereby manage forests according to the principles of sustainable development (see **Box 1**). It recognizes that forests provide multiple uses and that different benefits accrue to different stakeholders (Sabogal *et al.*, 2013). Hence, under SFM, forest management plans are developed through broad stakeholder consultation to address potential trade-offs, especially between economic values, local livelihood needs and long-term ecological sustainability.

Countries initially committed to SFM through the Forest Principles at the Rio de Janeiro Earth Summit in 1992. Subsequently in 2007, the United Nations General Assembly adopted the Non-legally Binding Instrument on All Types of Forest,[2] which encapsulates a strong international commitment to SFM. Several international criteria and indicator (C&I) frameworks exist to guide SFM, and measure progress against targets, including under the Montreal Process,[3] Forest Europe[4] and the International Timber Trade Organization (ITTO, 2015), as well as a host of national and local frameworks. SFM may be guided by national laws and regulations, or through international or national forest management certification standards.

The ecosystem approach has been a prominent strategy under the United Nations Convention on Biological Diversity (CBD) since the adoption of the Malawi Principles[5] in 1998. SFM was recognized by the CBD as a means of applying the ecosystem approach to forest ecosystems in 2004 (Decision VII/11 of CoP7[6]). SFM also has many parallels with landscape approaches. It is a vehicle for defining stakeholder objectives and negotiating conflicting use rights, including by way of fiscal transfers (e.g. PES schemes). It emphasizes the management of biodiversity for long-term sustainability and recognizes the importance of maintaining ecosystem functions and interactions across a range of spatial scales. The Forest Stewardship Council (FSC) and some national forest certification schemes endorsed by the Programme for the Endorsement of Forest Certification (PEFC) implement biodiversity management through the high conservation value (HCV) approach. Monitoring and adaptive management are central to implementation of quality SFM. Given the potential trade-offs among the different forest management objectives, outcomes must be tracked to enable early identification of any problems and implementation of remedial measures.

The results of Global Forest Resources Assessment 2020 of FAO indicate that considerable progress has been made towards enabling and implementing SFM globally (FAO, 2020a; Shono and Jonsson, 2022). Although global forest area continues to decrease, the rate of forest loss has slowed substantially over recent decades due to the reduction in deforestation in some countries and increase in forest area in others through reforestation and natural forest expansion. The area under long-term forest management plans is estimated to be 2.05 billion ha or just over 50 percent of forests globally (FAO, 2020a). Forest in protected areas has continued to increase and reached an estimated 726 million ha worldwide in 2020. Meanwhile, forest certification, which provides assurance that forest managers are using best practices to manage forests responsibly and sustainably, has expanded rapidly in the past two decades, reaching 435 million ha of certified

[2] https://digitallibrary.un.org/record/614195/files/A_RES_62_98-EN.pdf
[3] https://montreal-process.org
[4] https://foresteurope.org
[5] www.cbd.int/doc/meetings/cop/cop-04/information/cop-04-inf-09-en.pdf
[6] www.cbd.int/decisions/cop/7/11/7

forest worldwide in 2020. This equates to just over half (52 percent) of the global forest area officially designated primarily for production. Despite the progress, certified forest area is heavily skewed towards boreal and temperate forests, and remains negligible in low-income tropical countries (FAO, 2020a; Shono and Jonsson, 2022).

2. Framing of the study

Biodiversity mainstreaming is a major tenet of the CBD. Article 6 of its convention text states that countries should "integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross sectoral plans, programmes, and policies"[7]. Mainstreaming also contributes towards fulfilling Article 10(a), which calls on the Parties to "integrate consideration of the conservation and sustainable use of biological resources into national decision-making". In addition, mainstreaming is prominently featured in the Strategic Plan for Biodiversity 2011–2020 and its Aichi Targets. Strategic Goal A aims to "address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society", and Target 2 calls on member countries to integrate and incorporate biodiversity into national and local development and poverty reduction strategies and planning processes, as well as into national accounting and reporting systems[8].

Mainstreaming involves taking objectives from one issue domain and integrating these objectives into other issue domains where they are not yet sufficiently addressed, and has been applied to issues such as the environment, gender and human rights (Karlsson-Vinkhuyzen *et al.*, 2017). This approach becomes necessary when other policy domains or economic sectors have a strong bearing on the issue of concern, as in the case of biodiversity, which has a crucial but underappreciated role in supporting sustainable development through underpinning ecosystem services (FAO and UNEP, 2020). The concept of biodiversity mainstreaming recognizes the role of Indigenous Peoples and local communities, and by inference the importance of local knowledge, in managing and protecting wild biodiversity in forests, as well as benefiting from it.

Biological diversity, as pertains to forest management, includes the diversity existing among plants, animals, fungi and microbes in forest ecosystems, including functional groups such as trees and other plants, pollinators, seed dispersers and below ground macro-, meso- and micro-organisms. It also includes aquatic or marine organisms where these are a component of the forest ecosystem. However, this report will not cover *ex situ* conservation of domesticated species, such as commercial tree varieties or breeds of domestic animals, and nor do we cover trees in agricultural settings, such as orchards or agroforestry systems.

Box 1 provides the definitions of key terms and concepts as used in this study.

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7 www.cbd.int/convention/text
8 www.cbd.int/sp/targets

This report covers forests that are managed for economic interests, as well as for regulating, cultural and supporting ecosystem services. As such, the scope includes natural forests, forest plantations and forests re-established through restoration under various objectives irrespective of jurisdictional or tenurial circumstances. We also do not restrict forests by area, and thus include forest fragments and woodlots in agricultural landscapes, where they often provide valuable ecosystem services. However, our study does not include strictly protected areas, such as national parks and wildlife sanctuaries, where the primary aim of management is biodiversity conservation. A substantial literature exists on the management of protected areas and it would be superfluous to cover it here. In short, we cover all types of forest outside of protected areas.

BOX 1

Definitions of key terms and concepts

<u>Biological diversity:</u> "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Article 2 of the CBD).

<u>Biodiversity mainstreaming:</u> "the process of embedding biodiversity considerations into policies, strategies and practices of key public and private actors that impact or rely on biodiversity, so that it is conserved and sustainably used both locally and globally" (Huntley and Redford, 2014 for the Global Environment Facility Scientific and Advisory Panel).

<u>Deforestation:</u> The conversion of forest to other land use independently whether human-induced or not (FAO, 2018).

<u>Ecosystem:</u> "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Article 2 of the CBD).

<u>Ecosystem approach:</u> "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the ecosystem approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems" (CBD[a]).

<u>Ecosystem restoration:</u> "the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity" (UNEP, 2021[b]).

Forest: Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*.

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[a] www.cbd.int/ecosystem

[b] https://wedocs.unep.org/bitstream/handle/20.500.11822/36251/ERPNC.pdf

It does not include land that is predominantly under agricultural or urban land use (FAO, 2018).
Genetic material: "any material of plant, animal, microbial or other origin containing functional units of heredity" (Article 2 of the CBD).
Genetic resources: "genetic material of actual or potential value" (Article 2 of the CBD).
Habitat: "the place or type of site where an organism or population naturally occurs" (Article 2 of the CBD).
Non-wood forest product: Goods derived from forests that are tangible and physical objects of biological origin other than wood (FAO, 2018).
Planted forest: Forest predominantly composed of trees established through planting and/or deliberate seeding (FAO, 2018).
Plantation forest: Planted forest that is intensively managed and meet all the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing (FAO, 2018).
Protected area: "a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives" (Article 2 of the CBD).
Reforestation: Re-establishment of forest through planting and/or deliberate seeding on land classified as forest (FAO, 2018).
Restoration: "any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state" (IPBES, 2014[c]).
Sustainable forest management: "dynamic and evolving concept, which aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations" (The United Nations General Assembly, 2008).
Sustainable use: "the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations" (Article 2 of the CBD).

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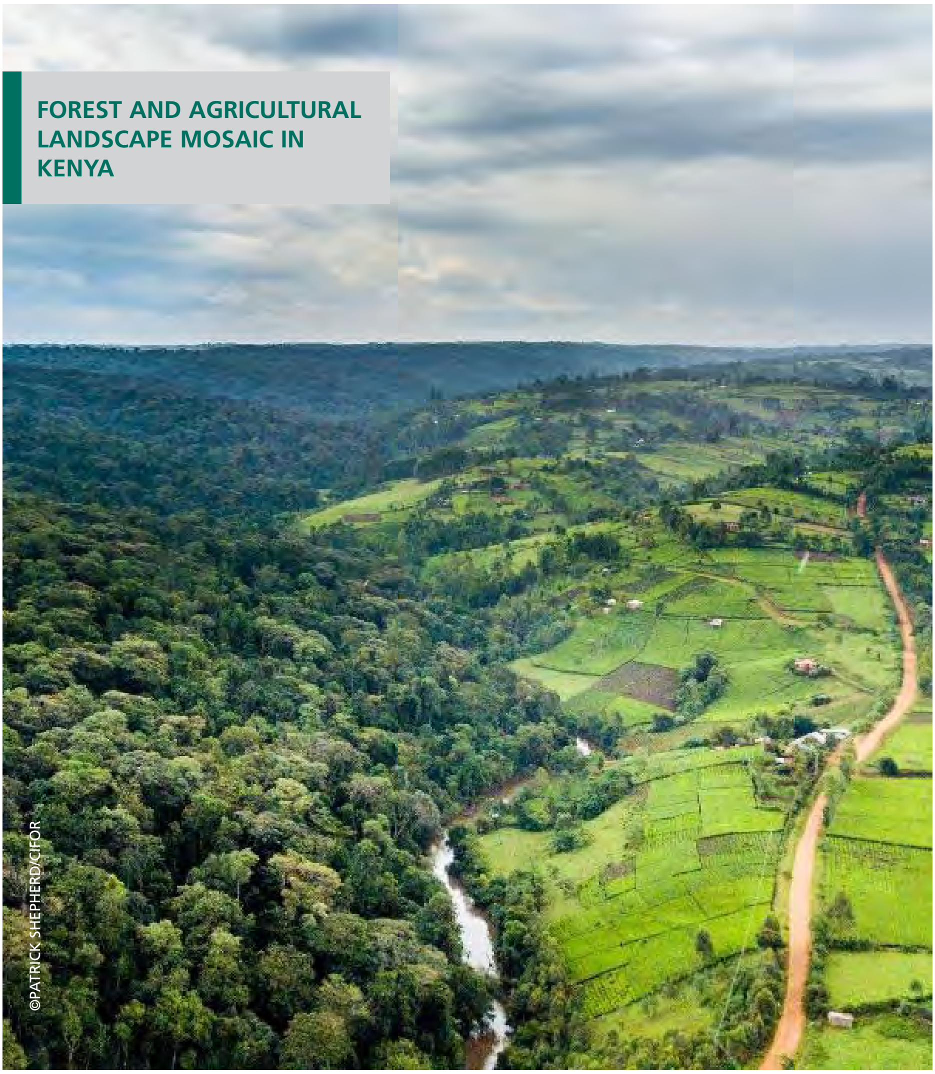
[c] https://ipbes.net/sites/default/files/downloads/doc/IPBES_3_7_EN.doc

Source: As referenced in text

PART 2. MAINSTREAMING BIODIVERSITY IN FOREST POLICY AND MANAGEMENT


FOREST AND AGRICULTURAL LANDSCAPE MOSAIC IN KENYA

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3. Biodiversity mainstreaming in forest sector policies, strategies and programmes

3.1. BACKGROUND

Biodiversity mainstreaming requires a process of integrating considerations pertaining to the sustainable use and conservation of biodiversity into legislation, policies and everyday management (Redford *et al.*, 2015). All economic activities impact biodiversity to various degrees, and mainstreaming biodiversity is a strategic response aimed at stemming biodiversity loss and ensuring sustainability of benefits. Analyses suggest that agriculture and forestry were responsible for approximately 60 percent of biodiversity loss in terms of mean species abundance up to 2010, and that projected losses of 55 percent up to 2050 can be halved through combinations of technological advances, improved management and changes in consumptive behaviour (Kok *et al.*, 2018).

With respect to the forest sector, mainstreaming biodiversity involves the harmonization of environmental regulations and policy with those governing forests. It also involves identifying opportunities and synergies with other areas of government policy, such as in climate change mitigation and adaptation (Seddon *et al.*, 2020). Implementation may involve enhanced regulation, as well as the use of fiscal and market incentives. Furthermore, it may involve changes in forest governance structures, such as government decentralization or community-based forest management. Biodiversity mainstreaming also requires support through investments in the generation of knowledge pertaining to biodiversity and the management of natural resources, training in forestry and environmental sciences, and institutional strengthening, as well as raising the profile of environmental issues through public education. Mainstreaming biodiversity must engage different actors involved in the governance of forests, including government, private sector, civil society and local communities. As such, mainstreaming is more about steering the sector towards better consideration of biodiversity in plans and actions than top-down regulation (Karlsson-Vinkhuyzen *et al.*, 2017). Nevertheless, to be effective, biodiversity mainstreaming needs political will and policy support.

Compared to other economic sectors that exert a strong influence on biodiversity (e.g. agriculture), there has been a focus on biodiversity management within the forest sector for several decades, reflecting the importance of forests as repositories of biodiversity and the ecosystem services that healthy forests provide. For instance, securing environmental values, including biodiversity conservation, in production forests is one of the three central pillars of SFM. Hence, a substantial body of knowledge on biodiversity management in forests has been accrued (Putz *et al.*, 2012; Pawson *et al.*, 2013; Edwards *et al.*, 2019). Moreover, there is good evidence that better biodiversity management leads to not only improved outcomes for forest biodiversity (Bicknell *et al.*, 2014; Chaudhary *et al.*, 2016), but also climate change mitigation (Ellis *et al.*, 2019). Nevertheless, forest biodiversity continues to be lost at an alarming rate. Hence, this is an opportune time to reflect on progress, identify barriers and levers for improved biodiversity management, and enhance understanding of effective interventions for mainstreaming biodiversity in the forest sector.

3.2. NATIONAL BIODIVERSITY STRATEGIES AND ACTION PLANS

Individual countries implement the goals of the CBD through their national biodiversity strategies and action plans (NBSAPs). Over 190 countries have pledged to increase efforts to integrate biodiversity into policies of their forestry, fisheries, agriculture and tourism sectors, and in 2018 this was extended through the Sharm El-Sheikh Declaration to the energy, infrastructure, manufacturing and processing sectors (CBD, 2018). By elaborating specific national biodiversity targets and actions to achieve them, NBSAPs serve an important starting point for biodiversity mainstreaming.

Based on a review of 144 updated NBSAPs available at the end of 2017, Whitehorn *et al.* (2019) found that 91 percent of NBSAPs recognize that biodiversity contributes to the national economy and 43 percent provided specific details. Interestingly, developing countries were more likely to give specific details about the contribution of biodiversity and ecosystem services to the economy than developed countries. Biodiversity loss was perceived as a threat to productivity in 85 percent of NBSAPs, while the potential productive benefits arising from sustainable management of biodiversity were recognized in 90 percent of NBSAPs for at least one sector. However, only 50 percent of NBSAPs recognized that there may be conflicts or trade-offs between biodiversity and productivity. Most NBSAPs only examined the contribution of biodiversity to agriculture, forestry, fisheries and tourism, while few considered other sectors such as water, other extractive industries, renewable energy and infrastructure development (Whitehorn *et al.*, 2019).

Meanwhile, Uetake *et al.* (2019) examined 133 NBSAPs using a text-mining approach to investigate the use of terms for integrated approaches (e.g. landscape approach) and found that 99 percent of countries used at least one term, 50 percent mentioned more complex terms (e.g. cultural landscapes; socioeconomic production landscapes), and that the use of such terms has been increasing. These trends indicate that these concepts are gaining a higher profile in national planning (Uetake *et al.*, 2019), which may be taken as an indicator of the increased relevance of biodiversity mainstreaming in national policy-making.

Although NBSAPs provide a basis for developing sector specific policies for the sustainable use and conservation of biodiversity, an assessment conducted by the CBD found poor levels of biodiversity mainstreaming in national development strategies (CBD, 2018). For example, of the 196 Parties to the Convention, only 47 Parties had conducted valuation studies of biodiversity and only 40 Parties claim that biodiversity has been integrated into national development plans. While some success stories exist (Karlsson-Vinkhuyzen *et al.*, 2017), progress on mainstreaming biodiversity is often hampered by several barriers, including: a focus on short-term economic gains; fragmented decision making; limited communication among stakeholders; and lack of financial resources, time and knowledge (CBD, 2018; Whitehorn *et al.* 2019). In particular, means barriers commonly undermine biodiversity conservation in developing economies, and globally biodiversity conservation remains grossly underfunded (Coad, Watson and Geldmann, 2019; Balmford *et al.*, 2002).

3.3. CLIMATE POLICY AND NATIONALLY DETERMINED CONTRIBUTIONS

The Paris Agreement on climate change calls on all parties to acknowledge "the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity, recognized by some cultures as Mother Earth". Here, the critical role of protecting and restoring healthy ecosystems for both climate change mitigation and adaptation is well recognized. Countries implement the goals of the Paris Agreement on climate change through their nationally determined contributions (NDCs). At least 66 percent of signatories to the Paris Agreement have included nature-based solutions in some form, and over 70 percent of NDCs are estimated to contain references to efforts in the forest sector, while 42 percent include afforestation and restoration as an approach to mitigate climate change (Seddon *et al.*, 2019). Furthermore, REDD+ is included in most developing countries' NDCs and climate change policies (Pham *et al.*, 2018). The implementation of REDD+ in countries is guided by national REDD+ strategies, which define programmes and activities to reduce emissions from deforestation and forest degradation, and supports a set of safeguards which include biodiversity conservation.

This focus on forests as part of climate mitigation strategy is well justified. For 2007–2016, global CO_2 emissions from land-cover change (primarily deforestation) represented approximately 12 percent of global emissions. Over the same period, the terrestrial carbon sink absorbed about 28 percent of greenhouse gas (GHG) emissions (3.0±0.8 GtC per year), mainly in forests (Seddon *et al.*, 2019). However, there is a concern that the focus on maximizing carbon sequestration might result in prioritizing afforestation with a limited number of exotic species. This could divert attention from supporting improved forest management and restoration of productivity in degraded natural forests, which can provide greater benefits to biodiversity and local livelihoods. There has been much debate on the relationship between carbon storage and biodiversity, with evidence showing that these benefits can but not always have a positive linear relationship (Soto-Navarro *et al.*, 2020). Careful planning is needed to pursue opportunities where carbon sequestration and conservation result in direct biodiversity benefits, avoiding potentially perverse outcomes (Di Marco *et al.*, 2018).

3.4. PLEDGES ON RESTORATION AND ENDING DEFORESTATION

Many countries and partner organizations have signed up to ambitious targets to end deforestation and restore forests, with existing restoration commitments by 115 countries under the CBD, the United Nations Convention to Combat Desertification (UNCCD), the United Nations Framework Convention on Climate Change (UNFCCC) and the Bonn Challenge totalling 1 billion ha (Sewell, van der Esch and Löwenhardt, 2021).

The Bonn Challenge[9], currently involving more than 70 pledges from countries, subnational jurisdictions and private sector partners, aims to restore 350 million ha by 2030 through forest and landscape restoration, in line with the Aichi Targets. The Trillion Trees Partnership[10] proposes to improve the protection and management of 105 million ha of forests, restore 20 million ha and reduce deforestation by half by 2050 through directing funds to crucial forest conservation projects across the world. Climate, biodiversity and livelihoods comprise the key benefits targeted by this initiative. In addition, several regional initiatives have been launched, securing political commitments to implement forest and landscape restoration through agreed regional strategies. These include the African Forest Landscape Restoration Initiative (AFR100)[11], Initiative 20x20 in Latin America[12], the ECCA30[13] initiative in Europe, the Caucasus and Central Asia. The UN Decade on Ecosystem Restoration (2021–2030)[14] aims to leverage these country and regional efforts to prevent, halt and reverse the degradation of ecosystems on every continent.

Forest in transition at the deforestation frontier

9 www.bonnchallenge.org
10 www.trilliontrees.org
11 https://afr100.org
12 https://initiative20x20.org
13 https://infoflr.org/bonn-challenge/regional-initiatives/ecca30
14 www.decadeonrestoration.org

Furthermore, the movement towards deforestation-free commodities has gained momentum, and many private companies have committed to eradicating deforestation from their supply chains. The New York Declaration on Forests[15] – signed in 2014 by 37 governments, 63 NGOs, 53 multinational companies and 16 Indigenous community groups – pledges to end deforestation by 2030. The European Union proposing a regulation to minimize European-driven deforestation and forest degradation by promoting the consumption of deforestation-free products, with the aim of reducing European Union's global footprint in terms of GHG emissions and biodiversity loss (European Union, 2021).

These global commitments and initiatives explicitly target biodiversity as one of the key objectives and offer tremendous opportunities to mainstream biodiversity in efforts to improve forest protection, management and restoration.

3.5. FOREST SECTOR POLICY AND GOVERNANCE

Although there is substantial literature on SFM, forest certification and other aspects relevant to biodiversity mainstreaming, literature specifically focusing on biodiversity mainstreaming within the forest sector is thin. Importantly, evaluation of the pros and cons of different policy interventions, the contexts under which particular interventions work well and do not work so well, and what combinations of interventions produce synergistic benefits are lacking (Huntley and Redford, 2014).

Sarkki *et al.* (2016) assessed biodiversity mainstreaming in Finland – one of the world's most forested countries – and concluded the multi-actor processes that Finland employed for developing NBSAPs, involving a long-term iterative process with balanced sector representation, succeeded in generating sector level responsibilities for biodiversity conservation. They also noted that the presence of ecologists and conservation biologists in relevant ministries further contributed to successful biodiversity mainstreaming. The remaining challenges cited to halt biodiversity loss were competition for funding among the core issues, responsiveness to new knowledge and governance gaps, and diffusion of responsibilities from the environmental sector to other policy sectors.

Meanwhile, the Organisation for Economic Co-operation and Development (OECD) conducted a review of biodiversity mainstreaming in agriculture, forestry and fisheries across 14 countries (OECD, 2018), and concluded that continued challenges arise from: 1) poor horizontal and vertical institutional coordination; 2) inadequate human resources and capacity, particularly within sector line ministries; 3) failure to collect and disseminate policy-relevant data for mainstreaming; and 4) insufficient financial resources for biodiversity conservation.

In summary, these studies indicate that developing biodiversity strategies through broad stakeholder consultation, including with relevant line ministries, promotes responsibility for biodiversity mainstreaming across government sectors. Financial support and capacity development are essential to the process, while academic institutions also have a critically important role. Biodiversity

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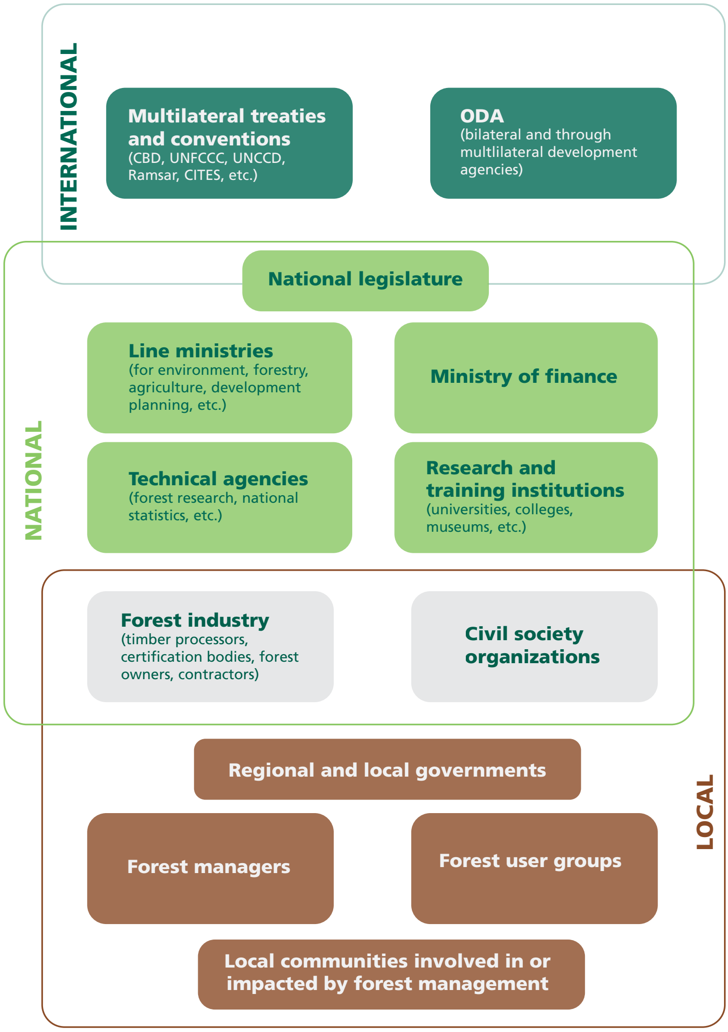
15 http://forestdeclaration.org

Figure 1. Stakeholders involved in biodiversity mainstreaming in the forest sector



Source: Authors' own elaboration

research contributes to improved knowledge about the sustainable use and conservation of biodiversity, while training supports capacity across both the public and private sectors.

Forest governance is complex and often fragmented (**Figure 1**), and hence biodiversity mainstreaming requires synergistic approaches implemented through a wide range of policy instruments. Biodiversity conservation may seem foreign and counter to the interests of certain critical actors, such as logging contractors or wood processing firms. Therefore, biodiversity mainstreaming requires a range of governance modes from government enforced regulation to market-based steering (Sarkki *et al.*, 2016; Karlsson-Vinkhuyzen *et al.*, 2017). Consideration of the enabling factors for effective implementation will be crucial to success.

Assessments agree on a couple of essentials for mainstreaming biodiversity in forestry. First, effective government-led land use and development planning is pivotal for integrating diverse measures to enhance biodiversity conservation in forests, including strict conservation, sustainable management of production forests, community-based forest management and restoration (OECD, 2018; Kok *et al.*, 2018). Natural capital contributes 36 percent of GDP in developing economies, and hence mainstreaming biodiversity in national development plans, green growth strategies and the like is crucial for sustainable development (OECD, 2018). Second, mainstreaming strategies need strong political support and are underpinned by legislation supporting nature protection (Karlsson-Vinkhuyzen *et al.*, 2017).

In **Figure 1**, the boxes represent the principal institutions involved at international, national and local levels. National governments make international commitments on biodiversity and translate these commitments into NBSAPs, which are then integrated into sectoral laws, regulations and policies. This process is supported by research and training organizations, as well as government technical agencies, who provide knowledge and technical expertise, as well as building capacity for biodiversity management. Research and training institutions also support the process by generating essential knowledge pertaining to biodiversity, such as species' distributions, habitat mapping, genetic resource management and ecosystem service evaluation. Furthermore, these processes are influenced and supported by civil society organizations (e.g. environmental NGOs, indigenous rights organizations).

National forest biodiversity policies and regulations are (usually) implemented by regional and local governments, who have responsibility for local land use planning and management. Forest managers, who may include private owners, forestry corporations, Indigenous Peoples and local communities, work with local government and other forest user groups (e.g. ecosystem service beneficiaries), often supported by research and training institutions and civil society organizations, to develop and implement forest management plans that provide sustainable productive benefits to a range of stakeholders, while safeguarding biodiversity. Establishing fluid, timely and transparent communication of information concerning the sustainable use and conservation of biodiversity among institutions for the development of national policies and regulations, guidelines and standards, incentive instruments, development plans (national, regional, local) and forest management plans, and in monitoring outcomes across levels, is essential to assure positive outcomes.

4. Approaches and tools for biodiversity mainstreaming

4.1. BACKGROUND

Preventing deforestation – especially of species-rich tropical and subtropical forests – is the single most important action required to reverse the global biodiversity crisis on land. Through managing forests for their productive benefits, forests may be retained and expanded, which offers an enormous opportunity for achieving the conservation and sustainable use of biodiversity (Edwards *et al.*, 2019; Harrison *et al.*, 2020). This of course requires that forests are managed sustainably. A crucial role of SFM is to protect forests against degradation, including through encroachment and other illegal activities, and ensure that benefits of forest management are equitably shared, thereby contributing to the maintenance of forest land use. Currently, approximately half of the world's forests are covered by long-term management plans, which indicates the intention to manage forests for long-term purposes. However, the coverage of forest management plans is uneven, with the highest coverage found in the boreal domain (88 percent) decreasing to only 21 percent in the tropics (Shono and Jonsson, 2022). To prevent deforestation and reduce biodiversity loss, as well as to more equitably share the benefits derived from forests, a huge amount more forest needs to be brought under SFM.

Where forests are being managed for timber, including selectively logged forests and plantations, the quality and intensity of management strongly determines their ability to support biodiversity (Brockerhoff *et al.*, 2008; Chaudhary *et al.*, 2016). Well-managed forest can support biodiversity, comparable to that occurring in pristine forests, and underpin valuable ecosystem services (Gibson *et al.*, 2011; Edwards *et al.*, 2014b; Brockerhoff *et al.*, 2017). In this section, we consider the policy instruments that governments can employ to enhance biodiversity mainstreaming within the forest sector. For convenience, these are divided into the following categories: spatial planning-based approaches; species-based approaches; regulatory instruments; economic instruments; marked-based instruments; participatory forest management; and support to knowledge and capacity development (**Table 1**). These are not necessarily distinct and mutually exclusive categories, but the approaches and tools work together at various levels to guide and support actions to mainstream biodiversity in forest management.

TABLE 1.
Instruments for biodiversity mainstreaming in forest management

Mainstreaming instruments	Enabling conditions
Spatial planning-based approaches	
Designation of other effective area-based conservation measures (OECMs) or partial use reserves (e.g. IUCN Categories V and VI)	There is a viable business case for protection Conservation objectives can be met while maintaining other forest uses Forest users, including Indigenous Peoples and local communities, support the designation and management plans Funds and capacity exist for monitoring and enforcement
Designation of small-scale protected habitats (e.g. IUCN Categories III and IV)	Knowledge concerning the nationwide distribution of threatened habitats exists Opportunity costs are limited and/or landowners/users can be compensated Agencies responsible for implementation have enforcement authority Funds and capacity exist for monitoring and enforcement
Species-based approaches	
Species management: protected species; invasive species; overabundant species; and harvested species	Knowledge concerning species abundance, distribution, ecology and intraspecific genetic variation exists Protected status is based on threat status (including threats to genetic diversity) and protection extends to critical resources, such as nest or feeding sites and habitats Regulations and/or guidelines for the control of invasive species and overabundant species are current, evidence-based and fit for task Agencies responsible for implementation have enforcement authority Funds and capacity exist for monitoring and enforcement
Regulatory instruments	
Permits/licenses requiring sustainable forest management	Government has legitimacy to assign user rights (and that conflicts with Indigenous Peoples and local communities do not exist or can be managed) National standards and guidelines for SFM, including provisions for biodiversity, are available Capacity exists in the private sector to implement SFM, including the development and implementation of forest management plans with quality biodiversity provisions Forest agencies, including where appropriate at local level, have capacity to monitor implementation and effectively deal with non-compliance
Conservation concessions and permit retirements	Forest manager has legal tenure or user rights to trade ecosystem services, and provisions for concession do not conflict with other user rights (e.g. Indigenous Peoples) Funds exist to compensate forest managers for non-extractive use of forests Government support and strong legal environment exist to enforce contracts

Harvest quotas and permits for extraction of non-wood forest products (NWFPs)	Quotas can be set according to evidence of sustainable harvest limits Forest agencies can monitor harvesting and track consignments from forest to market Forest agencies, alone or in collaboration with other agencies, can take enforcement action against illegally harvested forest products along the market chain System for administering permits is efficient, transparent and accessible to users, and fees are proportional to the value of the resource
Environmental impact assessments (EIAs)	Laws and regulations pertaining to EIAs are clear and enforceable System for preparation and review of EIAs (e.g. public consultation) is transparent and the ministry responsible for EIAs has the capacity to oversee their implementation
Economic instruments	
Taxes (tax breaks), permit and license fees, and subsidies through which economic incentives are provided for improved biodiversity outcomes	Economic incentives are sufficient to foster improved management for biodiversity outcomes Incentives are clearly linked to specific management actions or biodiversity outcomes that can be monitored Capacity exists to implement and monitor the system Compliance failures result in timely suspension of permits, licenses or economic breaks
Removal of perverse incentives	National and sub-national development planning are aligned across sectors Environmental ministry (or forest agency) has support for the removal of perverse incentives from other sectors
Biodiversity offsets	Quality information exists concerning the relative value of biodiversity, enabling calculation of offset costs in a transparent manner Robust system for making payments for offsetting and for selling biodiversity credits is in place (e.g. biodiversity banks) Strong legal environment exists to enable enforcement of contracts
Market-based instruments	
Payments for ecosystem services (PES) schemes	Quality information exists concerning the value of ecosystem services at national and local scales (e.g. national natural capital accounting system) Mechanisms exist to facilitate set up of PES schemes involving diverse stakeholders, such as public–private partnerships Fiscal transfers are made in a transparent and equitable manner, so that those bearing the opportunity costs benefit from the payments Risks can be managed and mitigated to ensure permanency Strong legal environment exists to enable enforcement of contracts
Forest certification for SFM	Quality national standards and guidelines for SFM that include provisions for biodiversity are available Capacity exists in the private sector to implement and monitor SFM, including development and implementation of forest management plans and biodiversity provisions There are sufficient incentives for obtaining and maintaining certification Producers (or producing countries) are able to ensure legality of forest products supported by good forest governance and adequate institutional capacity

Participatory forest management	
Community-based forest management	Community interests are aligned with improved forest management, and specifically improved biodiversity management
	Legal tenure or forest use rights are guaranteed through a license or other legal provisions
	Capacity to support, implement and monitor community-based forest management exists among forest agency staff, local government, NGOs and local communities
	There is sufficient social capacity among local communities to ensure permanency and to develop forest enterprises
	Robust systems exist for monitoring compliance and enforcing SFM provisions, especially with respect to biodiversity
Support to knowledge and capacity development	
Investment in research and training for biodiversity	Universities and colleges have existing courses on biodiversity and forestry, or these can be developed
	There is sufficient demand for knowledge, information and training for biodiversity
	Funds are available for capacity building, research, and development of tools for biodiversity

Source: Authors' own elaboration

4.2. SPATIAL PLANNING-BASED APPROACHES

Large-scale land use planning is a critical tool for implementing government policy on biodiversity. By explicitly acknowledging trade-offs in outcomes for different land use objectives, such as production of food, energy, raw materials and ecosystem service provisioning, multiple objectives can be met through a well-considered spatial plan. Considering biodiversity objectives in spatial planning can greatly enhance biodiversity outcomes and is a commitment under the CBD (OECD, 2018). Large-scale spatial planning must also consider the effects of other sectors, especially agriculture and infrastructure, on forest biodiversity.

Multiple-use protected areas

Due to the bias in the location of protected areas on remote sites with less competition for other land uses, many ecosystems, such as lowland rainforest, are under-represented in protected area networks. Hence, improving biodiversity outcomes will necessitate increasing the protection of under-represented habitats and ecosystems. However, because of high levels of human occupancy and activity, scope for designating additional large-scale strictly protected areas (i.e. IUCN categories I and II) is often limited.

Where high biodiversity values and demands for productive use overlap over large areas, using other types of designation, such as other effective area-based conservation measures (OECMs)[16] or limited use protected areas (e.g. IUCN categories V or VI) is a possible solution (Maxwell *et al.*, 2020) (**Table 1**). Under these designations, productive activities are governed by stricter controls than

[16] Defined as “a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socioeconomic, and other locally relevant values”. CBD/COP/DEC/14/8 dated 30 November 2018.

would apply elsewhere but are permitted so long as they do not compromise the objectives of the designation. This enables biodiversity objectives to be explicitly incorporated into local planning and administration, and drivers of biodiversity loss can be controlled (e.g. through issuing of licenses).

Multiple-use buffer zones can also improve the effectiveness of protected areas by allowing productive activities to take place in the surrounding landscape. For example, in Zambia, extensive game management areas, amounting to 167 000 km^2 or 2.5 times the area under strict protection, have been established as buffer zones around national parks where activities such as tourism, hunting and sustainable wildlife management are practised (Bwalya Umar and Kapembwa, 2020; Mkanda, Mwakifwamba and Simpamba, 2014).

The first draft of the post-2020 global biodiversity framework[17] proposed a target of conserving 30 percent (up from the current 17 percent) of the global land area through protected areas and OECMs. Given the aforementioned constraints on expanding strictly protected areas, countries are likely to emphasize increases in OECMs, and a significant part of global land area covered in natural forests could potentially qualify. An important distinction of OECMs from strictly protected areas is that an area may qualify as an OECM if it achieves the stipulated biodiversity outcomes, regardless of who manages the land and for what other purposes. Indigenous territories, communal land, state- or privately-owned forests may all qualify, provided that management achieves the desired biodiversity outcomes, such as preventing deforestation and protecting endangered species. Thus, OECMs present a valuable opportunity to mainstream forest biodiversity conservation among other land use objectives.

Four criteria are used in screening eligibility as an OECM: 1) area is not currently recognized as a protected area; 2) area is governed and managed; 3) area achieves sustained and effective contribution to *in situ* conservation of biodiversity; and 4) area has associated ecosystem functions and services and cultural, spiritual, socioeconomic and other locally relevant values (IUCN-WCPA, 2019). Some types of forest management may require little change to qualify as an OECM, aside from adopting biodiversity conservation objectives and enabling monitoring of outcomes. For example, it has been well documented that indigenous management often leads to better biodiversity outcomes, in particular through reduced deforestation (Garnett *et al.*, 2018; Fa *et al.*, 2020; Sze *et al.*, 2022). In some cultural landscapes, certain traditional activities may even be required to maintain the character and biodiversity of the area, for example, grazing in parklands (Garnett *et al.*, 2018). In such situations, designation of an OECM could provide the Indigenous community with better recognition of their rights as forest managers and provide an entry point for a dialogue with the community over biodiversity conservation objectives.

Natural forests that are being sustainably managed for economic benefits, including timber, may also qualify as OECMs, so long as the four screening criteria are met. However, forests that are managed for large-scale timber

[17] www.cbd.int/doc/c/abb5/591f/2e46096d3f0330b08ce87a45/wg2020-03-03-en.pdf

production, even though these forests may have significant conservation values, are unlikely to qualify as OECMs as environmentally damaging industrial activities are not allowed (IUCN-WCPA, 2019). However, given the diversity of contexts in which the concept of OECM may be applied, each case needs to be assessed carefully and separately, and there may well be exceptions to this general understanding. Nonetheless, it is worth stressing that in most cases, qualifying for OECM will require a step-up in the quality of biodiversity management in forests, for example, to improve the protection of endangered species.

In addition to increasing the total land area under protection and improving the representation of poorly covered ecosystems in a protected area network, these multiple-use protected areas provide a tool for achieving connectivity across multi-use landscapes with appropriate spatial planning at national and regional scales.

Protecting threatened habitats

Increasing strict protection at finer spatial scales through small reserves or protected habitat legislation (e.g. IUCN Categories III and IV) can be effective if the opportunity costs are small (or land managers can be compensated) and information pertaining to threatened habitats is readily available (Volenec and Dobson, 2020). These may include relatively small sites with prominent natural features (e.g. caves, cliffs, ancient groves, among others), as well as fragments of natural ecosystems that require active management to ensure the survival of specific habitats or species.

Fine-scale protected habitat legislation could be an effective way of defining set-aside areas within forests managed for production. However, it requires that private landowners, forestry corporations and communities respect land use restrictions on designated sites, and that there is capacity for monitoring and enforcement.

Ecosystem service provisioning

Large-scale spatial planning can also identify where forests should be managed or restored to optimize the provision of ecosystem services (Chazdon, 2008; Edwards *et al.*, 2021a). Water regulation is the most common ecosystem service incorporated into such spatial planning processes. Forests regulate water quantity, quality and timing and provide protective functions. The quantity of water flowing from a forest is determined by the amount of precipitation minus evapotranspiration and water stored in the soil (FAO, 2021). Thus, establishing forests in areas with marginal precipitation may reduce stream flows below critical thresholds. However, over larger scales, evapotranspiration from forests falls elsewhere as rain, supporting agriculture and other activities (Creed *et al.*, 2019), and potentially justifying the maintenance or restoration of forests for water.

Many urban administrations have found that protecting, or regrowing, watershed forests to protect and enhance urban water supplies is more cost effective than installing water treatment infrastructure (Postel and Thompson, 2005). Watershed forests may also be critical for the provision of water for irrigated agriculture and other high value uses (Larsen, 2017; Creed *et al.*, 2019).

A clean stream running through a forested watershed

For example, when the Panama Canal was expanded it was found that forest restoration in the canal watershed would be required to enable operation of the canal through the dry season (Larsen, 2017). Moreover, it was noted that exotic, monoculture teak plantations transpired more water than native forests and did not provide the desired water infiltration into deep soil layers, necessitating the restoration of plantations with native species (Marshall *et al.*, 2021). In addition to water regulation, spatial planning for ecosystem services provisioning should also consider other forest functions, such as enhancing pollination of agricultural crops, providing recreational opportunities, and mitigating natural disasters.

Large-scale spatial planning needs to recognize the connections and trade-offs among the ecosystem services, as well as risks and benefits to human well-being. It should also be noted that such trade-offs may occur across different temporal and spatial scales, with the benefits of simplifying ecosystems providing short-term local benefits, while the costs may be incurred in other locations or by future generations (Cardinale *et al.*, 2012). Where forests are managed or restored primarily for providing ecosystem services, options exist for establishing payments for ecosystem services (PES) schemes.

Increasing forest cover through restoration

Forest restoration has become a national priority in many countries along with the global restoration movement. Increasing forest cover through restoration and managing these forests, following best SFM practices, can contribute to economic productivity goals and simultaneously enhance biodiversity outcomes. **Chapter 7** provides a detailed discussion on this topic.

A community-managed forest plantation established on denuded land in India supplies timber and other ecosystem services.

Land sparing versus land sharing

An ongoing debate in conservation circles contrasts the merits of land sparing versus land sharing strategies (Perfecto and Vandermeer, 2010; Fischer *et al.*, 2008; Phalan *et al.*, 2011). Land sparing involves increasing land-use intensity in some areas, so that land elsewhere can be freed up for biodiversity conservation. On the other hand, land sharing advocates for enhancing biodiversity conservation in productive landscapes.

Most studies and models focused on agricultural landscapes find that sparing is the optimal strategy. For example, in the Colombian Choco-Andes, intensification of cattle grazing is predicted to drive abandonment and natural forest regeneration on marginal pastures, which for the same level of productivity has better biodiversity outcomes than retaining wildlife-friendly habitat on cattle ranches (Edwards *et al.*, 2021b). Moreover, Gilroy *et al.* (2014a) reported that the benefits of sharing increased closer to forests, while sparing outcomes were independent of distance to forest.

Nonetheless, some critics of the land sparing approach point out that sparing is unlikely to actually occur in many situations (e.g. Angelsen, 2010), and agricultural intensification could escalate future conservation costs as agricultural rents increase (Phelps *et al.*, 2013). In Zambia, agricultural intensification through the use of improved maize seed varieties on fertile soils led to reduced deforestation, but increased inorganic fertilizer use did not have significant correlation with deforestation (Pelletier *et al.*, 2020). Thus, the outcomes of agricultural intensification on land sparing were dependent on the intensification technology used. Meanwhile, research in Kalimantan, Indonesia found that better land-use allocation outperformed both land sparing and sharing approaches in delivering multiple ecosystem services including biodiversity (Law *et al.*, 2015). It is also important to recognize that in some circumstances both agricultural productivity and biodiversity values can be increased on the same unit of land through agroecological approaches (Sinclair *et al.*, 2019), such as agroforestry and diverse mixed plantations.

Studies considering the sparing–sharing trade-offs in a forestry context are not so common (Betts *et al.*, 2021). Looking at birds, dung beetles and ants within selective logging concessions in Borneo, it was found that a sparing strategy (i.e. more intensive logging in some areas to allow more set-aside) maintained higher overall species richness (Edwards *et al.*, 2014a). However, research contrasting large-scale conservation planning strategies in Kalimantan, Indonesia found that much greater gains could be achieved through improved forest management – in both protected areas and selective logging concessions – than through optimizing sparing vs sharing approaches (Runting *et al.*, 2019).

Furthermore, it is critical to examine the scale of intervention when considering land sparing vs land sharing. For instance, a large forest plantation of exotic species may endanger endemic species, local genotypes, and unique community associations, and have major impacts on wide-scale ecosystem functioning, such as hydrology (Veldman *et al.*, 2015). Whereas, the same total area of smaller plantations, interspersed with natural forest and other land uses, may not have the same negative impacts on biodiversity (see **Box 5**).

Native forest, tea plantation and Eucalyptus *forest plantation representing intensive and extensive land uses*

4.3. SPECIES-BASED APPROACHES

Strategies for species management play an important role in supporting sustainable use and conservation of biodiversity. They enable governments, often in partnership with NGOs and civil society organizations, to harmonize efforts across sectors and levels of government to manage species that are strongly influenced by human activities.

These include:

- species threatened by human activities, especially those that occur at low densities naturally or are wide ranging, and therefore require protection over large areas;
- migratory species, as provisions need to be put in place to provide habitat and critical resources at all points along the migration path;
- species causing human–wildlife conflict through crop raiding or direct harm to humans;
- invasive species;
- overabundant native species; and
- harvested species.

Having national strategies on species and genetic resource management (Kettle *et al.*, 2020), with appropriate supporting legislation covering each of these categories, sets clear objectives for authorities and should facilitate cross-sectoral cooperation. Biodiversity conservation in forests intersects with all of these categories of species. Hence, it is important that forest sector policies support, and forest management planning and implementation reflect, national species management strategies.

Threatened species

Rare and threatened species often require cross-sectoral management, because they exist at low densities or move over large areas and use distinct types of habitats to access critical resources. For example, many large waders feed in wetlands, but roost and nest in large trees. Some hornbills roost communally in large numbers in a small patch of forest, but disperse widely each day (Chew and Supari, 2000). Cave roosting bats may travel tens of kilometres every night while feeding. Many of the large predators, such as tigers, bears and wolves, need huge areas to supply their energy needs (Clancy *et al.*, 2020). Hence, in the absence of vast protected areas, such species need to move across productive landscapes including forests and agricultural land. Moreover, studies indicate that protected area coverage is unbalanced and insufficient to ensure long-term survival of many species, requiring that management of threatened species extends into productive landscapes (Clancy *et al.*, 2020; Kearney *et al.*, 2020; Loiseau *et al.*, 2020). At a national level, species-specific strategies will often be required to support the conservation of rare and threatened species. At a minimum, national protected species legislation should be enforced throughout the national territory and not only within protected areas.

*Asian elephant (*Elephas maximus*), a species listed as Endangered on the IUCN Red List, feeding in a degraded peat swamp habitat, Indonesia*

To support the conservation of these species, forest sector planning and forest management must dovetail with the specific national strategies for threatened species. Often this will entail identifying and protecting the critical forest resources they need (e.g. roosting or feeding sites) and ensuring that forests contribute to landscape connectivity in order to facilitate large-scale movement (Senior, Hill and Edwards, 2019). In the case of threatened plants or other sedentary species that live entirely within forests, the specific habitat and resources supporting these species should be identified and secured.

Migratory species

Migration is defined as the regular seasonal movement of an animal population. Species migrate over variable distances, with some species covering tens of thousands of kilometres between breeding sites and over-wintering sites. Most of the long-distance migrants are birds but also include bats, butterflies, fish, reptiles and mammals. Other species may migrate over much shorter distances, using different components of the same landscape during different seasons, such as grazing herds following the flush of new grass or amphibians with strong breeding-site philopatry[18].

The Ramsar Convention[19] specifically addresses the protection of wetland sites used by migrating wetland species. However, many shorebirds, raptors and woodland birds also migrate from temperate northern hemisphere breeding sites to subtropical and tropical overwintering sites. Conservation of these species requires identifying and protecting habitat and resources in both breeding and

[18] Philopatry is the tendency of an animal to remain in or return to the area of its birth.
[19] www.ramsar.org

A wetland in Burkina Faso serving as an important feeding ground for migratory birds

overwintering ranges, as well as at critical stopover sites (Horns and Şekercioğlu, 2018; Schuster *et al.*, 2019). Declines in migratory birds have been linked to intensification of land use in breeding sites, degradation of overwintering sites and threats due to infrastructure development, as well as hunting along migration routes (Kirby *et al.*, 2008). For example, many migrating shorebirds are threatened by coastal development at stopover sites (Murray and Fuller, 2015; Mu and Wilcove, 2020). Degradation of forest habitat at overwintering sites in Mexico is driving declines in monarch butterflies (*Danaus plexippus*), along with reductions in larval food plants in the United States of America (Brower *et al.*, 2012; Wilcox *et al.*, 2019). As with the protection of threatened species, forest management should dovetail with national strategies for migratory species and, specifically, protect critical resources used by migratory species. In addition to protecting critical habitats, this may entail managing operations to avoid disturbing species when they are in residence, for example by temporarily restricting activities such as recreation, hunting or timber harvesting. As with threatened species, it is critical that legal provisions for protection of migratory species extend to the entire national territory, not just protected areas.

Human–wildlife conflict

Managing human–wildlife conflict is a thorny issue that often pits the interests of biodiversity conservation against those of local communities, who must bear the direct impact. For example, in Zambia, a combination of low economic benefits for local communities and human–wildlife conflict reduces local support for conservation in game management areas (e.g. Bwalya Umar and Kapembwa, 2020). Instances of human–wildlife conflict include crop raiding, livestock depredation, property damage, and human injury or death (Distefano, 2005; Karanth, Gupta and Vanamamalai, 2018; Long *et al.*, 2020). If the animals in question are not threatened in terms of their conservation status, then these animals can be removed or culled. However, where the species in question are threatened, such as in the case of elephants and large carnivores, solutions are more elusive (Distefano, 2005).

Nevertheless, forest management can play a key role in species management strategies depending on the type of damage caused and which animals are responsible. Collecting quality data at a national level on the incidence of human–wildlife conflict and assessing the effectiveness of measures is essential (Distefano, 2005; Long *et al.*, 2020).

Potential measures to reduce human–wildlife conflicts include: the use of barriers (e.g. electric fences or ditches) or buffers of unattractive habitat (e.g. plantation forests); allowing limited culling to deter further raiding; planting unattractive crops close to the forest; compensation systems for damage caused by wildlife; community-based natural resource management schemes; and incentive and insurance programmes (Distefano, 2005). Beehive fences are an innovative solution for deterring crop raiding by elephants, while simultaneously providing economic benefits to communities, and have been deployed in both Africa and Asia (King *et al*., 2017; van de Water *et al*., 2020). With regards to compensation schemes, there is considerable debate over their effectiveness. Schemes are often plagued by high transaction costs, low levels of compensation and inconsistent qualification criteria (Karanth, Gupta and Vanamamalai, 2018). Clear national level policies developed through broad stakeholder consultation and with a focus on community-led solutions are essential (Karanth, Gupta and Vanamamalai, 2018).

Invasive alien species

Invasive species are species that are non-native to a particular ecosystem and whose introduction causes, or is likely to cause, sociocultural, economic and/or environmental harm, or harm to human health. In new environments, such species may not have natural enemies that normally keep populations in balance, and their new host trees may have insufficient or no resistance to them. Therefore, invasive species can have devastating consequences for forests and their products and services.

Many forests worldwide are subject to severe outbreaks of invasive species, resulting in detrimental impacts on biodiversity, human health and ecosystem services (IPBES, 2019). Globally, it is estimated that the economic cost of invasive species, which includes production losses to crops, pastures and forests, as well as environmental damage and control costs, has amounted to USD 1.288 trillion over the past 50 years (Zenni *et al*., 2021). Forest pests such as the fungus Dutch elm disease (*Ophiostoma ulmi* and *Ophiostoma novo-ulmi*) and the emerald ash borer (*Agrilus planipennis*), an exotic beetle, have devastated vast areas of forest and transformed native tree communities (Webber, 2019; Klooster *et al.*, 2018). Invasive alien species are one of the main causes of global biodiversity loss, and the relative impact is increasing across all forest biomes intensified by climate change, habitat destruction and pollution (CBD, undated).

Managing invasive species and avoiding new introductions of species with known potential to become invasive require coordinated efforts by many actors, nationally, regionally and globally (FAO and UNEP, 2020). As such, management of invasive species usually falls into two modes of action: (i) interception at points of entry; and (ii) eradication or control of species that have escaped. The best approach to controlling an established invasive may be to create an economic harvest around the species, including for biomass and biochar production. As an example, the Japanese case study describes efforts to control bamboos by promoting new ways of using them (see Supplementary material).

It is important to note that only a small proportion of exotic species are invasive and a threat to native ecosystems. High quality evidence-based national strategies – backed with adequate investment in capacity and financial support for implementation – are essential. Moreover, there is good evidence to suggest that intact ecosystems are more resilient to invasion than disturbed forests or other degraded habitats (e.g. Teo *et al.*, 2003). This underscores the importance of maintaining the ecological integrity of forests through sustainable management to keep invasive species under control.

Overabundant species

As a consequence of human modification of the environment, some native species have become overly abundant causing severe damage as a result. Where large predators have been eliminated, or are functionally extinct, prey populations may increase dramatically causing damage to vegetation (Harrison, 2015). In various places, deer, wild goats and wild pigs have become overabundant. Browsing by deer and goats kills young trees, thus preventing forest regeneration, while in extreme situations they may damage the forest understorey leading to severe soil erosion (Martin, Chamaillé-Jammes and Waller, 2020; Côté *et al.*, 2004). Wild pigs feed on seeds and invertebrates in the surface soil, and can heavily disturb the understorey (Fujinuma and Harrison, 2012). Moreover, wild pigs cut seedlings for birthing nests which can alter forest regeneration dynamics (Luskin *et al.*, 2021). As a result, these overabundant species negatively impact forest biodiversity through the damage they cause, and by preventing forest regeneration, can nullify restoration efforts. These species are also likely to cause damage to crops in nearby agricultural lands.

Management of overabundant species usually involves fencing or culling. From a biodiversity conservation perspective, reintroducing large predators would often be the best and the most economical solution, but for social reasons such an approach may not always be possible (Martin, Chamaillé-Jammes and Waller, 2020). However, public opinion in many countries is changing and movements for rewilding may offer opportunities to address these problems through reintroduction of predators in the long term (Perino *et al.*, 2019).

Harvested species

Direct harvesting of species, whether for timber, NWFPs, meat or the wildlife trade, can have significant negative impacts on populations (Ticktin, 2004; Shackleton, Ticktin and Cunningham, 2018; Grogan *et al.*, 2010), including through the erosion of genetic diversity (Thomas *et al.*, 2014; Chiriboga-Arroyo *et al.*, 2021).

Logging or timber harvesting is the second most significant threat to trees of the world after habitat destruction, impacting over 7 400 tree species (BGCI, 2021). Threats to timber species from natural forest harvesting applies particularly to tropical hardwoods. Many tropical timber species are rare as a result of high species diversity, making sustainable harvesting challenging (Schulze *et al.*, 2008). For instance, in South America overharvesting of big-leaf mahogany (*Swietenia macrophylla*) has led to population declines, eroding a valuable renewable resource (Grogan *et al.*, 2010). Other highly sought-after timber species that are threatened include rosewood (*Dalbergia* spp.), of which 76 species are threatened, and *Diospyros* that include 164 threatened species. In Borneo, of the 162 species of Dipterocarps (which comprise the most important commercial timber species in Southeast Asia) assessed, 99 species are threatened with extinction, including 18 species assessed as Critically Endangered (Bartholomew *et al.*, 2021).

Overharvesting of animals for bushmeat, the pet trade and medicines is a ubiquitous problem throughout tropical and subtropical forests. Recent research has shown that wildlife populations are depressed in areas within 102 hours (about 4.5 days) of travel time from the nearest settlement, meaning that few tropical forests remain in pristine condition (Morton *et al.*, 2021). In temperate countries,

Wild orchid in an undisturbed tropical lower montane forest

*A sapele tree (*Entandrophragma cylindricum*), listed as Vulnerable on the IUCN Red List, being harvested in the Democratic Republic of the Congo*

mass rearing and release of game birds, such as ducks and pheasants, for sport hunting is also an under-appreciated issue (Harrison, 2015). The massive increase in docile prey populations likely has a very disruptive effect on ecosystems, but it is a poorly researched topic.

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora)[20] controls the trade of endangered species, but it only entails regulation of international trade of these species. At a national level, countries may put in place regulations to control harvesting of species, for example by requiring special permits for certain valuable timber species. Likewise, harvest of some non-timber plants, such as orchids, palms and other popular horticultural species, may be controlled by permit systems. In most countries, hunting of specified game species is controlled by permits (Harrison, 2015), although Indigenous Peoples may have permit exemptions for some species, often under the condition that species are harvested for subsistence purposes only. A substantial improvement in the governance of harvested species in forests is required to ensure sustainability and to protect threatened species. This will require greater determination by governments to improve and enforce legislation.

Forest managers can also assume greater responsibility for promoting better governance of forest resources, including for NWFPs. For example, NWFP harvesting can be negotiated with the local forest users so that resources are sustainably and equitably managed, while opportunities for enhancing production through agroforestry can likewise be explored (Schulze *et al.*, 2008). It is often

[20] https://cites.org/eng

assumed that traditional harvesting of NWFPs is sustainable, or at least that it is not the business of the forest manager to intervene. However, novel markets or improved market access can trigger over-exploitation of NWFPs. For instance, throughout Southeast Asia, rattans – climbing palms that are harvested to make furniture – are now extremely rare wherever there is road access (Meijaard *et al.*, 2014). Therefore, sustainable levels and methods of harvesting should be determined based on best available science and revised through monitoring (Schulze *et al.*, 2008).

4.4. REGULATORY INSTRUMENTS

Permits and licenses mandating sustainable forest management

In most countries, governments use concession licenses, cutting quotas and other forms of permits to regulate the use of forest resources. The granting of these licenses and permits are often preconditioned on demonstration of intent or evidence of SFM, based on relevant government regulations. For example, some countries mandate that logging concessions are audited and certified under national or international forest management standards in order to maintain logging permits. Governments can also require the development of a forest management plan, which is reviewed and approved by authorities, based on which harvesting and other activities are implemented. Furthermore, governments can issue harvesting permits based on the sustainable volume of harvest, calculated using national forest inventory data and growth modelling. In other cases, issuing transport permits serves to prevent illegal harvesting and trade of forest products.

Informal, unregulated logging often results in forest degradation and loss of state revenue but may provide local employment

Challenges in using regulatory instruments to ensure conservation of forest biodiversity include: poor governance and corruption; issuing licenses that create conflicts with customary forest users; insufficient capacity or interest among the private-sector forest managers to implement SFM including biodiversity provisions; and inadequate capacity and resources in the forestry agencies to monitor implementation and effectively deal with non-compliance of SFM-related provisions.

Conservation concessions and permit retirements

Conservation concessions are similar to logging concessions but, as the name suggests, are dedicated to biodiversity conservation (Wolman, 2004). Usually, a conservation NGO pays the concessionaire to compensate for avoided logging. In Indonesia, an ecosystem restoration concession scheme has been introduced to restore selectively logged forests that have been depleted of commercial timber and subsequently been abandoned. Under this scheme, restoration concession licenses of 60–100 years are awarded, which allows for activities such as restoration, ecotourism, conservation, watershed protection, and management of NWFPs. Ecosystem services and NWFPs can be marketed to generate revenue to fund restoration activities, but timber harvesting would only be permitted once commercial timber stocks have recovered. Although a spectrum of potential revenue sources exists, donor and charitable funds cover the bulk of operating costs for most of these restoration concessions currently (Harrison *et al.,* 2020).

Permit retirements are similar but involve the permanent retirement of logging licenses, and therefore require government involvement (Wolman, 2004).

Harvest quotas and permits for extraction of NWFPs

Although NWFPs contribute significantly to local and regional economies, and people have benefited from a wide variety of NWFPs for many generations, harvesting of NWFPs is generally much less regulated than that of timber resources. Governments can, and some do, assign harvest quotas and permits for extraction of NWFPs, such as bushmeat. Quotas can be set according to evidence of sustainable harvest limits, ensuring that the biodiversity represented in NWFPs are conserved *in situ*. For such a permitting mechanism to function, the system for administering permits must be efficient, transparent and accessible to users, and fees should be proportional to the value of the resource.

There are significant challenges associated with the regulation of NWFP harvesting, including the difficulty in monitoring harvesting and tracking consignments from forest to market, as NWFP collection often occurs in remote areas and at small scales. Forest agencies, alone or in collaboration with other agencies, must have the authority and sufficient resources to enable enforcement actions against illegally harvested forest products along the market chain.

Environmental impact assessments

Environmental impact assessment (EIA) is a well-established mechanism for assessing, managing and mitigating the potential environmental impacts of development activities, including on biodiversity. Most countries operate a system that requires various levels of EIA according to the scale of potential impacts. Thus, a new hydroelectric dam may require a comprehensive EIA, whereas forest harvesting may only require a short environmental impact statement. Some countries mandate EIAs for forest management activities, such as clearfelling or establishing a plantation, usually based on area criteria. EIAs thus provide a means for local government and the responsible ministry (usually the environmental ministry or equivalent) to: review proposed large-scale forestry activities; check that they comply with development and large-scale spatial planning objectives; and ensure that mitigation measures and management comply with best practice. The EIA process usually also provides for public consultation. Where EIA regulations are well implemented, they can provide a further check on the quality of forest management and compliance with national policies on the environment and biodiversity.

4.5. ECONOMIC INSTRUMENTS

Tax breaks, grants and subsidies

National governments usually collect land taxes and business taxes, which can be leveraged to improve SFM and biodiversity outcomes (Matta, 2015). Forest owners and forest managers can be awarded tax breaks for compliance with specific management objectives, such as the production of an approved forest management plan, forest certification or establishment of set-aside areas. Similarly, permit and license fees may be conditional on performance. Licenses can be revoked or renewed, and the fees graduated according to whether specific biodiversity objectives are met.

Many countries support the forest sector through subsidies, national forest funds and pension schemes. These constitute major investments by national governments in the forest sector and, as with taxes, can be leveraged to achieve specific forest management and biodiversity outcomes (Matta, 2015). For example, subsidies can be given to forest owners for complying with specific management criteria that aim to improve biodiversity outcomes, such as the use of native and mixed species in forest plantations or increased rotation length (Brockerhoff *et al.*, 2017). Or they can compensate forest managers for establishing set-aside areas (Sarkki *et al.*, 2016). Subsidies can also be used to lower the entry barriers for PES schemes or forest certification. Outcomes are likely to be improved if: fund objectives are aligned with national forest and biodiversity strategies and well-publicized; the funds are sustainably financed; governance is transparent; and there is appropriate oversight (Matta, 2015).

Grants are another economic instrument that can be used to incentivize forest owners or managers to modify their management objectives for improved

Conversion of biologically diverse native forest to crop plantations may be supported by agricultural subsidies and national development strategies

biodiversity outcomes. Examples from the case studies include: Forest Biodiversity Programme for Southern Finland (METSO); Scotland's system of woodland grants; and Japan's implementation of environmental taxes linked to support for local forest management (see Supplementary material).

Removal of perverse incentives

Current agricultural support policies play a significant role in driving deforestation, and perverse incentives are a common issue that undermines biodiversity mainstreaming. For instance, agricultural subsidies may lower the costs of land development, thereby promoting deforestation (Goers, Lawson and Garen, 2012). Alternatively, by subsidizing agricultural inputs, governments may increase the marginal cost of land, undermining restoration initiatives (Abensperg-Traun *et al.*, 2004). Agricultural input subsidies can also lead to overuse of toxic pesticides (Lewis *et al.*, 2016). Repurposing certain types of support and subsidies can lead to ending or reducing these practices that promote deforestation for agricultural expansion (FAO, UNDP and UNEP, 2021).

Within the forest sector, subsidies may promote forest plantation expansion at the expense of natural forests, leading to a substantial loss of biodiversity (Edwards *et al.*, 2021a). As part of national biodiversity mainstreaming, governments should review taxes and subsidies to identify perverse incentives and align incentive structures with the sustainable use and conservation of biodiversity. For example, strategies for increasing timber production through forest plantations should require that plantations are established on degraded land that does not support natural forest. Furthermore, incentives could be put in place for improved

Primary peat swamp forest in Brunei Darussalam conserved as a set-aside by an oil company

management of forest plantations for biodiversity conservation and ecosystem service provisioning (Brockerhoff *et al.*, 2008, 2017).

Biodiversity offsets

Biodiversity offsets are where developers, either voluntarily or as a requirement of no net biodiversity loss[21] regulations, compensate for unavoidable biodiversity loss by protecting, enhancing or creating sufficient habitats elsewhere. In principle, this approach facilitates a pro-development environment that protects or enhances biodiversity. In 2016, the IUCN developed the first global policy on biodiversity offsets (IUCN, 2016). The policy addresses the design, implementation and governance of biodiversity offsets in the context of the mitigation hierarchy (i.e. avoid > mitigate > offset biodiversity loss) and includes consideration of those circumstances where the use of biodiversity offsets might not be appropriate. In 2017, IUCN and The Biodiversity Consultancy[22] launched a global biodiversity offset policy database containing national environmental laws and legislation regarding offsets from 198 countries[23]. Furthermore, the European Union and some other governments have adopted a strategy of no net loss of biodiversity through biodiversity offsetting (Tucker, Quétier and Wende, 2020).

Biodiversity offsets have been criticized by some because they require a substantial investment of human resources for limited biodiversity gains, and

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21 www.iucn.org/sites/dev/files/content/documents/ensuring_no_net_loss_-_bull_et_al_2018.pdf
22 www.thebiodiversityconsultancy.com
23 https://portals.iucn.org/offsetpolicy

may undermine protected area management (Guillet and Semal, 2018). Moreover, scientific evidence is weak that offsetting succeeds in compensating for biodiversity losses, and that which exists suggests performance is poor (Josefsson *et al*., 2021).

Biodiversity offsetting is unlikely to be relevant for forest sector developers. However, biodiversity offsetting could be a means of generating income for expanding and improving protected area management, or for generating funds for forest restoration. For example, in Brazil under the old Forest Code, farmers were required to maintain 20 percent of their land under forest management, but this requirement was largely ignored. When the new Forest Code was negotiated, farmers were given the option of paying to offset restoration, which has generated substantial funds for restoration initiatives (Nunes *et al.*, 2017).

4.6. MARKET-BASED INSTRUMENTS

Payments for ecosystem services

Income generated through PES schemes has been increasing globally over time. REDD+ payments alone could reach USD 30 billion per year for forest-protection activities, including SFM, biodiversity conservation and forest restoration (Edwards *et al.*, 2019). PES schemes, such as the examples of REDD+ from the case studies in the Democratic Republic of the Congo and Mexico, as well as water payments in Malaysia (see Supplementary material), can incentivize national and local governments and communities to support management of forests for ecosystem service benefits. PES mechanisms for watershed protection, whereby urban water users pay for upland forest protection, and for carbon traded on voluntary markets, are well developed. On the other hand, payments for biodiversity remain exploratory (Fripp, 2014) due to difficulties in identifying the buyers or the beneficiaries, as well as challenges associated with monitoring biodiversity and understanding the changes in terms of causes and effects.

There are often positive correlations and overlaps (as well as potential trade-offs in some cases) among the different ecosystem services. Although most PES schemes are focused on the delivery of a single ecosystem service, some schemes have considered multiple or bundled ecosystem services (Kangas and Ollikainen, 2022).

Ensuring that benefits from PES schemes trickle down to the neediest, who are also often those who bear the largest opportunity costs, can be challenging (Burivalova *et al.*, 2019). Inequitable distribution of benefits can undermine environmental outcomes (Samii *et al.*, 2014). A review of 78 studies assessing payments for forest ecosystem services schemes in the Global South found that the availability of capital assets is an important determinant of participation (Jones *et al.*, 2020). However, they also found that non-financial motivations also influenced willingness to participate, indicating that PES schemes should be designed to improve both social and environmental outcomes (Jones *et al.*, 2020).

Among the possible barriers for participating in payments for ecosystem services schemes are high transaction costs (e.g. complexity of application process), lack of access to start-up capital, and insecure land tenure with land title often being an eligibility requirement (OECD, 2018). Hence, governments can encourage the development and expansion of PES schemes by creating an enabling environment and addressing some of these entry barriers. Making high-quality information on the value of forest ecosystem services (e.g. national natural capital accounting) available can also potentially influence decision-makers in governments and businesses.

Commodity certification

Forest certification is a valuable tool to promote and demonstrate responsible forest management, including biodiversity conservation in production forests. Certification provides assurance that the forest manager is following best practices in managing forests that will result in not only stable forest production, but also conservation values (FAO, 2016). International forest certification, mainly under the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC), has grown rapidly over the past two decades, driven by market demand for legal and sustainably produced timber (**Box 2**). Forest management certification requires the development of a forest management plan according to established criteria, third party auditing of implementation, and traceable forest products (i.e. chain of custody certification). In addition to timber, FSC certification can cover forests managed for NWFPs, but this depends on the specific national interpretations of the global standards. FSC has also published *Ecosystem Services Procedure* to provide a framework for FSC-certified forest managers to demonstrate the impact of their activities on the maintenance, conservation, restoration, or enhancement of ecosystem services (FSC, 2018).

Under the FSC, maintenance of biodiversity is ensured through the high conservation value (HCV) approach. In the case of PEFC, the global benchmark standard for SFM requires that measures be taken during forest operations to maintain or improve biological diversity.

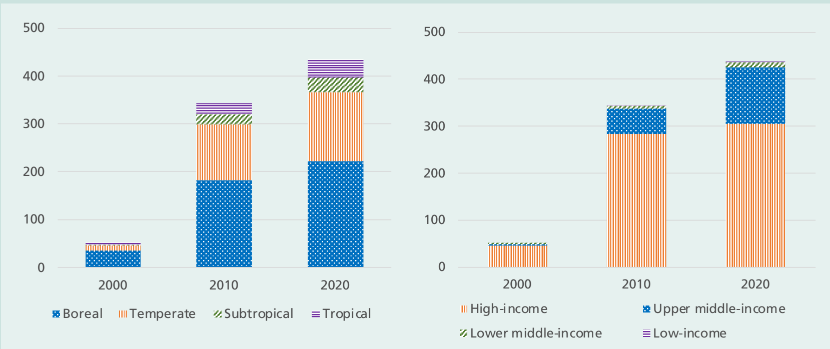
Despite the rapid growth of certified forest areas, forest certification is still heavily biased towards the boreal and temperate domains. The extent of certified forest area in subtropical and tropical domains, where much of forest biodiversity is hosted, remains modest, comprising only 7.1 and 8.9 percent of the total certified area, respectively (Shono and Jonsson, 2022). International forest certification has remained almost irrelevant in low-income tropical countries where such market-based instruments to guide sustainable production could provide the greatest value, while addressing biodiversity conservation. There are several motives for obtaining forest certification, including corporate social responsibility, market access and premium price on certified products. However, in many markets, consumers are unaware of forest certification and what it implies. Hence, one way the governments of purchasing countries can support SFM is to require or incentivize buyers to purchase certified timber.

As consumers, governments – including sub-national and local governments – can use public procurement policies to support forest certification and promote

BOX 2.

Mainstreaming biodiversity through forest certification

Forest certification arose from the environmental movements and international tropical timber boycotts of the 1980s and 1990s, when environmental NGOs decided to work with industry partners to promote SFM. The two main schemes are the Forest Stewardship Council (FSC), supported more by NGOs, and the Programme for Endorsement of Forest Certification (PEFC), which is an industry-backed initiative. Both schemes implement agreed upon principles for SFM with specific criteria and indicators, and require forest managers to practice responsible forest management (McDonald and Lane, 2004; Sheil, Nasi and Johnson, 2004; Linser *et al.*, 2018). While FSC is a global organization with global principles and criteria that are tailored to local conditions through national interpretations, PEFC works by endorsing national or local level standards.



FSC and PEFC certified forest area (in million hectares) in 2000, 2010 and 2020 by climatic domain (left) and income category (right) (Shono and Jonsson, 2022)

There seems little doubt that forest certification has increased awareness on and promoted the implementation of SFM globally. However, how much it has achieved in and of itself is difficult to establish. Implementation of forest management standards should generally lead to better biodiversity outcomes (Gullison, 2003). Nevertheless, despite over 25 years of practice in forest certification, some studies find a weak evidence base for positive impacts (van der Ven and Cashore, 2018). One of the problems is the low level of coverage globally, especially in tropical countries where most of the world's biodiversity resides. Low levels of awareness and regard for forest certification in some important markets undermine the process, especially where certification leads to increased timber prices (or smaller profit margins). In producer countries, a common complaint about certification is the high transaction costs, which can be a barrier to entry, especially for small-scale producers. However, it needs to be highlighted that a large part of these costs reflects the actual cost of SFM. For example, in Romania where strict government regulation and FSC certification run in parallel, 69 percent of FSC's standards requirements are legally assessed. Moreover, 54 percent of identified non-conformities with the FSC standard represented legal violations (Buliga and Nichiforel, 2019).

Forest certification has also enabled leadership for SFM and improved biodiversity management (Karlsson-Vinkhuyzen *et al.*, 2018). FSC through its balanced representation of industry, social and environmental sectors and transparent processes, has been a leader in defining standards and promoting better forest management. Guidance on developing national interpretations and the national interpretations themselves provide a basis for understanding how to implement SFM in the country's context. Moreover, the adoption of the HCV approach has led to the development of protocols and practices for assessing and implementing high quality biodiversity management in forests in many countries.

Source: Authors' own elaboration

these values to the public. Governments can also support the development of national SFM standards and high conservation value guidelines either directly, or through support to research institutes, development organizations and environmental NGOs. Bilateral support through official development assistance (ODA) has been used to establish forest management standards and support implementation in several countries (e.g. Le *et al.*, 2012). National governments can also make forest certification a requirement under certain types of licenses or incentivize participation through offering discounts on license fees. The latter can be justified, because forest certification reduces oversight costs to the government. Indeed, in countries where capacity for SFM is limited, especially in the public sector, leveraging forest certification may be a cost-efficient way to improve forest management and mainstream biodiversity conservation.

Sustainable value chain development and corporate social responsibility funds

Green purchasing refers to the procurement of products and services that have a reduced environmental footprint and less adverse impact on human health compared to competing products and services. Forest products and agricultural commodities can have huge environmental and social impacts depending on how and where the raw materials are sourced and produced. A number of countries and private sector companies have implemented strategies to avoid the purchase of products that are produced illegally and through unsustainable practices, particularly through deforestation.

With regards to forest products, one of the principal factors undermining sustainable and responsible forest management globally is illegal timber harvesting. To address this issue, the Source: Authors' own elaboration has established the FLEGT (Forest Law Enforcement, Governance and Trade) programme[24] under which Voluntary Partnership Agreements (VPAs) are signed with producer countries. Under these agreements, producer countries must guarantee that timber

[24] www.euflegt.efi.int/home

Sawmill in Ghana supported by FLEGT programme preparing legal sawnwood for domestic and international markets

exported to the European Union comes from legal sources. Of the VPA countries, only Indonesia has started issuing FLEGT licenses for verified legal timber products exported to the European Union. Other countries have similar mechanisms such as the Lacey Act[25] in the United States of America and the "*Goho*(=legal)-wood"[26] in Japan to ensure import of forest products made with legally harvested wood.

Corporate social responsibility (CSR) commitments made by companies seeking to mitigate reputational or operational risks can also be leveraged in support of SFM and biodiversity conservation. The example of public–private partnerships to improve the management of rural forests in Japan highlights such opportunities to leverage CSR funding in support of community action for SFM and biodiversity conservation.

4.7. PARTICIPATORY FOREST MANAGEMENT

Equitable sharing of the benefits of biodiversity is one of the central pillars of the CBD. It is important that forest managers recognize the rights of Indigenous Peoples and local communities as their participation in forest management is critical to its success (Gilmour, 2016).

Through the nationalization of forest resources that occurred in many countries, Indigenous Peoples and local communities often lost access to their traditional livelihoods, which were dependent to a large degree on forest resources. Hence, the legitimacy of national forest ownership may be contested, which can lead to uncontrolled exploitation of forest resources (Barr and Sayer, 2012). Indigenous Peoples manage approximately 28 percent of the world's land surface, intersecting with 40 percent of terrestrial protected areas and ecologically intact landscapes, and 37 percent of all remaining natural lands (FAO and FILAC, 2021; Garnett *et al.*, 2018; Fa *et al.*, 2020).

25 www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information/lacey-act/lacey-act
26 www.goho-wood.jp/world

Community elder explaining the location of a sacred forest area

One of the most tried and tested approaches to improving the rights of Indigenous Peoples and local communities, specifically their right to access and benefit from forest resources, is community-based forest management (Gilmour, 2016). Many countries have mechanisms for recognizing customary land use through various forms of participatory forestry, even when legal recognition of rights, such as land tenure, is complicated or impossible. Community-based forest management can be a means to redress historical injustices, contribute to the development of marginalized peoples and improve forest management. Typically, under community-based forest management, resource rights and management are devolved to the community, who develops and implements a forest management plan to make sustainable use of forest resources (Gilmour, 2016). Nevertheless, the state forest authority normally retains an oversight function, approving plans and issuing licenses, and is often also involved in capacity building. Community-based forest management is a means to achieve the dual objectives of increasing equity in access to the benefits derived from forest biodiversity and in bringing more forest under SFM.

In many cases, community-based forest management produces better biodiversity outcomes than direct management by government agencies. Similarly, it has been shown that lands that are traditionally owned, managed, used or occupied by Indigenous Peoples perform better in resisting deforestation compared to unprotected areas (Garnett *et al.*, 2018; Fa *et al.*, 2020; Sze *et al.*, 2022). For example, a meta-analysis of 40 protected areas and 33 community forests across the tropics found on average that community forests had lower and less variable deforestation rates than protected areas (Porter-Bolland *et al.*, 2012). In another case, one year after titling indigenous lands in the Peruvian Amazon, deforestation rates were down 75 percent and forest degradation rates 65 percent lower (Blackman *et al.*, 2017). In Viet Nam and China, land tenure reforms involving the transfer of millions of hectares of public lands from state collectives to households led to increases in forest cover (Gilmour, 2016). In Nepal, 23 percent of forests are managed by 18 000 registered forest user groups, involving 1.6 million households. These community groups are awarded ten-year extendable forest concessions that enable them to use and sell all forest products for their own benefit. The uptake of this form of community-based forest management has been linked to declines in forest loss, increases in forest quality and restoration of forests (Gilmour, 2016).

The benefits of community-based forest management for biodiversity benefits are often paramount. Nonetheless, community forestry can confer benefits for biodiversity conservation by reducing illegal activities and empowering the community to defend their forests against external threats. Further benefits accrue when communities implement SFM and focus on business models that produce better biodiversity outcomes, such as PES schemes and sustainable NWFP enterprises. The case study example from Peru of the palm, aguaje (*Mauritia flexuosa*), shows that commodity-based approaches can also be used to enhance community benefits and biodiversity through improved management.

Demographic pressures, erosion of traditional leadership, new markets and new harvesting technologies can undermine the sustainability of traditional natural resource management. For example, in some areas hunting for bushmeat may have been sustainable over hundreds or thousands of years, but with increased market access and new and more lethal technologies, such as shotguns and wire snares, it is no longer sustainable (Harrison, 2015; Robinson and Bennett, 2000; Morton *et al.*, 2021). Community-based forest management offers an opportunity to blend traditional knowledge with science-based natural resource management to achieve sustainable outcomes.

Despite the enormous potential to provide benefits to both people and biodiversity, community-based forest management can be challenging to implement and remains modest in coverage (Klooster and Masera, 2000). One such challenge is potential conflicts among neighbouring communities over rights to forest resources. In particular, hunter-gatherer communities have often been displaced and marginalized by settled peoples, and may struggle to assert their rights, not least because of their nomadic lifestyle (Matsuura, 2017). Even with adequate regulations in place, community-based forest management requires a high capacity among the institutions supporting the process, including local government, forest agency officials and development NGOs, to negotiate agreements and assist in the development of forest management plans to produce the desired social and environmental outcomes. These processes need commitment over the long term and financial support. In addition, traditional forest uses may not provide sufficient benefits to meet development goals without value-added processing and enterprise development. Business acumen and social capital are required to establish and operate viable community-based forest enterprises. Last, community-based forest management must be underpinned by quality monitoring (Villaseñor *et al.*, 2020). Failure rates of community enterprises are often high after withdrawal of projects, reflecting the fact that it takes time to build social capital (Macqueen, 2013).

4.8. SUPPORT TO KNOWLEDGE AND CAPACITY DEVELOPMENT

Quality biodiversity management requires detailed knowledge concerning biodiversity values, the distribution of biodiversity, species biology, threats, impacts of management interventions, traditional management practices, and so on. Hence, governments can increase capacity for biodiversity management by supporting research and training on biodiversity and forest management. This approach can be achieved through support to tertiary education institutions, including universities and technical colleges. Support can take the form of research grants on biodiversity-related topics and funding for courses at undergraduate and diploma levels, as well as short courses for professional development. It is also essential to provide educational opportunities at local levels, including school courses and field days.

Community workshop to develop a forest management plan in Ghana

Traditional knowledge and values have critical roles to play in biodiversity management and conservation, and governments can establish mechanisms to facilitate their inclusion into educational programmes. Indigenous Peoples have been domesticating plants for at least 10 000 years – and transforming forests through plant cultivation, seed dispersal and propagation, and *in situ* tending of useful resources. This traditional knowledge can contribute to sustainable utilization of biodiversity and ensuring food security, while in addition supporting forest restoration and biodiversity conservation.

5. Barriers and threats to biodiversity mainstreaming

To a large extent, the barriers to biodiversity mainstreaming are the lack of (or inadequate) use of the regulatory, financial, or supporting instruments mentioned above. Nonetheless, we can draw attention to several specific issues.

5.1. DEFORESTATION

Deforestation is the single most important driver of forest biodiversity loss. When a forest is cleared as a process of land conversion, a very substantial proportion of the associated biodiversity is lost with it (Gibson *et al.*, 2011). Thus, measures to mainstream biodiversity conservation within the forest sector must be matched with efforts to reduce and eliminate deforestation. The commitment among national leaders reached at the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow to halt deforestation by 2030 will be critical to stemming global biodiversity loss, as well as contributing to efforts to restrict global warming to less than 1.5 °C. Furthermore, the Abidjan Call adopted at the 15th Session of the Conference of the Parties of the United Nations Convention to Combat Desertification (UNCCD) reaffirmed the commitment of world leaders to combat desertification, halt biodiversity loss and mitigate climate change in an integrated manner[27].

Since 1990, an estimated 420 million ha have been deforested, including over 80 million ha of primary forests, although the deforestation rate has declined from 16 million ha/year in the 1990s to 10 million ha/year from 2015 to 2020 (FAO, 2020a). As protected areas encompass only 18 percent of forests globally (FAO, 2020a), ensuring that forests are retained through management for economic benefits and other ecosystem services will be essential (Edwards *et al.*, 2019; Harrison *et al.*, 2020). Hence, the global focus on promoting SFM as an approach to combat deforestation is well justified. Adequate forest governance is a critical enabling condition for realizing SFM, and improved governance has reliably been shown to contribute to reduced deforestation (Busch and Ferretti-Gallon, 2017; Fischer, Giessen and Günter, 2020).

Large-scale commercial agriculture, primarily for cattle ranching, soybean and palm oil, is responsible for an estimated 40 percent of deforestation (FAO and UNEP, 2020). Therefore, tackling deforestation through ensuring deforestation-free commodity chains is a key strategy for combating deforestation (FAO and UNEP, 2020; Hoang and Kanemoto, 2021; Leijten *et al.*, 2020).

Besides the large-scale commercial agriculture, another 33 percent of

[27] www.unccd.int/sites/default/files/2022-05/COP15_Summit_Abidjan%20call.pdf

deforestation is due to agricultural expansion and fuelwood collection by small-scale farmers (FAO and UNEP, 2020). Hence, programmes for poverty alleviation and alternative livelihoods will also be crucial (e.g. Ferraro and Simorangkir, 2020). In addition, efforts to recognize indigenous and local peoples' rights through tenure reforms, designating OECMs, and upscaling community-based forest management also hold promise for reducing deforestation (Gilmour, 2016).

5.2. ILLEGAL FOREST ACTIVITIES AND CORRUPTION

Illegal timber harvesting is estimated to account for 15–30 percent of global timber production and 50–90 percent of forest harvesting in many tropical countries (INTERPOL, 2019). The illegal trade in timber is valued at USD 51–152 billion annually (INTERPOL, 2019), which amounts to a huge sum in lost tax revenues for lower-income countries and is a major driver of forest degradation and sometimes deforestation. Forests are cleared and degraded illegally not only by companies, but also by small-scale farmers to access resources and claim land rights (FAO, 2020a). These illegal activities and corruption undermine efforts towards SFM by supplying markets with under-priced illegally obtained timber (Santos de Lima *et al.*, 2018) and are a major barrier to biodiversity mainstreaming within the forest sector.

5.3. LOW PROFILE OF CONSERVATION OUTSIDE PROTECTED AREAS

Management of biodiversity outside protected areas is critical in efforts to stem biodiversity losses given the limited and uneven coverage of protected areas. However, many countries struggle to fund protected area management (Coad, Watson and Geldmann, 2019), let alone implement high quality biodiversity conservation outside protected areas. Several of the case studies also noted the lack of attention given to protecting threatened species outside of protected areas, as well as the bias towards animals in protected species legislation. In addition, many decision-makers in government and industry regard biodiversity conservation and development as a trade-off. Hence, they are reluctant to consider biodiversity issues outside protected areas, although protected area performance heavily depends on the management of the wider landscapes within which protected areas are embedded.

Enhancing awareness and capacity for biodiversity and environmental management within line ministries can help mainstream biodiversity in sectoral planning. In addition, implementing national ecosystem service assessments and natural resource accounting may help persuade decision-makers that the sustainable use and conservation of biodiversity is a critical development issue.

5.4. INSUFFICIENT CAPACITY, FINANCING AND REGULATORY OVERSIGHT

Many developing countries struggle to enforce forest and biodiversity regulations because of insufficient capacity, especially at sub-national levels. To address this issue, governments need to implement capacity building through training programmes supported by tertiary education institutions. Monitoring SFM and biodiversity management also requires financial investment over the long term. Where human resource capacity for direct regulatory oversight by governments is limited, government can focus on community-based forest management – where local communities provide much of the oversight – and in leveraging financial instruments such as certification.

5.5. LACK OF INDIGENOUS PEOPLES AND LOCAL COMMUNITY PARTICIPATION

Indigenous Peoples and local communities are often dependent to a large degree on forest resources for their livelihoods (FAO and UNEP, 2020). Although forests under indigenous custody have been shown to produce better biodiversity outcomes and better resist deforestation (Garnett *et al.*, 2018; Fa *et al*., 2020; Sze *et al*., 2022), Indigenous Peoples struggle to defend their lands, forests and resource rights, in addition to suffering persecution, marginalization and other forms of injustice (Gilmour, 2016). Consequently, forest biodiversity is disappearing along with opportunities to learn from traditional practices.

The interests of Indigenous Peoples and local communities are often not given sufficient consideration in national forest policy and in the development of forest management plans. This failure is not only a step backwards for development and poverty alleviation, but also undermines management legitimacy (Barr and

A half-processed log abandoned in the forest by illegal loggers

Sayer, 2012). Attempts to implement measures to promote the sustainable use and conservation of biodiversity under such circumstances are unlikely to succeed. Empowering and engaging Indigenous Peoples and local communities by securing their rights to lands and associated natural resources can contribute to protecting biodiversity, as well as enhancing the equitable sharing of benefits and improving livelihoods (Gilmour, 2016).

A local community practising shifting cultivation in Viet Nam

6. Integrating biodiversity into forest management

Actively managed forests, including those that have been selectively and repeatedly logged, often support significant levels of biodiversity. These managed and often degraded natural forests play a key role in biodiversity conservation acting as corridors and refugees for native biodiversity. Furthermore, these forests continue to provide multiple benefits to a range of stakeholders, including important ecosystem services and support to local livelihoods (Berry *et al.*, 2010).

The condition of selectively logged forest (Burivalova, Sekercioğlu and Koh, 2014) or secondary forests regrowing on abandoned agricultural land (Chazdon, 2014) varies tremendously, as do forest recovery rates (Cook-Patton *et al.*, 2020). Where best practices in forest harvesting have been followed, forests not only retain more biodiversity, but recover more quickly restoring productive values and ecosystem services. Conversely, where best practice is not followed, the outcomes may be much poorer. Therefore, the quality of forest management has a critically important role in determining the value of production forests for a range of values, including biodiversity (Bicknell *et al.*, 2014; Chaudhary *et al.*, 2016).

Forest plantations under short-rotation, even-aged monoculture management, especially of exotic species, generally support only a small proportion of the native biodiversity. Biodiversity management in these forests, therefore, focuses on the management of set-aside areas that protect vulnerable habitats and provide corridors for native biodiversity. The success of biodiversity management depends on the appropriate identification of vulnerable habitats, the total proportion of the forest reserved as set-aside and the spatial configuration of these areas (see **Chapter 7** for further treatment of this topic).

Forest plantation with natural forest retained along riparian buffers. Prior to planting tree crops (left) and a few years after planting tree crops (right).

Conversely, in the management of natural forests, protection of biodiversity within production stands becomes more important. In addition to the management of set-aside areas, factors such as the total volume of timber removed (or size of clear-cuts), the application of reduced impact logging techniques **(Box 3)**, the number of large trees retained, and the protection of critical wildlife resources, including fruit trees, hollow stems and dead wood, need to be considered (Con *et al.*, 2001; Meijaard *et al.*, 2005; Putz *et al.*, 2012). Where best practices have been followed, forests can recover from the short-term impacts of harvesting operations within a few months to 1–2 years (Martin *et al.*, 2015). However, the recovery of forest structure and timber stocks to pre-felling levels takes decades (e.g. 60–100 years in Bornean forests) (Ruslandi, Cropper and Putz, 2017).

Enrichment planting may accelerate the recovery of timber stocks (potentially reducing cutting cycles to 45 years in Bornean forests), but the inevitable selection of robust, faster growing tree species for planting will reduce the diversity of the stand. The outcome for biodiversity will depend on whether the focus is on accelerated recovery of forest structure or the maintenance of the full contingent of native species. Diversity of arthropods, the most diverse group of terrestrial animal species, is highly correlated with tree diversity at both stand and landscape scales in forests (Basset *et al.*, 2012; Zhang *et al.*, 2016). Thus, the recovery of timber stocks and forest structure with reduced tree diversity is unlikely to cater to the needs of a wide variety of arthropod species. It may be possible to accommodate both outcomes through a carefully considered spatial plan, including set-aside areas (Edwards *et al.*, 2014a).

In terms of harvesting systems, under clear-cut management, much of the stand level biodiversity is lost during harvesting, which will gradually accumulate again

Rapid regrowth of vegetation in a canopy gap created by selective logging as the stand regrows. Biodiversity values tend to be highest in old stands where trees are large and have accumulated more epiphytes, and the understorey has been colonized through natural regeneration (Brockerhoff *et al.*, 2008). However, harvesting can also increase habitat heterogeneity and enhance landscape level biodiversity for some taxa (Hill and Hamer, 2004). Even-aged stands support lower biodiversity because of their low structural diversity, but this can be improved through thinning and retention of old trees. Under clear-cut systems, longer rotations and management of forests for structural diversity tend to promote higher biodiversity benefits (Brockerhoff *et al.*, 2008).

6.1. ASSESSING AND MANAGING RISKS TO BIODIVERSITY

All forest management operations, no matter how unobtrusive, have some impact on forest ecosystem functioning and therefore on biodiversity (Sheil, Nasi and Johnson, 2004). The removal of biomass, residual damage to the forest through harvesting, construction of roads and other infrastructure, and soil disturbance from heavy machinery all negatively impact biodiversity through habitat degradation, loss and fragmentation. Thinning or controlling competing vegetation may also disturb sensitive species or habitats. Seemingly harmless activities, such as just entering the forest for recreation or to conduct a survey, may disturb nesting birds or animals with young.

In addition, overharvesting of specific resources may threaten certain species. This applies especially to hunting (Poulsen *et al.*, 2009; Morton *et al*., 2021), but also to harvesting of commercial timber species and other valuable plants such as orchids or agarwood[28]. Collecting a particular resource too early or too late likewise may cause damage and limit future productivity or prevent the species from successfully regenerating. Construction of access roads associated with forest harvesting often exacerbates these pressures on biodiversity. Hence, it is essential that the forest managers put in place systems to govern and protect these resources from overharvesting (Poulsen *et al.*, 2009). Furthermore, some forests may be vulnerable to illegal encroachment.

Forest managers should conduct biodiversity risk assessments before initiating any major operations and on a regular basis, for example monthly. This will often involve completing a simple checklist of issues that need to be considered and flagging any activities that entail higher risks (Lindenmayer, Franklin and Fischer, 2006), enabling the forest manager and environmental staff to apportion their efforts appropriately. Managers can assign staff to mark ecologically sensitive areas that must not be disturbed so that the risk of accidental damage is lessened. Furthermore, risk assessments ensure staff are made aware of potential risks to biodiversity, so that mitigating action can be taken.

[28] A highly valuable resinous and fragrant heartwood of *Aquilaria* species (Naziz, Das and Sen, 2019)

BOX 3.
Reduced impact logging (RIL) to lessen the impact of harvesting in tropical forests

It has been shown that many actively managed tropical forests support only marginally lower biodiversity than primary forests (Gibson *et al.*, 2011). Most biodiversity indicators recover quickly after well-managed selective logging before the rate flattens off near the maximal value. Under selective logging systems, timber harvesting is the intervention with the largest impact on biodiversity. Therefore, careful management of harvesting operations can substantially improve outcomes for biodiversity (Bicknell *et al.*, 2014; Chaudhary *et al.*, 2016).

A wealth of knowledge has been accumulated on how to reduce the impacts of logging. These approaches are commonly referred to as reduced impact logging (RIL) (ITTO, 1999; Dykstra *et al.*, 2002; Sist *et al.*, 2003; Putz *et al.*, 2008). The main RIL interventions involve: 1) pre-harvest forest inventories and mapping; 2) pre-harvest planning of roads, skid trails and landings; 3) pre-harvest cutting of vines and lianas from harvest trees; 4) construction of roads, landings and skid trails to minimize environmental impact; 5) the use of appropriate felling and bucking[a] techniques; 6) winching of logs to skid trails; 7) the use of yarding systems that protect soils and residual vegetation (e.g. cable yarding) where possible; and 8) post-harvest assessments to evaluate the implementation of RIL practices. Even for forest plantations where timber is usually harvested through clearfelling, the management of roads and avoiding excessive soil disturbance are critical to limiting damage and facilitating recovery.

A forest block selectively logged using RIL practices showing quick recovery of vegetation only after a few years

[a] Sawing of felled trees into shorter lengths (Helms, 1998).

Roads often have the single largest impact on the forest (Kleinschroth and Healey, 2017; Laurance, Goosem and Laurance, 2009). Roads may be a linear barrier for dispersal of some species and can impact freshwater systems through siltation and stream blockage (Kleinschroth and Healey, 2017; Chappell *et al.*, 2004). Hence, proper road planning, construction and maintenance, including managing drainage from roads, can make a substantial difference to the biodiversity impacts of timber harvesting. It is also important to properly close secondary roads after use, which reduces erosion and discourages unauthorized access (Kleinschroth and Healey, 2017). Other measures to reduce the impact of selective logging include directional felling to avoid damage to the residual stand, proper design of skid trails for log extraction, careful operation of skidders (which are often bulldozers in the tropics), and the use of a logfisher which uses a wire from a mobile crane arm to lift the end of the log and winch it to the side of the road (Putz *et al.*, 2019).

RIL also reduces stand recovery time by reducing damage to the residual trees (Putz *et al.*, 2008). With further improvements, such as narrower roads and minimized skidding distance, GHG emissions caused by timber harvesting can be reduced by up to 50 percent (Ellis *et al.*, 2019). Unfortunately, the quality of RIL implementation is often poor. Indeed, timber contractors typically have low awareness and inadequate training, and lack proper supervision and compensation (Putz *et al.*, 2008). However, logging companies might be motivated to improve compliance with RIL specifications, if they were able to access carbon finance for avoided emissions, which would also improve outcomes for biodiversity.

Source: Authors' own elaboration

6.2. ESTABLISHING AND MANAGING SET-ASIDE AREAS

Establishing and managing set-aside areas is one of the main tools for biodiversity conservation in production forests (Dykstra, 2002). While standards vary among countries, often a minimum of around 15 percent set-aside is required within a managed forest. These include areas that should be protected for ecosystem services, such as steep slopes and buffers along waterbodies and salt licks, as well as specific habitats, including threatened habitats and areas occupied by endangered species (Lindenmayer, Franklin and Fischer, 2006). Set-aside is also used to protect cultural values and local community resources (e.g. community-managed land within a forest), areas of particular cultural significance (e.g. cemetery forest), areas providing critical ecosystem services to local communities (e.g. watershed forest), and areas for hunting and NWFP collection.

Identifying set-aside areas is an important part of the forest planning process and set-aside areas should be identified on maps, as part of the forest management plan, and where possible, marked on the ground. Some certification schemes (e.g. FSC) and some national forest regulations apply HCV procedures (see **Box 4**) to identify and prioritize areas for set-aside selection. Ideally, information on threatened habitats or areas used by threatened species is available from

Signposts marking an area set-aside for conservation of wildlife within a logging concession

government sources. If such information is not available, an important step in the forest planning process should a forest survey to identify these areas.

Set-aside areas should be protected against degradation through forest management activities. In most cases this will mean that forest roads, timber harvesting and planting are not permitted within set-aside areas. If the area is especially sensitive, it may also entail controlling recreation and NWFP collection. In some cases, interventions may be required to protect their biodiversity value, for example by controlling the spread of an invasive species, preventing overgrazing, or managing the overstorey to protect an endangered understorey plant. Set-aside areas should serve as fine-scale protected areas within the production forest where biodiversity values are prioritized over other interests.

BOX 4.

High conservation value (HCV) approach

The high conservation value (HCV) approach is a process of identifying, managing, monitoring and reporting on the presence of HCVs within the area of interest. It was first developed in the context of FSC forest certification , but has since been adopted by other forest certification standards, as well as agricultural commodity certification standards, including the Roundtable on Sustainable Palm Oil and the Roundtable on Responsible Soy .

The approach has also been adopted outside the context of certification for a variety of uses, such as land-use planning, conservation advocacy, and designing responsible purchasing and investment policies (Stewart *et al.*, 2008). The HCV approach aims to maintain and enhance significant environmental and social values within production landscapes and is used globally from the tropical to boreal biomes. Although conceived for forest management at landscape or smaller scales (Higman *et al.*, 2005), it can be applied to any ecosystem and at any scale. For example, several attempts have been made to use it to identify priority areas for national level protected areas (Mikusiński *et al.*, 2021).

The HCV approach identifies six conservation values as follows (FSC, 2015):

HCV 1: Species diversity. Concentrations of biological diversity including endemic species and rare, threatened or endangered species, that are significant at global, regional or national levels.

HCV 2: Landscape-level ecosystems and mosaics. Large landscape-level ecosystems and ecosystem mosaics and intact forest landscapes that are significant at global, regional or national levels, and that contain viable populations of the great majority of the naturally occurring species in natural patterns of distribution and abundance.

HCV 3: Ecosystems and habitats. Rare, threatened or endangered ecosystems, habitats or refugia.

HCV 4: Critical ecosystem services. Basic ecosystem services in critical situations, including protection of water catchments and control of erosion of vulnerable soils and slopes.

HCV 5: Community needs. Sites and resources fundamental for satisfying the basic necessities of local communities or Indigenous Peoples (for livelihoods, health, nutrition, water, etc.), identified through engagement with these communities or Indigenous Peoples.

HCV 6: Cultural values. Sites, resources, habitats and landscapes of global or national cultural, archaeological or historical significance, and/or of critical cultural, ecological, economic or religious/sacred importance for the traditional cultures of local communities or Indigenous Peoples, identified through engagement with these local communities or Indigenous Peoples.

An area is defined as containing HCV if at least one of these values that are significant at global, regional or national levels, or critical at local levels is present. Areas are identified as containing HCVs must be managed so that these values are protected or enhanced. Assessments are required to consider the potential impacts of management on HCVs and how they might be mitigated, as well as possible conflicts between values, such as threatened species protection (HCV 1) and indigenous hunting (HCV 5). Assessments are reviewed through broad stakeholder consultation and final designations are governed by the precautionary approach.

The HCV approach has several distinct demonstrated advantages. First, it has high level of buy-in among conservation organizations and forestry corporations, particularly those pursuing timber certification. Second, the six HCVs capture all the critical elements required for quality biodiversity management in production forests (or agricultural landscapes). In particular, the inclusion of social and cultural dimensions under HCV 5 and HCV 6 aligns well with the CBD's concepts on equitable sharing of biodiversity benefits and the importance of cultural values. Last, it is a mature approach that has been adapted, modified and improved over the past two decades.

One criticism of the HCV approach has been the vagueness of definitions. What exactly counts as globally, regionally or nationally significant concentrations of biological diversity (HCV 1)? The presence of a Critically Endangered species (based on the IUCN Red List) might be a simple criterion to agree on, but what population of a Threatened species would count as significant? Or how do you assess a situation where there are multiple endemics that are not rare where they occur? Similar issues arise with other HCVs. For example, how large and how intact does a landscape have to be to be globally, regionally or nationally significant? According to the HCV Network[a], it is 20 000 ha in Indonesia, 100 000 ha in Ecuador and the Plurinational State of Bolivia, and 500 000 ha in Papua New Guinea, while in other instances no threshold has been set. The flexibility facilitates broad application of the approach but requires that quality national level guidelines (national interpretations) are available. The establishment of the HCV Network has helped to facilitate this process and there are currently 13 national interpretations, as well as guidelines for developing them.

[a] www.hcvnetwork.org

Another criticism that has been levelled at the HCV approach is the focus on prioritization rather than management (Edwards, Fisher and Wilcove, 2012). For example, an area of previously logged tropical forest would probably not qualify as HCV 2. However, with appropriate management, such forests have a high potential for biodiversity conservation (Meijaard *et al.*, 2005; Berry *et al.*, 2010). Widespread species that are sensitive to forest disturbance may experience dramatic range contraction and hence population decline, if forests are not managed with a view to protecting these species. But, as widespread species, they would not normally be identified as HCV. Most of these concerns can be allayed, if context-specific national interpretations are available as such issues can be identified and addressed in the process of developing the guidelines. It is necessary that conservation organizations and scientists engage in the development of national interpretations in order to promote higher quality HCV assessments and ultimately better biodiversity management (Senior *et al.*, 2015).

A more pertinent criticism is that, because of time and cost constraints and perhaps also capacity gaps, HCV assessments and monitoring of HCV management implementation during certification audits can both be cursory and inadequate (Senior *et al.*, 2015; Areendran *et al.*, 2020).

Source: Authors' own elaboration

6.3. PROTECTING KEY BIODIVERSITY RESOURCES

Some small-scale features can provide critical resources for wildlife. Features that serve as key biodiversity resources include: very large trees, hollow trees, standing and fallen deadwood; plants that supply important fruit or seed resources, such as large climbers, figs and some palms in tropical forests; rare plants; nesting sites for raptors or other endangered birds; and caves, dens or burrows that are used, or might be used, by threatened wildlife (Lindenmayer, Margules and Botkin, 2000). Key biodiversity resources may also include species that provide important NWFPs (e.g. bee nesting trees) and are protected throughout the forest. Some of these features, when they are large enough, may be covered by set-aside areas. For example, a large bat cave, a swamp dominated by an important palm, or major roost site might be best designated and managed as set-aside.

Identification of key biodiversity resources is usually a stand-level activity and requires a detailed survey. Hence, key biodiversity resources are often identified during pre-harvesting or pre-planting surveys. Forest managers and their environmental staff should be provided with a list of key biodiversity resources, based on which such resources are mapped and marked on the ground to avoid damage. Each type of feature should be associated with a specific management prescription that is defined during forest planning. For example, a raptor's nest may require a buffer of a specified size and a prohibition on timber harvesting during the breeding season. Deadwood and fruit resources may be protected against logging, or it may be required that a specified minimum density

Commercial timber species of harvestable size surrounded by regeneration. Tree growth is monitored to enable the determination of sustainable harvest.

of resources be retained. Management of key biodiversity resources, therefore, requires a pre-intervention survey to identify and map features, and a post-intervention survey to monitor compliance with the prescriptions.

6.4. SUSTAINABLE MANAGEMENT OF TIMBER RESOURCES

As reported previously, timber harvesting is a major threat to trees of the world and impacts a huge number of tree species, particularly tropical hardwoods. In a selective logging system, the biggest determinant of the ecological and environmental impacts of timber harvesting is the volume of timber extracted over time (Burivalova, Sekercioğlu and Koh, 2014). Lower harvest intensity would result in less impact and better biodiversity outcomes in general. In addition, longer intervals between harvesting cycles tend to promote better outcomes for biodiversity as the time since disturbance is strongly related to the degree of biodiversity recovery. Therefore, lower harvesting volume combined with a longer rotation period would result in higher time-averaged biodiversity value overall, although this may not guarantee sustainability of each harvested species.

Ensuring adequate regeneration and sustainability of commercial timber species in the tropics presents a challenge. Selective logging which is commonly used in harvesting of natural forest in the tropics, often does not create conditions that enable regeneration of light-demanding timber species that are present in low densities and show clumped distribution patterns. Higher harvesting intensity on the other hand creates larger and more frequent canopy gaps, creating larger impact on the ecosystem and often promoting vigorous regeneration of pioneer and invasive species which may arrest or slow down natural succession. Sparing–

Community collecting non-wood forest products

sharing trades-offs indicate that for a given volume of timber extracted, more intense harvesting in a smaller forest area combined with more set-aside may improve biodiversity outcomes (Edwards *et al.*, 2014a). However, this approach may lead to the extirpation of valuable timber species from the intensively harvested stands, putting further pressure on the set-aside areas.

In order to sustain production from these commercial timber species, carefully implemented harvesting operations with appropriate limits need to be combined with silvicultural treatments so as to enhance the abundance and growth of commercial timber species. These silvicultural treatments typically involve enrichment planting of seedlings of commercial timber species in canopy gaps or creating conditions conducive to the establishment and growth of natural regeneration of targeted species (Gräfe *et al.*, 2021). Ideally, a sustainable harvesting regime should be designed for each harvested species, considering its life history, including regeneration ecology, growth rates, distribution and size composition to ensure their long-term viability.

6.5. REGULATING NON-WOOD FOREST PRODUCT HARVEST

Although timber harvesting has by far the greatest impact on biodiversity, harvesting of NWFPs, including plant resources and animals, can also substantially impact biodiversity. Therefore, appropriate regulation of harvest and management of NWFPs is required to ensure their sustainability. NWFPs come from a diverse range of species, and each species requires case specific management. Here, we describe a few examples to illustrate the problems that can arise and the potential solutions to address them.

Jernang or "dragon's blood" (*Daemonorops* spp.) is a climbing palm found in Indonesia and elsewhere in Southeast Asia. The seed aril of immature seeds produces a bright red resin that is used to produce a high value royal red dye. The seeds are harvested before they are mature, often by cutting the stem of the plant to access seeds in the canopy. This practice can result in near-complete regeneration failure, although recovery can be rapid if seeds are allowed to mature and germinate as young plants grow well in gaps. Sustainable management can be achieved through protecting certain plants and collecting wild seedlings for planting in forests or peoples' gardens (Kaad, 2014; Moulana *et al.*, 2021).

The mopane worm (*Gonimbrasia belina*) is a species of Emperor moth from southern Africa that is often found on mopane trees (*Colophospermum mopane*). The caterpillars are widely eaten and constitute an important source of protein. They also provide the basis for a valuable regional industry. In many areas, mopane worms have been overharvested. Moreover, heavily infested trees may be cut down to facilitate the collection of the caterpillars, decimating the supply of host trees for the caterpillar. Options for sustainable harvesting include issuing collecting licenses with harvest limits, designating resource rights to specific forest areas, and prohibiting the felling of host trees (Ghazoul, 2006).

Rattans, understorey palms and orchids are also often over-collected, although opportunities exist for enrichment planting and semi-domestication to ensure sustainability (e.g. Meijaard *et al.*, 2014).

6.6. SUSTAINABLE MANAGEMENT OF FOREST GENETIC RESOURCES

The sustainable management of genetic resources and conservation of genetic diversity in production forests is an often-overlooked aspect of forest biodiversity conservation (Jalonen *et al.*, 2014). In high latitude forests, where tree species diversity is low and many species are wind pollinated, timber harvesting may only have minor impacts on genetic diversity. However, in the tropics, tree species diversity is high, and many species have low population densities. Moreover, because of seed dispersal constraints, most species have clumped distributions (Seidler and Plotkin, 2006; Plotkin, Chave and Ashton, 2022). This means that, for many species, most seeds produced by a tree are pollinated from a small number of neighbouring adults.

Given these conditions, even light selective harvesting can reduce the number of potential pollen sources and severely reduce the genetic diversity of future seed crops. In addition, many pollinator species have weak flight capabilities. As such, the increased distances between flowering adults following logging may result in a change in behaviour, whereby the pollinators forage just within a single tree crown (Ghazoul and McLeish, 2001). This results in an increase in self-pollinated seeds or reduced seed production for self-incompatible species. Forest fragmentation can have similar effects, whereby pollinators predominantly forage within a fragment and the genetic diversity of seeds becomes a function of fragment size (Ghazoul and McLeish, 2001; Breed *et al.*, 2015). However, the effects of fragmentation on tree genetic diversity are species-dependent, and trees pollinated by highly mobile

A nursery of diverse forest tree seedlings

species, such as large honeybees and vertebrates, may not be so affected (Dick, 2001; Ismail *et al.*, 2014; Breed *et al.*, 2015; Lowe *et al.*, 2015).

A series of steps can be taken to manage the genetic diversity of trees in diverse tropical production forests (Jalonen *et al.*, 2014; Krishnan *et al.*, 2020). First, ensuring that set-aside areas protect a representative sample of all habitats found within the forest management area will conserve genetic diversity at the landscape scale. A large proportion of the set-aside area is often allocated to the protection of steep slopes and stream buffer zones, as well as threatened habitats. However, the tree species found in these environments will not be representative of the forest as a whole. Hence it is necessary to designate set-aside to ensure protection of all habitats. A general guideline may be that a minimum of 10 percent of all habitats occurring within the forest is protected. Second, avoiding unnecessary disturbance to the residual stand and understorey (e.g. through RIL implementation) will help preserve genetic diversity as a substantial proportion of tree population genetic diversity is represented by seedling and juvenile tree cohorts. Last, maintaining forest connectivity within the forest management unit (FMU), as well as between it and the wider forest landscape, will enable gene movement over large areas. This approach supports natural selection for different genotypes, which is likely to be essential for climate change resilience (Senior, Hill and Edwards, 2019; Krishnan *et al.*, 2020).

Genetic considerations may also be important for the management of NWFP resources, especially where it is the seeds or the fruits that are harvested. Over-harvesting of seeds may prompt reproductive failure (Kaad, 2014), and forest degradation can lead to reduced yields through a reduction in pollination success

(Chiriboga-Arroyo *et al.*, 2021). In addition, forests and forest fragments in agricultural landscapes provide a valuable ecosystem service in supporting the pollination of agricultural crops (Krishnan *et al.*, 2020). Moreover, forest diversity promotes pollinator diversity which enhances the quality of the pollination service (Fründ *et al.*, 2013; Winfree *et al.*, 2018).

The final area where genetic considerations are crucial is in tree planting (see **Chapter 7** and **Box 6** for further discussion). It is worth noting that a considerable economic opportunity exists for communities and companies managing forests to supply high quality seeds and seedlings to support ambitious global restoration efforts. Within plantings, in addition to matching species to fine-scale variation in site conditions, the spatial planting pattern may be an important consideration. For example, if planting species for future NWFP production, considering the optimal conspecific distance in the future adult cohort may be crucial. Individuals should be close enough to ensure quality pollination and hence good seed or fruit production, but far enough apart to avoid competition (Thomas, Atkinson and Kettle, 2018). Similar concerns apply to ecological restoration, if the future forest is to regenerate naturally and maintain high genetic diversity over time. Given that species vary in their distribution patterns according to factors such as canopy position, pollination system and seed dispersal system (Seidler and Plotkin, 2006; Plotkin, Chave and Ashton, 2002), a good guide is to plant species in patterns and at densities replicating their distribution in a natural forest.

Forest guards patrolling a forest area to deter illegal activities

6.7. MANAGING AND CONTROLLING INVASIVE SPECIES

Some forest management activities can increase the risk of invasive species. Invasive species may dominate open habitats and disturbed sites, arresting natural regeneration, altering community composition, and impacting ecosystem functions. Furthermore, invasive species can increase fire risks. Invasive species are not only one of the key causes of global biodiversity decline, but also a serious threat to biodiversity in managed forests.

To mitigate the impacts of invasive species on biodiversity, forest productivity and provision of other ecosystem services, forest managers should implement an invasive species management plan. During the forest planning phase, potential or existing invasive species should be identified and protocols for their management developed. Where invasive species have yet to enter a forest, the most likely path of entry is along the access roads. Hence, a part of any invasive species management plan should be to monitor access roads and eradicate any invasive species found before they get into the forest proper. For the already established invasive species, management will vary according to the characteristics of the species. Forest managers should follow protocols for reporting and controlling invasive species in line with any national invasive species management plans or strategies. Forest restoration also often requires specific strategies for the removal or control of alien invasive species (Weidlich *et al.*, 2020).

Many of the invasive plant species are light-demanding pioneers that thrive in degraded habitats, and hence they are shaded out as the tree canopy re-establishes. Intact forests are also more resilient against invasion than degraded forests. As such, minimizing the impact of forest operations and maintaining continuous forest cover as much as possible should contribute to mitigating risks from invasive species.

6.8. PROTECTING FORESTS FROM ILLEGAL AND UNAUTHORIZED ACTIVITIES

It is essential that forest managers have protocols in place to ensure protection of forest resources, as well as biodiversity. Production forests are often susceptible to encroachment and unsustainable harvests of NWFPs. Failure to protect forests against unsustainable hunting and collection of NWFP resources is a major driver of biodiversity loss (Ghazoul, 2006; Morton *et al.*, 2021; Moulana *et al.*, 2021). To successfully manage biodiversity, forest managers should operate forest enforcement teams to prevent and monitor illegal activities, and to report such occurrences to local authorities. Roads provide access for encroachment, as well as for hunting and collection of NWFPs (Laurance, Goosem and Laurance, 2009; Poulsen *et al.*, 2009). Thus, controlling access along roads is of paramount importance. Checkpoints can be used to prevent unauthorized vehicular access, but monitoring of roads should also be done to prevent unauthorized foot traffic. Within logging areas, secondary roads should be closed to enable the forest to recover and inhibit access. Cooperation with local communities, including co-management of NWFP resources, is essential to building a social fence for forest protection (Gilmour, 2016).

Depending on the duration of logging licenses, a considerable proportion of production forests in a country may not be under active management at any particular point in time, which leaves them vulnerable to uncontrolled hunting and NWFP harvests. Therefore, the government agencies charged with protecting forests or biodiversity may need to conduct enforcement activities across the forest estate (and not just within protected areas). It may also oblige governments to consider operating larger concessions with long-term licenses, as this ensures a greater proportion of the forest estate is under active management at any point in time.

7. Tree planting and restoration

7.1. THE GLOBAL RESTORATION AGENDA

Globally, 29 percent of forest mosaics are degraded (Nkonya, Mirzabaev and von Braun, 2016), with much of the forest degradation in recent decades concentrated in the tropics (FAO, 2016). Degraded land has reduced capacity to supply productive benefits and ecosystem services, and degradation is a major driver of extreme poverty, negatively affected the livelihoods of 3 billion people worldwide (Nkonya, Mirzabaev and von Braun, 2016). Forest and land degradation is also detrimental to biodiversity conservation.

In response to the land degradation crisis, and recognizing the potential of well-designed restoration to address multiple societal goals, including poverty alleviation (SDG 1), climate change mitigation (SDG 13) and biodiversity conservation (SDG 15), countries, development organizations and the private sector have come together to work towards achieving ambitious restoration targets through the various global and regional commitments (see **Section 3.4**). These restoration commitments present an incredible opportunity to reverse the consequences of prolonged poor natural resource governance (Edwards *et al.*, 2021a).

Landscape approaches to restoration also provide an opportunity to design optimal forest landscape configuration in order to meet multiple objectives, including biodiversity conservation. For example, restoration of forest buffers and corridors can enhance the quality of protected areas and provide connectivity at landscape scales (Brockerhoff *et al.*, 2008; Clark *et al.,* 2009; Berry *et al*., 2010). Improving the quality of existing forest patches in agricultural landscapes can also result in enhanced habitat value and connectivity (Arroyo-Rodríguez *et al.*, 2020). A large proportion of tree diversity in the landscape may be preserved in small fragments (Liu and Slik, 2014), and hence enhancing the size, quality and connectivity of these fragments is likely to greatly improve biodiversity outcomes.

The biodiversity benefits of restoration will depend on the initial condition of the land to be restored, the planned future state of the forest and the restoration methods applied, as well as interactions between the restored forest and the surrounding landscape (Harrison *et al.*, 2020). The quality and type of restoration also has a substantial impact on the ability of restored forests to perform the intended functions (Edwards *et al.*, 2021a). Where natural regeneration or planting of a diverse range of native species from quality seed sources are used (Thomas *et al.*, 2014), restored forests underpin high quality ecosystem functioning and provide valuable habitat for biodiversity (Seddon *et al.*, 2019; Girardin *et al*., 2021).

7.2. RESTORATION TYPES

Restoration may be applied to a wide range of forest ecosystems, from montane forest to mangroves, tropical to boreal, and in production versus conservation contexts. The scale of the benefits and their distribution among stakeholders, however, vary tremendously among ecosystems and the restoration approaches applied (Cook-Patton *et al.*, 2020).

Selection of restoration methods will be largely guided by the main objectives of restoration, including the future use of the restored forest, the severity of degradation, and barriers to forest regeneration. There exists a panoply of restoration options available, ranging from simple protection from disturbance to intensive planting with site amelioration.

Control of invasive species may also be an important consideration, especially where these suppress native species, arrest succession or lead to increased fire risk (Weidlich *et al.*, 2020). Appropriate species selection and maintenance of genetic diversity are critical considerations in restoration planning where tree planting is employed (**Box 6**). Where forests are being restored for timber (or other NWFP) production as the primary objective, planning of future set-aside and production areas is required, and the management focus transitions from restoration to production once timber stocks have been restored (Harrison *et al.*, 2020). In either case, restoration of the forest habitat should result in a substantial gain for biodiversity. Selection of appropriate interventions for accelerating forest recovery, with an emphasis on maximizing the use of natural regeneration, will not only reduce costs but improve biodiversity outcomes.

Restoration of degraded natural forests

Forests that have been degraded due to selective logging, slash-and-burn agriculture, fire and other disturbances retain many of the structural elements of the native forest ecosystem and often a considerable proportion of the species found in pristine forests. They may also continue to supply valuable ecosystem services to local communities, including as sources of fuelwood and NWFPs, and hold substantial carbon (Berry *et al.*, 2010; Edwards *et al.*, 2014b). However, because they have lost much of their commercial timber stock, degraded forests are often regarded as having limited economic value by decision-makers and are vulnerable to conversion (Burivalova *et al.*, 2020). With over 400 million ha of tropical forests allocated to selective logging, much of it done unsustainably, these forests represent a fail-safe restoration opportunity (Edwards *et al.*, 2019, 2021a).

Logged-over forest or areas recovering from low intensity disturbances with seed sources nearby can recover quickly without intensive interventions simply by protecting the site and natural regeneration from disturbances (FAO, 2019). Logged forests often have diverse seedling and sapling cohorts, which will grow to occupy the canopy over time if given the chance. However, natural recovery does take time, usually requiring at least several decades (e.g. 60–100 years for Bornean forests) until the forest recovers the structure and diversity resembling that of an old-growth forest (Philipson *et al.*, 2020).

Interventions to assist the natural successional processes can speed up recovery, including the accumulation of biodiversity. For example, enrichment planting may be used to enhance the diversity of regenerating forests that are far from seed sources and, consequently, are lacking regeneration of large-seeded, late successional species. Where late successional species are present, but their growth is suppressed, thinning of the pioneer canopy or liana cutting may accelerate forest recovery (Swinfield *et al.*, 2016; Mills *et al.*, 2019). Where establishment of seedlings among the competing vegetation is slow, and sometimes prone to periodic fires, assisted natural regeneration, aimed at improving survival and enhancing the growth of naturally regenerating seedlings, may be effective (FAO, 2019; Shono, Cadaweng and Durst, 2007). However, these more active interventions do come at a substantial cost. Carbon finance and future harvest of timber or high-value NWFPs may provide a business case for private investment (Harrison *et al.*, 2020).

Opportunities also exist to further enhance the biodiversity outcomes through supplementary planting of species that have been overharvested or are endangered, and by augmenting wildlife resources, such as favoured fruit species. By managing these degraded forests for restoration, they can be protected from deforestation and other insidious threats such as poaching, which will provide important benefits for biodiversity (Harrison *et al.*, 2020; Edwards *et al.*, 2021a).

Natural regeneration on abandoned agricultural land

In many places, marginal agricultural land is being abandoned through socio-economic processes, such as increasing labour costs and rural urban migration (Chazdon, 2008). Reforestation of marginal agricultural land can be facilitated through policy interventions, such as PES schemes, grants or simply the removal of perverse subsidies, such as agricultural grants for developing marginal land (FAO, UNDP and UNEP, 2021; Chazdon *et al.*, 2020). Where the abandoned farmland borders natural forest, natural regeneration often proceeds rapidly, locking in improved ecosystem service and biodiversity benefits without the need for planting (Edwards *et al.*, 2021a). The time elapsed since abandonment strongly dictates the biodiversity benefits of secondary forests, with near-complete recovery of some communities within 30 years (Gilroy *et al.*, 2014b). Restoration through assisted natural regeneration is much more economical and usually results in more resilient restoration. In sites that are at a distance from patches of natural forests, and where large frugivores have been depleted impeding dispersal of large-seeded late successional species, enrichment planting may be beneficial in improving biodiversity outcomes.

A whole suite of assisted natural regeneration interventions exists, varying in intensity from simply protecting natural regeneration from browsing and fire, marking and weeding around naturally established seedlings, to control of competing vegetation and enrichment planting with threatened or economically important species, thus enabling the practitioner to adapt their approach to the conditions and needs at fine spatial scales (Shono, Cadaweng and Durst, 2007; Chazdon *et al.*, 2017; Shono *et al.*, 2020).

Assisted natural regeneration resulting in rapid forest regrowth in Zambia

Restoration through the establishment of planted forests

Well-planned and well-managed tree planting is an important component of the global restoration efforts (Holl and Brancalion, 2020). However, tree planting can have negative consequences when the emphasis on planting overrides other key considerations such as addressing the socioeconomic drivers of deforestation, making use of natural regeneration, and protecting and enhancing the remaining natural forests. Nevertheless, where the initial condition of the land is poor and highly degraded, recovery is likely to require tree planting and in some cases soil amelioration measures. Planted forests vary widely in their structure, species composition, their management and the combination of services provided, ranging from monoculture plantation forests managed on a short rotation to mixed planting of diverse native species managed for non-productive services.

Plantation forests[29] have a simple age structure, low species and genetic diversity, and are usually clear-cut on a regular cycle of no more than a few decades. These factors limit the potential of plantations to support biodiversity, although their biodiversity value can be improved considerably through appropriate design and management (Brockerhoff *et al.*, 2008; Pawson *et al.*, 2013). Much of the biodiversity recorded in plantations represents spillover from neighbouring natural habitat and rarely extends far into the plantation. For example, in southwest China, approximately 50 percent of bird species found in neighbouring natural forests were recorded in rubber plantations, but this declined to a handful when there was no natural forest within 500 m of a sample point (Sreekar *et al.*, 2016).

[29] Defined as planted forest that is intensively managed and meets all the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing.

Nevertheless, plantation forests provide important productive functions and so may be an appropriate restoration approach where this is being prioritized. If plantations are managed to high quality SFM standards, they will also include set-aside areas managed as natural habitats and may contribute other wildlife resources such as nesting or roost sites (**Box 5**). When situated around natural forest patches, forest plantations can also 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). In addition, by providing a forest canopy, 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). Plantations may also serve to 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 GHG emissions and biodiversity impacts of these materials, hence contributing to a more sustainable society (Girardin *et al.*, 2021).

The biodiversity value of plantation stands tends to increase through time, through processes such as understorey natural regeneration and the colonization of trunks and branches with epiphytes. Large trees may also provide other wildlife resources, such as nest sites. Hence, increasing rotation lengths, managing uneven-aged stands, and retaining some large trees can all contribute to enhanced biodiversity outcomes (Brockerhoff *et al.*, 2008, 2017).

If plantations are being planned with biodiversity benefits in mind, they should be carefully designed to avoid perverse outcomes. Conversion of degraded natural forest to a forest plantation, even with the best set-aside planning, will almost

Forest plantation of native species in China being managed for multiple objectives certainly result in a negative outcome for biodiversity and most often a net loss of carbon as well, and hence would generally not be considered restoration.

Biodiversity across landscapes can also be enhanced by diversifying the planted forests themselves. Where the planted forests are more similar to natural forests in terms of species composition (e.g. native species or closely related species) and structure, a greater proportion of the native biota may be able to use plantations (Quine and Humphrey, 2010; Brockerhoff *et al.*, 2008). This type of planting for ecological restoration is more complex to manage, requires more research inputs, and is usually more expensive. There are also likely trade-offs in terms of timber production. However, the rate of biodiversity recovery is quicker and biodiversity benefits greater. There are initiatives in countries such as China and Japan to convert plantations forests, originally established primarily for timber production, to mixed species forests supplying more balanced ecosystem services including biodiversity.

On-farm restoration

Addressing local needs is a critical component of restoration. Although local communities will often benefit from forest restoration through supplies of forest products and ecosystem services, it is also necessary to extend restoration into farmland through various agroecological interventions, including promoting agroforestry, silvopasture, woodlots and restoration of small forest fragments (Sinclair *et al.*, 2019; Edwards *et al*., 2021a). While these interventions are strongly focused on local productive benefits, there are often positive biodiversity outcomes as well (Arroyo-Rodríguez *et al.*, 2020). Agricultural landscapes with high tree cover can support substantial biodiversity through providing both habitat and

*Interplanting of teak (*Tectona grandis*), banana and cacao in an agroforestry system*

BOX 5.

Integrating biodiversity conservation into forest plantation management

Klabin is the largest packaging paper producer and exporter in Brazil with a history of more than 120 years, currently operating 25 mills and managing 578 000 ha of forests. Its supply of fibres for pulp and paper production comes from forest plantations of loblolly pine (*Pinus taeda*) and eucalyptus (*Eucalyptus* spp.). Klabin was the first company in the Southern Hemisphere to achieve FSC certification in 1998, and all of its own plantations are now certified by FSC.

As part of the company's commitment to sustainability, Klabin has developed and implemented a mosaic forest management system. Under this system, 240 000 ha of protected native forests – accounting for nearly half of the company's total forest area – are interspersed with stands of planted forests of different ages (eucalyptus stands managed on a 7-year cycle and 15 years for the loblolly pine). This method provides a wide range of productive and ecological benefits, including: 1) protection of natural resources including genetic materials; 2) enhanced productive potential of the plantation forest; 3) control of pests and diseases by maintaining populations of natural predators; 4) protection of riparian buffers to maintain a clean water supply; 5) storage and sequestration of carbon lowering the carbon footprint of the fibre production; and 6) conservation and enhancement of biodiversity by providing refugia, habitat and ecological corridors that facilitate the movement of wildlife.

Blocks of forest plantation interspersed with native forests set aside for conservation

To date, 822 faunal species and 1 905 plant species have been identified in Klabin´s forests, including many species of conservation concern listed on the IUCN Red List.

This mosaic forest management system implemented by Klabin demonstrates that integration of biodiversity conservation in forest plantation management is possible. Such measures not only support the company's sustainability strategy, but also provide long-term production benefits by maintaining the flow of ecosystem services that underpin forest productivity. Klabin's approach to sustainable forest development focuses on integrating responsible silviculture, genetic improvement of plantation species, and environmental conservation. Building on its forest management certifications, the company plans to pursue verification under the FSC Ecosystem Services Procedure[a] in order to demonstrate the positive impact of its forest management activities on multiple ecosystem services.

[a] https://fsc.org/en/document-centre/documents/resource/316

Source: Authors' own elaboration

connectivity. Such landscapes may also support water services, especially where vegetation along steep slopes and riverine buffers are protected, as well as other ecosystem services including pollination, pest control, scenic values and recreation.

7.3. MANAGING RESTORATION RISKS

Guiding principles of restoration

Despite the potential of restoration to provide a wide range of benefits to society, there are also some risks associated with restoration, not least because of the pressure on countries to deliver on commitments that may be unrealistic (Fagan *et al.*, 2020). These risks include: the potential for the focus on restoration to divert attention away from addressing the ongoing deforestation and forest degradation, or even accelerating it by displacing agriculture and other land uses to existing forest areas; insufficient focus on local needs and livelihoods; falling short of expectations due to a failure to build in climate resilience; and the use of inferior planting materials (Edwards *et al.*, 2021a).

To minimize these risks, guiding principles for forest restoration have been developed under various initiatives, including the Global Partnership on Forest and Landscape Restoration (GPFLR)[30] (Besseau, Graham and Christophersen, 2018), the UN Decade on Ecosystem Restoration (FAO, IUCN CEM and SER, 2021) and Di Sacco *et al.* (2021).

The common elements identified in all of these principles include:

- maintaining and enhancing existing natural forests;
- engagement of multiple stakeholders and focus on governance;
- restoring for multiple benefits with a focus on maximizing biodiversity recovery;
- tailoring interventions to the local ecological, cultural and socioeconomic contexts;

[30] www.forestlandscaperestoration.org

- adaptive management for long-term resilience; and
- ensuring long-term sustainability, including economic sustainability.

If these principles are rigorously applied, potential risks of restoration can be avoided or managed to a large extent and restoration can be leveraged to generate multiple benefits for local communities, as well as for climate change mitigation and biodiversity conservation.

Maintaining focus on avoiding deforestation and degradation of existing natural forests

Tree planting has a strong appeal as a straightforward way of demonstrating and realizing forest restoration (Holl and Brancalion, 2020). However, unless safeguards are put in place, the restoration agenda risks diverting resources away from more effective and cost-efficient modes of biodiversity conservation and climate change mitigation (Edwards *et al.*, 2021a). It takes decades for restored forests to attain comparable levels of biodiversity and carbon storage as occurs in existing mature natural forests. Funds for restoration must therefore not divert resources from crucial protected area management activities, for which funding is grossly inadequate (Coad, Watson and Geldmann, 2019). Restoration is designed to achieve a broad set of development objectives, but it is nevertheless critical that support is maintained for other effective conservation activities, including avoiding deforestation, improving the management of existing forests and enhancing protected area management.

There are also risks that productive agricultural land is appropriated for forest restoration to meet restoration area targets, especially if the land in question is under state control (Fagan *et al.*, 2020). Given the need to massively increase agricultural productivity to meet the demands of growing populations and increased affluence (Tilman *et al.*, 2017), this is only likely to drive deforestation elsewhere. Forest restoration (as opposed to on-farm restoration, such as agroforestry, among others) should be targeted at areas supporting low agricultural productivity, where the ecosystem service values of forests exceed the opportunity costs of foregone agricultural production.

Last, there is a considerable debate surrounding restoration for climate change mitigation (Girardin *et al.*, 2021). On the one hand, forest regrowth is one of the few mechanisms that can enable countries to achieve net zero GHG emissions, because attaining zero emissions for most other sectors of the economy is impossible. On the other hand, even under the very ambitious scenario of restoring 678 million ha of native ecosystems by mid-century, global carbon sinks will be enhanced by only 2 Gt CO_2/year, which is less than 6 percent of the global GHG emissions in 2021 (Girardin *et al.,* 2021). Forest restoration is not a be-all and end-all strategy for climate change mitigation and needs to be coupled with approaches to decarbonize the economy, including reducing deforestation and forest degradation (Girardin *et al.*, 2021).

Balancing different stakeholder needs

Substantial funding for FLR will come from developed countries, whereas much of the restoration will take place in the Global South. The interest of donor countries will be on addressing global priority development issues, including climate change, poverty alleviation and biodiversity conservation, among others. Meanwhile, national governments in developing countries may wish to prioritize macro-economic development, for example, through expanding plantation forestry or by watershed restoration for irrigation schemes or urban water supplies. If the interests of these stakeholders dominate the dialogue, local cultural and livelihood interests may be overshadowed (Erbaugh *et al.*, 2020). Such a situation is likely to undermine the social benefits of restoration, as well as its permanence (Edwards *et al.*, 2021a). Indeed, disengaged local communities are unlikely to be incentivized to protect the restored forests, and future governments may reverse unpopular policies.

Community-based peatland restoration programme in Indonesia

As specified in the restoration principles, it is critical to address governance and associated issues, such as tenure and resource access rights. Land degradation reflects a failure of governance in managing natural resources sustainably. Thus, unless this underlying driver is addressed, restoration is unlikely to be successful. A focus on community-based forest management and building capacity in local government and communities is required for sustainable forest and natural resource management (Gilmour, 2016). The underlying inequalities in the distribution of benefits and costs need to be addressed, including through tenure adjustments and financial mechanisms, such as PES schemes. A focus on setting objectives locally, participatory monitoring and adaptive management is required.

Building in climate change resilience

Forests are both an important part of the solution to climate change and vulnerable to it (Seddon *et al.*, 2020; Edwards *et al.*, 2021a; Forzieri *et al.*, 2022). By increasing the uptake of atmospheric CO_2 and sequestering it in living biomass and soils, regrowing forests have enormous potential to help mitigate climate change (Girardin *et al.*, 2021). Conversely, deforestation and forest degradation can drive forests to flip from carbon sinks into sources (Gatti *et al.*, 2021). Forests and forest biodiversity are also vulnerable to climate change impacts, including increased frequency and severity of extreme climate events, especially droughts (Potts, 2003; Elias *et al*., 2020; Edwards *et al.*, 2021a; Forzieri *et al.*, 2022).

There are important trade-offs in tree adaptation to water availability. Under warmer temperatures, plants not only consume water faster but have a diminished capacity to restrict water loss during drought (Choat *et al.*, 2018; Brodribb *et al*., 2020). Higher temperatures and increased drought have already been linked with increased tree mortality, which is often skewed towards larger trees (Choat *et al.*, 2018). Under the current warming trajectories, models suggest large-scale mortality, range contraction and productivity loss through this century (Brodribb *et al.*, 2020). To counter climate change threats to existing and new forests, it is essential to promote diversity, both in terms of species and within species genetic diversity, which confers resilience, as well as allowing for gene flow and species migration through providing connectivity (Senior, Hill and Edwards, 2019).

Climate change can also increase fire risk. Large-scale fires alter hydrological regimes and drive changes in tree mortality, growth, and recruitment dynamics – both directly and indirectly through interactions with seed dispersers (McConkey *et al.*, 2011), pollinators (Harrison, 2000), and fungal symbionts (Harrison *et al*., 2013), as well as competitors (Gatti *et al.*, 2021). On a broader spatial scale, this will render some areas at an elevated risk for restoration investments, while other formerly inappropriate areas may become suitable.

Across all areas, the bioclimatic niches of species and forest types are expected to shift. For example, species may be expected to migrate up mountains in response to warmer conditions (e.g. Chen *et al.*, 2009). Hence, it is essential that national-scale restoration planning considers detailed climate predictions. This applies equally to forest restoration for ecosystem service provisioning and biodiversity conservation, as to commercial planting for timber or agroforestry. Where substantial uncertainty in climate models exists, as is often the case for changing precipitation dynamics, countries should focus on safer options initially and build in flexibility to alter plans as climate predictions improve (Gellie *et al.*, 2018). It will also likely become necessary to support assisted migration (Brodie *et al.*, 2021). Modelling of historical climates to determine the niche envelopes of seed sources and using climate predictions to establish the future distributions of those ecotypes will be essential for restoration success and the long-term resilience of forests (Edwards *et al.*, 2021a).

Genetic considerations and provision of quality planting material

To a substantial degree, restoration success will be determined by the quality of planning, including careful matching of species and genetic material to sites. Using seeds and seedlings of high genetic diversity and quality improves tree survival and hence more than compensates for the additional costs associated with establishing quality control processes for seed and seedling supply (**Box 6**; Nef *et al.*, 2021). Genetic quality is managed through selection of diverse seed sources, monitoring performance and filtering out poor stock. Restoration guides and other materials often suggest that local seed sources are best. However, this may not always be sound advice because of changing conditions driven by climate change (Thomas *et al.,* 2014; Breed *et al*., 2018; Bucharova *et al*., 2019). Planting material needs to be appropriately provenanced, so that the climate ranges of the planted tree species match the predicted future climatic conditions (Breed *et al*., 2013; Edwards *et al*., 2021a).

Establishing high quality seed and seedling supply systems is a prerequisite to successful restoration, but is far from straightforward, requiring substantial investment in knowledge for species selection and propagation, nursery infrastructure and market chains, and human capacity (**Box 6**; Thomas *et al*., 2014; Jalonen *et al*., 2018; Kettle *et al*., 2020). High quality restoration, especially in the context of climate change, requires an integrated learning and adaptive management approach.

High-quality seedlings in a nursery to be used for forest restoration

BOX 6.

Seed and seedling supply systems for restoration

A tree seed system can be considered as a value chain that begins with the source of tree seed (or seedlings) and ends at the market or user for the tree product or environmental service. A tree seed system encompasses the basic elements of seed production (including sourcing, collection, processing and storage, as well as nurseries for plant production), along with the assessment and control of seed quality (regulatory aspects). It also incorporates the distribution of seeds to users (markets), guidance for the use of seeds and seedlings, and the monitoring and communication of performance. Finally, it involves the development and maintenance of sources of seed (the conservation of tree genetic resources and tree breeding). Seed sources may be forests, farmland, plantations, seed orchards or clonal mother blocks (in this last case, for vegetative propagules rather than seed).

Tree seed systems can be formal, i.e. composed of public and private organizations with specialized or designated roles in production, distribution or regulation; or informal, i.e. being made up of private households, farmers and NGOs, disseminating material freely among each other (Lillesø *et al.*, 2011).

Most formal systems have been established with a commercial perspective or as a public investment to enhance the benefits of forest plantations, focusing primarily on improving forest productivity and in some cases on environmental benefits, including the conservation of biological diversity. Formal systems are important for restoration, biodiversity conservation, and climate change mitigation and adaptation at national levels, but they have their shortcomings. These include a focus traditionally on relatively few, often exotic, plantation species. Even with these formal systems (and the situation is worse for informal systems), most seed or seedling supply is of unknown genetic quality with little information on whether the material is adapted either to the current site conditions or future climates (Nyoka *et al.*, 2015; Jalonen *et al.*, 2018; Roshetko *et al.*, 2018).

A major challenge associated with tree-based ecological restoration is that it requires the use of many native tree species at the same time. Where these are diverse and healthy seed sources in the landscape, restoration may be possible through assisted natural regeneration. When planting is necessary, whether for replenishment or enrichment, securing the supply of a broad spectrum of genetically diverse, healthy and productive tree species is difficult due to limited availability. This bottleneck is a major challenge to be addressed if the current global restoration targets are to be achieved (Kettle *et al.*, 2020).

Another key challenge is to reach or include the variety of users. The value chain from seed source is often sub-optimal because many of the potential value chain actors are left out. To improve the current situation, it is necessary to unlock the potential of rural organizations, small-scale private nurseries and local communities to effectively participate in tree seed systems. This solution requires the integration of formal and informal approaches to tree seed supply, as well as support to develop informal suppliers into well-functioning business enterprises, making use of public–private partnership arrangements (Lillesø *et al.*, 2018).

Developing adequate tree seed supply systems for restoration requires knowledge of which trees to plant where and for what purpose, the capacity to communicate this know-how to inform tree planters, and the ability to provide appropriate trees for planting to users. Needed of course is the basic infrastructure of access to seed sources – for their collection, storage, conservation and testing – and for their distribution (Atkinson *et al.*, 2021).

This is a complex and resource-demanding process. The essential protocols required include:

- Assessment of tree species suitability in current and future climate. With over 60 000 tree species in the world across different climates and ecosystems, this is a major task.
- Species and seed source descriptions, including appropriate protocols for the assessment and monitoring of performance, and management prescriptions to improve use and performance. These currently exist for relatively few tropical tree species.
- Species and seed source recommendations for the specific geographies and intended uses. Ideally, such recommendations would also provide information on the benefits and returns that can be expected from their use and would include the mainstreaming of biodiversity.
- Mapping of the users and producers of seed, the priorities and demand of users and the supply capacity of producers.

Establishing tree seed supply systems for restoration in practice is still very much in its infancy, especially for native tree species in the tropics that have assumed increased importance for reaching biodiversity targets. The major challenge is to integrate existing knowledge at an early stage, while considering seed supply as an integral feature for success.

A well-functioning system that efficiently meets the evolving demand for quality seed and seedlings has four basic characteristics:

- User demand is based on knowledge of the benefits of using quality planting material.
- Effective production and distribution systems cater to users with a variety of appropriate portfolios of tree diversity.
- Supportive policies and regulations promote adequate tree seed supply systems among seed dealers and nursery entrepreneurs.
- Sustainable management and conservation of genetic resources are for use in current and future climates.

Restoration programmes should consider these elements in their planning, including genetic business plans as part of their programmes, in order to ensure well-informed choices in the use of planting material. Such plans need to be in place well in advance of restoration implementation.

Source: Elaborated by Lars Graudal

8. Biodiversity monitoring in forests

8.1. INTRODUCTION

Biodiversity indicators provide information that enables the detection of changes in the state of biodiversity and measurement of progress towards achievement of specific biodiversity objectives (Werner and Gallo-Orsi, 2016). There has been much written on the topic of biodiversity indicators with mixed results in terms of the links between the indicators and the biodiversity being monitored. For example, a review of biodiversity indicators across European forests found that only six of the 412 correlations between indicator and *indicandum* (the subject or aspect of biodiversity to be indicated) investigated represented strong evidence of a correlation (Gao, Nielsen and Hedblom, 2015). In part, this reflects the fact that biodiversity is a complex multifaceted concept, encompassing both the variability among living organisms and the ecological complexes of which they are part, and that many components are difficult or impossible to assess directly. In addition, the biodiversity indicators developed for one process (e.g. national conservation planning) may have limited applicability to other processes (e.g. forest management). Last, a set of indicators will reflect the interests of the stakeholders who selected them and may not adequately address the views of non-represented stakeholders. Unfortunately, when biodiversity indicators are not well designed, forest managers may come to view them as a nuisance, rather than as an opportunity for facilitating improved management, which is likely to compromise biodiversity outcomes.

As biodiversity monitoring is often expensive, common sense needs to be applied with respect to the selection of indicators, as well as to the intensity and frequency of monitoring. Certain indicators might be collected on a continuous basis, such as the records of people and vehicles entering and leaving the management area or the amounts of timber or NWFPs being transported. Some indicators may be monitored sporadically, covering particular management activities. For example, stand level data on large tree densities, the amount of dead wood, and the number of hollow trees and critical fruit resources may be recorded during pre- and post-harvest inventories. Other methods, for example, camera trap surveys of large mammals, may only be conducted once every ten years or continuously, but at low intensity. Opportunities to make cost savings through the use of remote sensing (Swinfield *et al.*, 2019; Skidmore *et al.*, 2021) or other technologies, such as soundscapes (Burivalova *et al.*, 2021) and DNA meta-barcoding (Zhang *et al.* 2016), should also be considered.

Perhaps most importantly, there should be clearly defined management responses to the indicator values. This requires that targets are agreed through the objective setting process (Hagan and Whitman, 2006). For example, it may be decided that 20 percent of a forest management area should be left as set-aside and that this should include all slopes greater than 25 degrees, required buffer zones on all watercourses, 100 percent of threatened habitats and not less than 10 percent of all other habitat types. Likewise, the objectives may require that a specified density of defined fruit resources, standing and fallen deadwood, large trees and hollow trees are retained in harvested stands. Such objectives set clear guidance to the forest manager on the responses required when monitoring data indicate that a target is not being met. Too often, biodiversity monitoring data are laboriously collected, entered into a computer, displayed as charts or spatial information, but no management response is triggered. In such cases, biodiversity monitoring simply adds to the burden of the forest management bureaucracy without serving its intended purpose.

8.2. DEFINING BIODIVERSITY OBJECTIVES

Defining the biodiversity objectives is the most important step in developing a biodiversity management plan and should be an integral part of the forest planning process (Hagan and Whitman, 2006; Sheil, Nasi and Johnson, 2004; Lindenmayer, Franklin and Fischer, 2006). To select an appropriate set of biodiversity indicators, it is first critical to define what the biodiversity objectives are (Failing and Gregory, 2003; Hagan and Whitman, 2006; Sheil, Nasi and Johnson, 2004). Objective setting involves some level of value judgments about the desired biodiversity outcomes, which may be dictated by legal or certification requirements, as well as the concerns of local stakeholders. For example, an objective might be that legal obligations for protecting threatened species and habitats are met. Another might be that Indigenous Peoples and local community resource access rights are respected, while guaranteeing sustainable management of harvested NWFPs. Broad stakeholder engagement in the process of selecting biodiversity indicators is essential to ensure legitimacy (Hagan and Whitman, 2006).

The objective setting process will be guided by national legislation on biodiversity and forest management, but in many cases may be expected to go further, especially where local interests dictate. Objectives may include:

1. Landscape level outcomes
   - proportion of mature forest protected, threatened habitats protected, area under natural forest management or plantations;
   - area of other natural habitats (e.g. open land and wetlands);
   - connectivity within the forest management area and across the wider forest landscape; and
   - provision of ecosystem services and scenic values.
2. Indigenous Peoples and local community rights
   - recognition of resource access rights and provision of livelihoods; and
   - protection of cultural values.

*Cameroon greenbul (*Arizelocichla montana*), a Near Threatened species on the IUCN Red List, netted as part of forest biodiversity monitoring*

3. Sustainable management of forest resources, including timber, plant-based NWFPs and wildlife (game species)
4. Protection of threatened species, including resources critical to their survival
5. Maintenance of stand level structural diversity and important biodiversity resources
6. Minimizing impact of forest management activities (e.g. timber harvesting) on biodiversity
7. Reduction of threats to biodiversity, including fires, poaching, encroachment and invasive species
8. Species reintroductions and assisted migration

8.3. IDENTIFYING APPROPRIATE INDICATORS

Biodiversity indicators can be categorized into those that describe the composition of biodiversity (e.g. species abundance, presence of threatened species, genetic diversity), those that relate to structure (e.g. population structure, habitat, landscape connectivity), and those that relate to functions (e.g. ecosystem processes and population dynamics) according to their organizational levels (Clergue *et al.*, 2005). Some indicators may also be designed to capture compliance with regulations and management prescriptions (Lindenmayer, Margules and Botkin, 2000).

Species community data

In the biodiversity indicator literature, it is often assumed that by collecting data about species communities something is achieved. For example, understorey birds, butterflies and dung beetles are among the groups that are often recommended as being good biodiversity indicators (Aguilar-Amuchastegui and Henebry, 2007; Kessler *et al.*, 2011), although almost all taxa – from leeches (Drinkwater *et al.*, 2020) to tardigrades (Miller, 2004) – have been recommended by someone at some point in time. However, community data and their relation to changes in the environment are difficult to interpret (Legendre and Legendre, 2012).

First, community datasets tend to be highly variable and separating signal from error is far from straightforward (Ramage *et al.*, 2013). Composition varies because of the failure to detect a species or to measure its abundance with sufficient accuracy (i.e. error variance) and because species populations are not evenly distributed in time and space. For example, certain species have fine-scale habitat preferences, while some mobile species may use different habitats seasonally. In addition, an individual's home range may have core and peripheral areas, or an individual may be transient at a site (e.g. when dispersing). Furthermore, there may be natural fluctuations in species populations that bear no relation to the impacts of forest management. Effects of forest management may be season dependent (Hamer *et al.*, 2005) or climatic effects may be more important than management actions (Hill *et al.*, 2003). High variation in community composition means that intensive data collection efforts are required to yield sufficient data in order to draw meaningful conclusions, especially in highly diverse environments such as tropical rainforests (Ramage *et al.*, 2013).

Second, different taxa respond differently to habitat changes at various scales, and therefore, the sampling scale is of paramount importance. For example, a meta-analysis found that forest disturbance causes bird diversity to decrease at small spatial scales and increase at large spatial scales, whereas butterflies follow the opposite pattern (Hill and Hamer, 2004).

Butterflies are often proposed as biodiversity indicators for their rapid responses to habitat and climatic changes

Last, there needs to be a clear expectation of the direction and amount of change following management intervention. Simply showing that there is a significant difference does not necessarily prove causation, because a certain amount of change will be expected following forest management activities. What is needed is a model that can separate the change expected under optimal management from that of when management is poor. Rarely are such models available for even the best studied taxa in the best studied sites.

In a research context, it may be interesting to study the impact of different interventions on species communities, for example, comparing the implementation of RIL against conventional logging practices, where the less perturbed system would presumably perform better (Asad *et al.*, 2021). It is important to advance best practice for biodiversity management through such trials. It would also be useful to investigate the amount of time required for species communities to recover to a state close to pre-intervention depending on the type and intensity of disturbance (Gilroy *et al.*, 2014b). However, outside of research scenarios, species community data make for impractical biodiversity indicators. Data are expensive to collect, specialists from academic institutions are often required to identify collections, and most importantly the data do not usually generate actionable information.

Rare and threatened species

Conserving rare and threatened species should always be an objective of forest biodiversity management and is usually a legal requirement. Unfortunately, however, rare species also make poor biodiversity indicators. First, they are often hard to detect. This poses something referred to as the Water Babies problem: "no one has a right to say that no water babies exist till they have seen no water babies existing, which is quite a different thing, mind, from not seeing water babies" (Kingsley, 1863). Second, low population densities can make it almost impossible to determine whether a population is increasing or decreasing. For example, despite an enormous camera trapping effort, the 95 percent confidence interval for a recent estimate of the tiger population in northern Myanmar was 7–71 (Lynam *et al.*, 2008). Conservation NGOs or wildlife researchers may advocate for intensive camera-trapping efforts, particularly if charismatic species such as tigers are present, but such data are unlikely to inform management. Again, studies of rare species may be meaningful in a research context but should be carefully evaluated before being recommended as a tool for biodiversity management in forests.

Applying the precautionary principle, one might determine a list of rare and threatened species that could or should be present, based on information about species' distributions and habitat preferences, or using tools such as the *Map of Life*[31] (Moura and Jetz, 2021; Jetz, McPherson and Guralnick, 2012), which may be supported by mixed approaches to confirm presence (e.g. camera traps, sign surveys, bioacoustics). Local forest users will also often have a detailed knowledge of the distribution of certain rare species (Padmanaba *et al.*, 2013).

[31] https://mol.org

This information can then be used to develop management plans based on best practice guidelines. However, it will rarely be possible to know if the actions taken are actually effective in protecting a rare species (at least over timescales that are meaningful to management). Hence, it will often be more practical to monitor indicators reflecting threats and management responses, such as the poaching pressure and enforcement actions taken (**Table 2**).

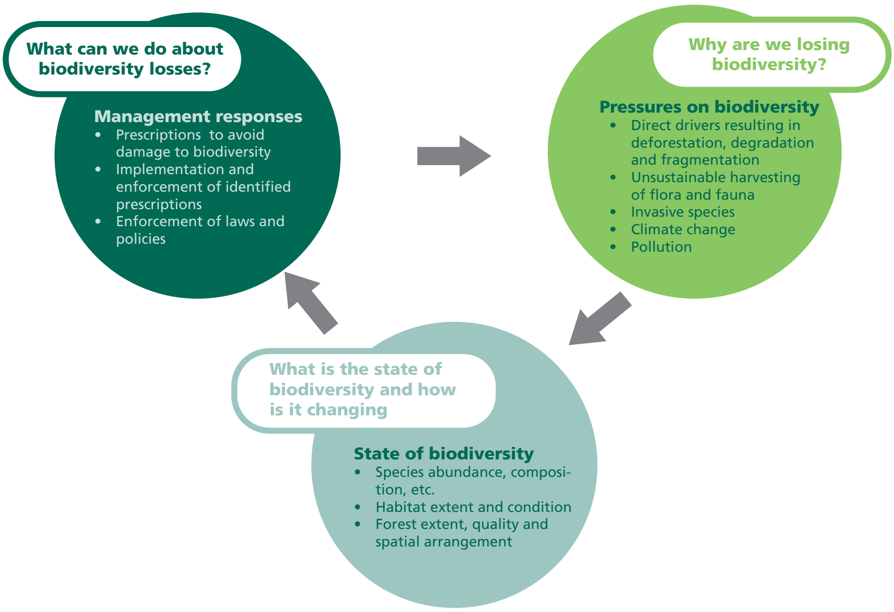
*Bornean orangutan (*Pongo pygmaeus*), a Critically Endangered species on the IUCN Red List, chained and held in prolonged captivity at the back of a house in a village.*

Pressure–state–response framework

A number of authors advocates the pressure–state–response framework (**Figure 2**), whereby indicators for each biodiversity objective are identified under each category (Hagan and Whitman, 2006). Pressure indicators would include assessments of hunting or harvesting pressure and impacts of forest management (e.g. logging) on species. If a biodiversity objective is that rare and threatened species are protected, a state indicator would be information pertaining to rare and threatened species, such as projected or confirmed species' presence and the distribution and availability of any known critical resources for those species within the forest management area. Response indicators would include management prescriptions to avoid disturbance or damage to critical resources. Some authors have suggested adding a benefit category to this framework in order to capture the benefits to people derived from biodiversity (e.g. Sparks *et al.*, 2011), although this may be more relevant at national scales than to forest managers.

A list of possible biodiversity indicators for forest management is given in **Table 2**. For each conservation objective, the relevant spatial scale is indicated, along with three groups of possible indicators, under the pressure–state–response framework. In practice, indicators should be locally relevant and selected through a broad stakeholder consultation process.

Figure 2. Pressure–state–response framework



Source: modified after Werner, F. A. & Gallo-Orsi, U. 2016. Biodiversity monitoring for natural resource management – An introductory manual. GIZ, Eschborn and Bonn, Germany

Good biodiversity indicators

Monitoring should supply information to support efficient biodiversity management, but not require so much effort as to divert attention from critical activities, such as the supervision of forestry crews and enforcement. As we have seen, the approach of monitoring biodiversity itself is often insufficient, ineffective or impractical due to the time and effort required and the fact that it is often difficult to link observed changes in biodiversity to management actions or the drivers of biodiversity loss. Monitoring pressures and management responses, which are supposedly linked to biodiversity outcomes, allows for practical measurement of progress towards achieving the established biodiversity objectives, albeit with lower confidence (Rao, Stokes and Johnson, 2009). In addition, modern tools such as remote sensing with drones (Baldeck *et al.*, 2015; Swinfield *et al.*, 2019) or satellites (Czyż *et al.*, 2020; Skidmore *et al.*, 2021), bioacoustics (Bradfer-Lawrence *et al.*, 2020; Burivalova *et al.*, 2021), DNA meta-barcoding (Yang *et al.*, 2014; Zhang *et al.*, 2016) and machine learning (Tuia *et al.*, 2021) may be used to reduce monitoring costs, although there are costs associated with the processing and analysis of data to be considered (Kitzes and Schricker, 2019).

Reviewing how data are collected (e.g. using tablets), processed and presented can also greatly reduce costs and increase the utility of data by making them available in a timely manner. All too often, data are entered into spreadsheets that sit on a computer until the next report is due, whereas data pipelines can be largely automated with a little upfront investment so that the data on a tablet go straight to an online dashboard that generates alerts as required. Efficiency can also be gained by collecting monitoring data as part of regular forest management activities. Conversely, some critical biodiversity resources may only be seasonally relevant, such as nests or roost sites, and so only require monitoring in the appropriate season.

Finally, indicators must also be locally relevant (Hagan and Whitman, 2006; Lindenmayer, Franklin and Fischer, 2006). Although some indicators are commonly applicable to many situations, rarely, if ever, are they universally applicable. Therefore, application of local knowledge in the selection and monitoring of indicators is crucial (Joa, Winkel and Primmer, 2018). Local people will be able to identify the resources that are important to them and determine whether they have declined or not in recent years. Such dialogue may serve as a useful entry point for collaboration, which can also greatly reduce survey costs as local people are often able to identify the location of threatened species or habitats (Padmanaba *et al.*, 2013).

Aside from local communities, local interest groups may also have important knowledge and skills to contribute to biodiversity management. For example, local birders may be able to identify important roost or nest sites, and may be willing to support surveys (Pocock *et al.*, 2018). Ultimately, good biodiversity management results from good forest management where forest planning is based on broad stakeholder consultation (Hagan and Whitman, 2006; Sheil, Nasi and Johnson, 2004).

Hagan and Whitman (2006) identify five criteria that all biodiversity indicators should satisfy.

1. Scientific merit: The indicator should be a reliable metric, ideally with good scientific support for setting target levels (e.g. amount of connectivity required). Unfortunately, for many components, scientific support for setting levels may be sparse or lacking, especially in diverse tropical systems. However, where this is lacking, best practice guidelines developed through broad stakeholder consultation provide a reasonable substitute.
2. Ecological breadth: The metrics used should relate to as broad a set of biodiversity components as possible. For example, connectivity is relevant to landscape and evolutionary processes, climate change resilience, and the maintenance of habitat, species and genetic diversity.
3. Practicality: It is essential that indicators are cost efficient in measuring and generating information in a timely manner.
4. Utility: The metric should generate actionable information for the forest manager.
5. Relevance: The metric must provide information about the biodiversity components that are of interest to stakeholders.

In addition, it is important to consider the frequency of assessment and spatial scale that is appropriate for the indicator in question. It is also crucial that an element of adaptive management is built into the process. Depending on national forest regulations, forest managers usually need to present reports and revise forest management plans periodically, for example at five- or ten-year intervals. These revisions present an opportunity to review performance on broad targets, such as the condition of set-aside areas and threatened habitats or targets for threatened species, as well as provide summations of data collected at shorter intervals over the intervening period. Such syntheses should be reported back to stakeholders and used to update forest management plans including, if necessary, revising management protocols if the objectives are not being met. For example, if threatened habitats have been damaged or threatened species are declining, this might signal a need to alter management plans to better protect these biodiversity resources.

As stated above, indicators should be locally relevant and selected through a broad stakeholder consultation process. Hence, the list of indicators and the targets provided here are meant to be suggestive. The table presents the biodiversity objective and components covered in the first column, with the relevant spatial scale and some management notes in the second column. The next three columns present indicators for the selected biodiversity objective under the pressure–state–response framework, respectively.

TABLE 2.
Biodiversity indicators for forest management

Biodiversity objective and biodiversity components covered	Spatial scale, monitoring frequency, and notes on management	Pressure indicators	State indicators	Response indicators
Protection of mature/old-growth forest, threatened habitats, and non-forest habitats Conservation of habitat, species and genetic diversity Provision of high quality genetic material (i.e. seeds and seedlings) for natural regeneration and planting	Landscape Set-aside areas determined in spatially explicit forest management plan[32] Continuous monitoring in areas with ongoing forestry activities (e.g. harvesting and road building)	Proportion of mature/old-growth forest and different forest habitats/types impacted by planned forest management Proportion of threatened habitats impacted by planned forest management Proportion of non-forest habitats impacted by planned forest management	Area of mature/old-growth forest, and different forest habitats/types Area of threatened habitats Area of non-forest habitats	Proportion of mature/old-growth forest and different forest habitats/types under set-aside (15–20 percent) Proportion of threatened habitats under set-aside (100 percent) Proportion of non-forest habitat under set-aside (80–100 percent) Set-aside boundaries marked on the ground (100 percent in areas with active forest management) Monitoring of forestry crews and patrolling of set-aside areas to prevent and record infractions Inventory, monitoring, and management of tree and NWFP seed sources
Connectivity among habitats maintained within the forest management area and as a component of the wider forest landscape Conservation of species and genetic diversity Climate change resilience	Landscape Set-aside areas for connectivity determined in spatially explicit forest management plan Monitoring continuously in areas with ongoing forestry activities (e.g. harvesting and road building)	Reduction in habitat connectivity	Proportion of different forest habitats/types connected[33] within the forest management area to form units of more than a certain minimum area[34] Proportion of different forest habitats/types connected to forest habitats in the wider forest landscape	Set-aside areas for connectivity delineated in spatially explicit forest management plan Set-aside boundaries marked on the ground (100 percent in areas with active forest management) Monitoring of forestry crews and patrolling of set-aside areas to prevent and record infractions

32 Forest management plans should be revised and updated regularly, e.g. every 5 years.
33 Connected should be defined by local best practice guidelines that indicate a minimum width of continuous natural forest canopy.
34 The appropriate minimum area will be forest type specific, but ideally should be sufficient to maintain viable populations of all species.

Biodiversity objective and biodiversity components covered	**Spatial scale, monitoring frequency, and notes on management**	**Pressure indicators**	**State indicators**	**Response indicators**
Protection of ecosystem services and scenic values Protection of ecosystem services and scenic values Climate change resilience	Landscape Set-aside areas for protecting ecosystem services and scenic values determined in spatially explicit forest management plan Monitoring continuously in areas with ongoing forestry activities (e.g. harvesting and road building)	Proportion of set-aside area for ecosystem service and scenic value protection potentially impacted by forest management activities	Area of forest identified as critical for protection of ecosystem services	Set-aside for protection of ecosystem services and scenic values delineated in spatially explicit forest management plan Set-aside boundaries marked on ground (100 percent in areas with active forest management) Monitoring of forestry crews and patrolling of set-aside areas to prevent and record infractions
Recognition of rights of Indigenous Peoples and local communities Ensuring equitable access to and use of biodiversity Support to livelihoods Climate resilience for Indigenous Peoples and local communities	Landscape Depending on the resources, this may require delineation of set-aside areas, protection of forest features that supply NWFPs, or granting access for collecting and hunting[35] within the forest management area	Proportion of set-aside area for Indigenous Peoples and local community resources potentially impacted by forest management activities Important NWFP resources potentially impacted by forest management activities Reduction in resources available to Indigenous Peoples and local communities due to forest management activities	Areas within the forest that are critical for protection of resources for Indigenous Peoples and local communities List of important NWFP resources List of resources collected and hunted by Indigenous Peoples and local communities Population with legitimate access to resources identified	Set-aside for protection of Indigenous Peoples and local community resources delineated in spatially explicit forest management plan Set-aside boundaries marked on the ground (100 percent in areas with active forest management) Monitoring of forestry crews and patrolling of set-aside areas to prevent and record infractions

35 These activities may necessitate issuing permits to identify legitimate users and enable sustainable management of resources.

Biodiversity objective and biodiversity components covered	Spatial scale, monitoring frequency, and notes on management	Pressure indicators	State indicators	Response indicators
Protection of cultural values	Forest management area Continuous Sites or features of cultural values present in the forest management area may require protection	Potential of forest management activities to impact cultural values Capacity of staff and contractors to implement standard operating procedures (SOPs) for management of cultural values	Identified cultural values requiring protection	SOPs for management of cultural values in forest management plan Mapping and marking of identified cultural values on the ground Investment of human and capital resources in management of cultural values
Sustainable management of forest resources, including timber, NWFPs and game species Sustainable use of biodiversity Conservation of genetic diversity Climate change resilience	Habitat to landscape Continuous monitoring of harvesting, with periodic monitoring of species' densities (and where appropriate, population structure)	Harvesting rates measured through appropriate means (harvesting records, monitoring at checkpoints, survey, etc.) Capacity of staff, contractors and local communities to implement resource management SOPs	Species densities pre- and post-harvest (or at periodic intervals for some NWFPs) Population structure, especially the presence of juvenile cohorts Game densities, or indices such as sign encounter frequencies	Forest management plans include estimation of sustainable harvesting rates Genetic management plans are in place for harvested species, including the inventory, conservation and management of tree and NWFP seed sources Investment of resources (human and capital) in sustainable management of harvested resources
Protection of threatened species and resources critical for their survival Conservation of habitat, species and genetic diversity Protection of rare and threatened species	Habitat to landscape Continuous monitoring with periodic summations Monitoring focuses on measuring pressures/risks (e.g. hunting or collecting) and management responses	Risks from direct exploitation and forest management activities (e.g. disturbance of breeding sites; degradation of habitat) Capacity of staff and contractors to implement SOPs for managing critical resources for threatened species	Presence (confirmed or likely) or area of occupancy Location and density of resources critical to survival of threatened species	Monitoring (including spot checks, video monitoring, counting snares and cartridges) of illegal exploitation at access points and through patrolling Investment in education and awareness-raising activities with local communities Investment in managing resources critical to the survival of threatened species

Biodiversity objective and biodiversity components covered	Spatial scale, monitoring frequency, and notes on management	Pressure indicators	State indicators	Response indicators
Maintenance of important habitat features and biodiversity resources Conservation of habitat, species and genetic diversity Protection of fine-scale habitat features (e.g. large trees, hollow trees, dead standing and fallen trees) and biodiversity resources (e.g. fruit resources, salt licks, nest trees, and roost sites)	Feature (i.e. small-scale habitat element) to habitat Monitoring normally entails pre- and post-harvesting assessments. May involve seasonal assessment of, for example, nesting habitat Usually pertains to management of timber harvesting but could apply to other activities, such as planting or recreation	Rate of loss or damage to important habitat features and biodiversity resources at stand level Capacity of staff and contractors to implement SOPs for protecting important habitat features and biodiversity resources Proportion of contract values linked to performance in implementing SOPs for protecting important habitat features and biodiversity resources	Densities of important habitat features and biodiversity resources at stand level	Important habitat features and biodiversity resources identified in forest management plan with specifications for management Implementation of pre- and post-harvest surveys, mapping and marking important habitat features and biodiversity resources Investment in managing important habitat features and biodiversity resources, including knowledge concerning their role in and importance for biodiversity conservation
Minimizing the impact of forest management activities on biodiversity Conservation of habitat, species and genetic diversity Protection of ecosystem services Facilitating recovery	Habitat to landscape Continuous monitoring or pre- and post-forestry activities (e.g. planting or harvesting) Impact of forest operations on biodiversity is usually managed by following best practice guidelines (e.g. reduced impact logging).	Capacity of contractors and forestry crews to implement best practice guidelines Proportion of contract values linked to performance on implementing best practice guidelines	Area of forest (length of roads) managed under best practice guidelines Implementation quality of best practice guidelines	Investment in training staff and contractors in best practices Investment in supervision of activities

Biodiversity objective and biodiversity components covered	Spatial scale, monitoring frequency, and notes on management	Pressure indicators	State indicators	Response indicators
Reducing risks of secondary impacts to biodiversity	Feature, habitat to landscape Frequency and design of monitoring depends on the type of threat[36] Threats to biodiversity should be identified in the forest management plan and specific threat management plans developed	Estimates of how different forest management activities increase or decrease the severity of identified risks	Area of FMU occupied or at risk from threat List of species at risk from threat Estimates of risk severity	Specific threat management plans developed to reduce overall threat and reduce negative impacts of forest management activities Investment in implementation of threat management plans Metrics associated with specific plans (e.g. areas along roads monitored for invasive species)
Species reintroductions and assisted migration Conservation of species and genetic diversity Restoration of natural ecosystem dynamics Climate change resilience	Habitat to landscape scales Monitoring of populations continuously (e.g. satellite collars) to annually (e.g. seedling survival) depending on taxa Species reintroductions and assisted migration would normally be conducted as part of a national strategy and with external funding	Impact of forest management activities on populations Threats from exploitation (e.g. hunting), fire, invasive species, among others	List of locally extirpated species Species for assisted migration programmes fitting climate niche provided by the forest management area identified Populations of species being reintroduced or introduced under assisted migration	Areas designated for species reintroductions/ assisted migrations Plans for managing species reintroductions/ assisted migration Investment in species reintroductions/ assisted migration programmes

Source: Authors’ own elaboration

[36] For example, fire risks may only need monitoring during dry season, whereas invasive species may require monthly monitoring, but only in affected areas.

PART 3. CASE STUDIES

To illustrate the status, progress and lessons learned with respect to biodiversity mainstreaming in the global forest sector, a series of country case studies were conducted in collaboration with national experts. Eight countries were selected with a view to providing a diversity of examples considering: geographical balance; type of forest biome (tropical, subtropical, temperate, and boreal); the state of national forest resources (in terms of forest cover percentage); focus of forest management (e.g. timber production, conservation and restoration); the nature of forest use by local communities; and the national development status. The countries selected were: the Democratic Republic of the Congo, Ethiopia, Finland, Japan, Malaysia, Mexico, Peru, and the United Kingdom (case from Scotland).

As with the main report, the focus of the case studies was on forests managed for various services and benefits including timber, fuelwood, livestock grazing and foraging, NWFP harvesting and provision of ecosystem services – especially water and carbon, rather than those managed specifically for biodiversity conservation, such as national parks and other strictly protected areas. The case studies also considered how biodiversity concerns are incorporated into forest restoration efforts.

The studies were conducted through a combination of stakeholder consultations and literature review, focusing on nationally relevant documents, such as government policy statements and laws. Coverage of academic literature pertained to only those studies directly relevant to the country in question to avoid duplication with the main report. The case studies examined the following topics:

1. Links between policies and regulations for biodiversity and forestry.
2. How Indigenous Peoples and local communities and their rights are considered in forest management and how this relates to biodiversity management.
3. Institutional arrangements for biodiversity management in forests and how cross-sectoral barriers are bridged (or not).
4. National experience on forest biodiversity management and how this experience varies across different management types, such as community forests, timber concessions and restoration projects.
5. Lessons learned from the national experience

The full reports are available as Supplementary material[37]. Here we present summaries and key lessons learned.

[37] Web link under preparation.

9. Democratic Republic of the Congo

By Marie-Bernard Dhedya Lonu

Supporting tropical moist forests in the Congo Basin, the Democratic Republic of the Congo hosts high levels of biodiversity. The perception of an abundance of resources and prioritization of protected areas as a mechanism for biodiversity management has resulted in less attention paid to better management of production forests, although there is now recognition that improving the management of biodiversity in forests outside protected areas is an important consideration.

There are some laws, decrees and orders that mandate and support biodiversity management in the Democratic Republic of the Congo. In addition, national strategies on biodiversity conservation in protected areas, community forestry and indigenous conservation areas promote biodiversity conservation and the involvement of Indigenous Peoples and local communities in these efforts.

However, it is perceived that these national laws are often not conducive to the integration of biodiversity in all relevant sectors and areas, including in forests outside protected areas, for several reasons. First, laws are often general and are limited to setting out the principles of biodiversity management without being accompanied by provisions for their implementation. Second, laws that lack harmonization across sectors may lead to inter-institutional conflicts. Third, many laws are not adapted to the current realities and imperatives of biodiversity management.

In addition, the rights of Indigenous Peoples who depend on forest biodiversity are not well recognized, except in some specific strategies such as community forestry and indigenous conservation areas, which must be strengthened.

Finally, the management of biodiversity focuses more on the animal and plant species, especially in protected areas, and other components (e.g. soil or aquatic biodiversity) or scales (e.g. ecosystem or landscape) are not given adequate attention.

Key findings include:

- Laws, policies and national strategies for biodiversity conservation should take into account forests other than protected areas.
- Biodiversity mainstreaming is required across all sectors that impact it (mining and land, among others).
- The well-being of Indigenous Peoples must be prioritized for their better integration into biodiversity conservation initiatives.
- The involvement of Indigenous Peoples, local communities and the private sector in biodiversity management should be a priority.

Forest and agricultural land mosaic near Yangambi, the Democratic Republic of the Congo

10. Ethiopia

By Fabio Pedercini, Lars Graudal, Søren Moestrup, Wubalem Tadesse and Ian Dawson

Ethiopia harbours enormously important forest biodiversity in a global context. Our review of the various government proclamations, strategies and policies affecting the conservation and sustainable use of this diversity indicates that most of the required policy framework for mainstreaming biodiversity in forest management is in place. However, there are some important gaps, such as a lack of documentation on species that should be protected and inadequate definitions of institutional mandates and instruments for cross-sectoral collaboration. Consulted stakeholders were of the view that the implementation of existing policies and strategies is weak overall. Barriers to mainstreaming include: the frequent restructuring of government institutions (and consequent erosion of institutional memory); conflicts in mandates between different levels of government; prior emphasis on agricultural expansion, which was often at the expense of forests; and insufficient capacity, especially in sub-national governments. Considering one specific forest restoration initiative, the most important supporting features for successful biodiversity mainstreaming are the involvement of the relevant government partners and capacity development across the range of actors, including government, private sector and local communities.

Key actions for further mainstreaming of biodiversity in forestry include:

- Clarify institutional mandates and develop mechanisms for cross-sectoral and inter-departmental collaboration.
- Build capacity for sustainable natural resources management and biodiversity conservation across all levels of government, and among relevant private sector actors, communities and civil society organizations.
- Establish a monitoring mechanism for biodiversity policy implementation.
- Establish a list of priority tree species for protection.
- Identify a list of potential species that should be used in tree planting and characterize situations when and where the focus should only be on indigenous species.
- Provide support for developing tools to assist biodiversity and forest monitoring and intervention design, including a forest biodiversity database.

Dorze woman travelling through the mountains of Entoto carrying fuelwood to sell at the local market

11. Finland

By Matti Ylänne and Lauri Saaristo

Following the ratification of international agreements on forestry and biodiversity, Finland has developed policies, strategies and action plans to implement these commitments, including under European Union legislation. Policies, strategies and action plans are written in a practical way and are included in Finnish legislation usually within 1–3 years. Legislation is normally clear and easy to implement in practice. There are many high-quality institutions and organizations working in the forestry and nature management sectors, and hence the capacity for biodiversity management is high. Biodiversity and other aspects of nature management, such as water and scenery protection, started to become an integral part of forest management at the beginning of the 1990s. Nevertheless, mainstreaming biodiversity in forestry still needs to be promoted and encouraged, including by means of incentivizing forest owners, as 61 percent of forests are in private ownership.

Winter forest in Finland

Key findings include:

- When forests and wood have sufficient economic value, investment in research, education and other issues related to forests are easily justified.
- Forest regeneration after timber harvesting has been compulsory since 1886 in Finland, and destroying forests is illegal.
- National forest inventory has been conducted since the 1920s. It provides openly available data about Finnish forests and forest resources.
- Protection of valuable habitats and their biodiversity has been legislated since 1997.
- Substantial funding to support biodiversity interventions is available generally in society and in commercial forestry.

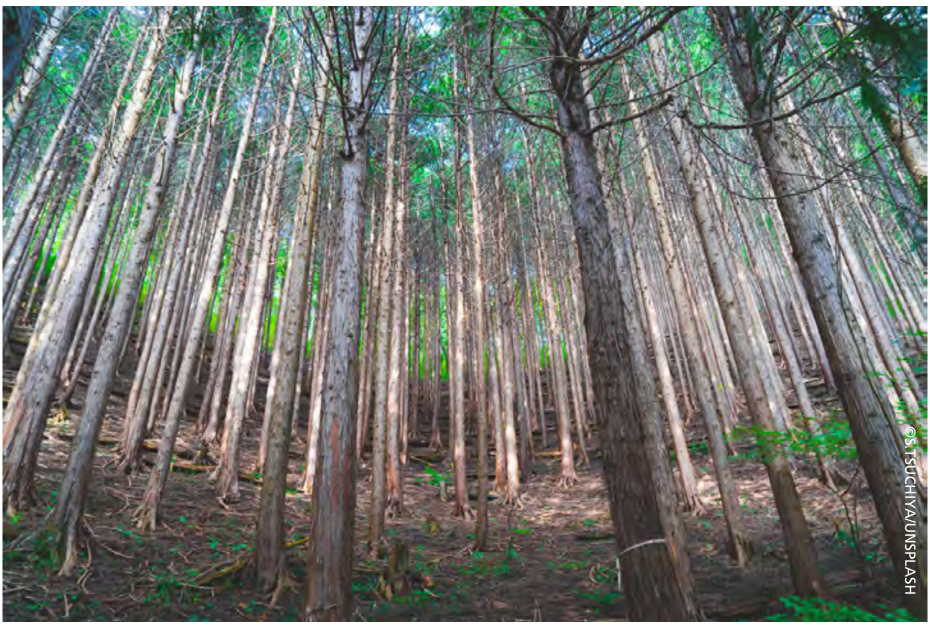
12. Japan

By Tohru Nakashizuka

Japan has a diversified system of area-based protection, implemented at national, provincial and local levels. This system includes national parks, which receive strict protection and are geared purely towards biodiversity conservation, albeit with co-benefits for scenic protection, recreation and other ecosystem services. Other designations are designed for protecting ecosystem services, or provide a mechanism to protect specific habitats or species occurrences, and operate through a system of licenses to control activities that may be detrimental to the conservation objective.

Changes in energy demand after 1950 led to the abandonment of broadleaf coppice forests or their conversion to coniferous plantations, which had a severe impact on forest biodiversity in Japan. Subsequently, many plantations were also abandoned, as the price of domestic timber became uncompetitive, leading to canopy overcrowding, shading out of undergrowth plants, erosion and other issues.

Various national and local government initiatives promote cooperation with the private sector to rekindle forest management. In addition, a number of



Forest plantation in Japan in need of thinning schemes, including the promotion of forest certification under national and international standards, environmental taxes, CO_2 credits linked to sustainable forest management and corporate social responsibility programmes, aim to improve forest management and restore biodiversity. For example, the Satoyama Initiative, which aims to restore traditional mosaic rural landscapes and their unique biodiversity, receives support from government (national and local), corporations, NGOs and community groups. Such initiatives are typically small in scale and characterized by management for multi-uses and broad stakeholder participation. The challenge for Japan is to scale up these initiatives in order to bring biodiversity into the mainstream.

Key observations include:

- The government should stimulate the forest sector to rekindle forest management.
- Forest certification should be mandatory or strongly incentivized.
- Novel partnerships for multi-use forest management, including with community groups, should be scaled up to impact a significant proportion of Japan's forests.

13. Malaysia

By Teckwyn Lim and Rhett D Harrison

The Malaysian Government recently published the Malaysian Forestry Policy (2021) which, for the first time, aligns forest policy, including forest biodiversity conservation, at the federal and state level. The Malaysian Forestry Policy provides a solid framework for mainstreaming biodiversity management across the national forest sector, including community forests and PES schemes. Nonetheless, several gaps are noted in the legislation pertaining to biodiversity protection and the rights of Indigenous Peoples. Specifically, there is no legal protection afforded to non-timber plants or the habitats or resource requirements of threatened species, and species protection is not related to threatened status. While Indigenous Peoples' rights are recognized in policy and in courts, this is not reflected properly in law. Furthermore, provisions for inter-agency cooperation, which is critical to enforcement efforts, are not specified in law or in the current policy, despite successful recent programmes involving multi-sectoral collaboration to bring down wildlife crime syndicates. Malaysia has a high uptake of forest certification and this has had a positive effect on biodiversity management in timber concessions. However, there is scope to improve transparency and

Primary tropical rainforest in Danum Valley, Sabah, Malaysia supports extraordinary biodiversity increase multi-stakeholder participation in the development of forest management plans. Best practice guidelines for sustainable forest management could also be improved, especially with respect to road specifications, and the current plantation development policy should be adjusted to avoid the conversion of natural forest.

Priority actions for biodiversity mainstreaming include:

- Implement actions based on the solid framework provided by the Malaysian Forestry Policy.
- Update legislation to protect non-timber plants, threatened species habitat and resources, and align protected status with threatened status.
- Recognize Indigenous Peoples' rights in law and expand community forest initiatives.
- Make explicit provisions for inter-agency cooperation at federal and state level.
- Enhance transparency and multi-stakeholder involvement in the development and monitoring of forest management plans.
- Diversify forest use through PES schemes and open forests that allow for recreation, other public uses and community forestry.

14. Mexico

By Clemencia Licona Manzur and Rhodri P. Thomas

Mexico is a biologically and culturally diverse country, which represents opportunities and challenges for managing resources, in particular forest ecosystems. For decades, Mexicans have worked to strengthen the institutional, legal, public policy and knowledge framework to manage natural resources, progressively incorporating considerations of pollution, climate change, and ecosystem and biodiversity management. The participation of Mexico in international initiatives has also prompted action at different levels. In this context, the government has initiated actions to mainstream biodiversity in the forestry sector.

Successes and failures in forest management – many under social land tenure conditions – can be found across the country, some of which consider biodiversity, and include the participation of different society sectors. There is a need for further harmonization and streamlining of institutions, policies and regulations, as well as better coordination across sectors and improved technological support. Opportunities can also be found in combining concerns and financial resources, such as in reforestation for ecosystem restoration and climate resilience. Using the experience of community forests, Mexico could become an example for biodiversity and SFM in the context of global change.

Priority actions for further biodiversity mainstreaming include:

- Simplify and harmonize regulations to reduce the burden of compliance.
- Clarify institutional roles and responsibilities to support the implementation of biodiversity mainstreaming and support cross-sectoral collaboration.
- Provide adequate long-term finance for SFM to support sustainable forestry projects, incentivize certification and meet targets for reduced deforestation.
- Address the issue of illegal timber and NWFP harvesting through regulation and enhanced awareness of the importance of Mexico's biodiversity.
- Empower community monitoring as a way to protect forest biodiversity.
- Promote reforestation that considers ecosystem restoration and resilience to climate change.

15. Peru

By Cesar Sabogal

Peru is among the countries with the greatest biological diversity in the world, with forests covering almost 72 million ha, mostly in the Amazon Basin. Continuous deforestation (around 10 million ha of forests lost so far) and degradation processes, however, threaten this rich capital. Although the recently updated NBSAP includes specific forest-related targets, Peru's National Strategy on Forests and Climate and the NDC do not explicitly incorporate forest biodiversity. The main policy and legal instruments in the forestry sector, however, explicitly include sustainable use of biodiversity and the benefits of biodiversity conservation.

The main challenges with regards to biodiversity mainstreaming are: unclear or divergent concepts and terms; a complex legislation not focused on implementation; overregulation and excessive administrative requirements; lack of specificity in the regulations; conflicting sectoral policies; and low political interest.

Indigenous Peoples' rights are incorporated into the forestry law, as well as in the NBSAP and the NDC. In practice, however, the land rights of Indigenous Peoples have not been a political priority, particularly where they collide with expansion plans for tourism, extractive industries and infrastructure development.

The institutional framework for mainstreaming forest biodiversity in forest management is affected by a series of challenges such as: institutional fragmentation (a sectoral divide between production and conservation); inadequate communication and collaboration among relevant institutions at the national and regional levels; ineffective participation of stakeholders; and a lack of human and financial resources for implementation. Nonetheless, there are a number of successful case studies, led by the private sector and civil society, to improve biodiversity conservation in production forests.

The following priorities are highlighted:

- Policy integration. Biodiversity must be recognized as a cross-cutting issue in the forestry and the agricultural sector with policies duly integrated at different government levels.
- Realistic regulations. The technical and cost implications of regulatory compliance need to be taken into account. Practical guides could be developed, considering local knowledge and experience.
- Broader, integrated vision for forest management and product value chain. There is a need to advocate for a more integrated vision for forest management by exploring options to add value to standing forests, e.g. generating income through NWFPs, ecotourism, among others. The State should more effectively support entrepreneurial initiatives to value biodiversity.

- Quantification of forest biodiversity. The value and contribution of biodiversity to the productive sectors have not been properly assessed and disseminated.
- Communication. The benefits of biodiversity, including their contribution to people's daily life and well-being, need to be convincingly communicated. Forest users need to be motivated and incentivized to implement good forest management practices.

Local women in Alto Mayo forest, Peru

16. United Kingdom of Great Britain and Northern Ireland (Scotland)

By Vanessa Burton and Alice Broome

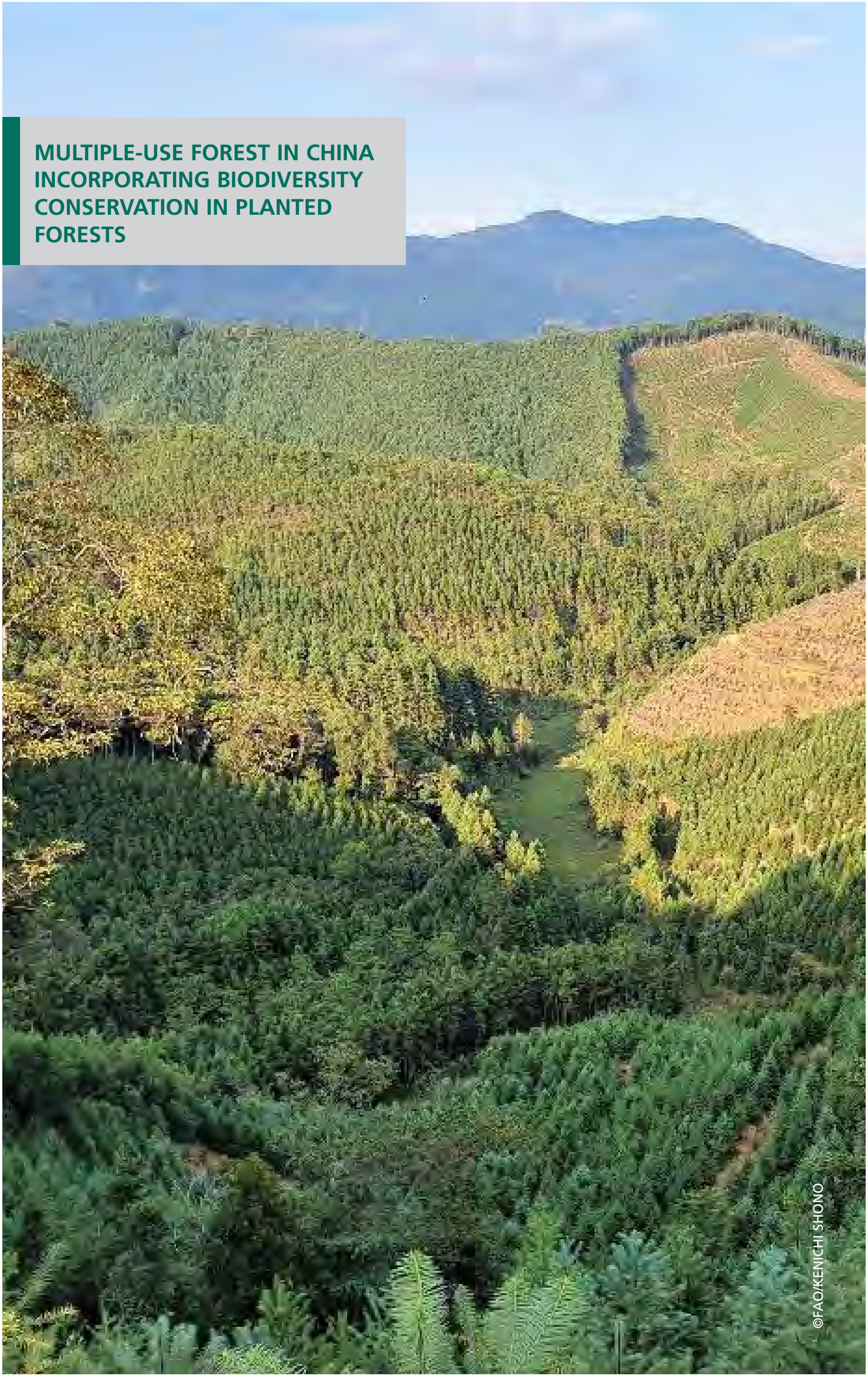
Scotland's policies and regulations relating to biodiversity management and forestry are strongly linked and well implemented. Institutional arrangements supporting the mainstreaming of biodiversity in forest management are robust, delivering effective legal enforcement for species and habitat protection and regulation of forestry activities through licenses, incentives and guidance. Responsibilities lie with the Scottish Government, its agencies responsible for nature and forest policy, the public bodies undertaking forestry, and with the landowners themselves. Land ownership patterns in Scotland are highly concentrated, dominated by large estates and absentee investors, and influenced by the legacy of feudal tenure. New legislation is in force to attempt to redress this imbalance, increase diversity, and provide greater community empowerment. Overall, consulted stakeholders thought biodiversity was reasonably well mainstreamed in forest management, although some considered that current policy and regulations were focused too heavily on iconic national species. Furthermore, the need was identified to engage, capture and communicate the value of biodiversity for all elements of the forest resource in Scotland, and to better balance delivery of policies for climate change with those for biodiversity.

Key actions to enhance biodiversity mainstreaming include:

- Increased multi-stakeholder engagement to tackle the largely divided views of biodiversity among professionals and foresters so that production objectives and measures for biodiversity are better integrated.
- Recognizing biodiversity value of production forests and secondary woodlands, and developing methods to incorporate values other than timber into decision-making.
- Utilizing existing regional forums for land use decisions, thereby integrating high-level policy with local objectives, accommodating a long-term, large-scale and multi-sector view on forest creation and management.

Forest landscape over Kilpatrick Hills, Scotland

PART 4. RECOMMENDATIONS



MULTIPLE-USE FOREST IN CHINA INCORPORATING BIODIVERSITY CONSERVATION IN PLANTED FORESTS

There are a number of measures and actions that governments and development partners can take to facilitate the mainstreaming of biodiversity in forest management. The most urgent and impactful priorities that have emerged from this review and the country case studies are described in this section.

1) Halting and reversing deforestation

Commitments and efforts to reduce deforestation should be further promoted and strengthened as a critical step to protecting biodiversity in forests. A focus is required on sustainable agricultural intensification, confining future expansion of agriculture to already deforested areas, removing perverse incentives and increasing penalties for deforestation. In addition, countries should consider novel approaches, such as social cash transfers (Ferraro and Simorangkir, 2020), to combat poverty as a major driver of deforestation. Corporate efforts to ensure their commodity supply chains do not embed deforestation can also contribute to reducing natural forest loss and should be encouraged. Forest management must become a financially viable land use option through the various regulatory, economic and market-based mechanisms described in this report in order to maintain forest land use.

2) **Combating illegal and unregulated forest activities**

Illegal and unregulated forest activities undermine SFM and are consequently the key driver of biodiversity loss in managed forests. An overly complicated and poorly harmonized system of laws and regulations with unclear and conflicting institutional roles contribute to the prevalence of illegal activities, among other factors, such as high levels of corruption and weak law enforcement. A further contributing factor is a burdensome permit or licensing system, which encourages illegality because of the high transaction costs and the opportunities it generates for corruption.

Where such problems exist, countries should update and simplify laws and regulations, focusing on their practical implementation and clarifying institutional roles across ministries and departments and government levels, including mechanisms for cooperation among departments. Investments are also required for implementation and capacity development in forest law enforcement, as well as in administration and monitoring. Information pertaining to the laws, regulations, licenses, among others, should be made readily available, ideally online, with transparent processes for applications and fee payment. Finally, forest managers, whether concessionaires, communities or private landowners, should be required to protect biodiversity against external threats such as poaching.

3) Recognizing forest tenure of Indigenous Peoples and local communities

Devolving authority through participatory forest management is often effective in combating illegal forest activities, especially where local communities are the de facto forest managers. Furthermore, OECMs will likely prove to be a useful mechanism for devolving forest management to communities as they provide a flexible form of governance that allows existing use and traditional management to be recognized and to continue, so long as the agreed upon biodiversity objectives are met. Emphasis should be on ensuring equitable sharing of benefits through the sustainable use and conservation of biodiversity.

4) Preventing conversion of natural forests into monospecific forest plantations

Conversion of biologically diverse natural forests into monospecific forest plantations is an issue in some countries, particularly in the tropics. Forest policies and regulations should be updated to direct forest plantation development to degraded lands that have limited biodiversity value so that increasing timber production through plantations does not come at a cost to biodiversity.

If established on degraded land and managed to high SFM standards, which includes measures such as the establishment of set-aside areas and protection of HCVs, plantations can have a positive impact on biodiversity, as well as on other ecosystem services such as recreation and water provisioning (Pawson *et al.*, 2013; Brockerhoff *et al*., 2017). There is also scope to improve biodiversity outcomes through silvicultural measures, such as managing uneven aged stands and mixed species stands, especially through incorporating native species (Brockerhoff *et al.*, 2008).

5) Ensuring sustainable management of harvested species

As reported previously, overharvesting of plants and wildlife is a serious problem driving widespread declines in biodiversity. Lack of attention given to protecting threatened species outside of protected areas and bias towards animals in protected species legislation often results in unsustainable management of commercial timber and many NWFP species in production forests.

It is essential that countries put in place solid protected species and protected habitat legislation, based on threat status (e.g. IUCN Red Lists), which is effectively enforced across the entire national territory, including but not limited to forests managed for economic benefits. In addition, it is essential that protected species legislation is extended to cover threatened species' habitats and the resources they use beyond protected areas. Countries can also improve protection through making information about protected species and habitats readily available. Hunting by Indigenous Peoples and local communities should be managed through a transparent, negotiated process to enable sustainable wildlife management. Likewise, highly sought-after wild plants should be identified and resource management plans put in place.

In production forests, annual allowable cut, rotation length and silvicultural practices should be developed based on best available data for each commercial species (or at least groups of similar species) to ensure adequate regeneration and the maintenance of genetic diversity of harvested species between harvesting cycles.

6) Managing and controlling invasive and overabundant species

Invasive species have caused enormous damage to forests and pose serious threats to biodiversity, especially in degraded and seasonally dry forests. To protect native biodiversity, it is important to control invasive species through nationally coordinated plans. Information regarding invasive species should be made readily available, and such information should be adopted in developing standard best practice for invasive species management. Forest management plans should include measures to monitor and control invasive species. The best approach to controlling an established invasive may be to create an economic harvest around the species, for example for biomass or biochar production.

Overabundance of wild herbivores is a common problem where predators have been functionally or literally extirpated (Côté *et al.*, 2004). From a biodiversity conservation perspective, reintroduction of predators is the ideal solution to an overabundance of herbivores. However, this approach is often not possible for social reasons. Management of herbivore populations through culling or exclusion using fences are more common approaches, particularly in cases where human populations are present in the landscape. Overgrazing may also be driven by livestock, particularly goats and sheep, which can create problems for forest regeneration. Measures such as the use of exclosures or fencing, sometimes with concurrent reductions in livestock populations, may be required to restore forests.

7) Leverage global momentum on restoration to enhance biodiversity conservation

Countries and international partners have made commitments to ambitious restoration targets, and this global momentum offers opportunities for enhanced biodiversity management in forests and across wider landscapes. These include: opportunities to improve habitat connectivity through restoration; ecological restoration of key biodiversity areas; expansion of habitats and threatened ecosystems; integration of genetic diversity in seed and seedlings production; and promotion of biodiversity-friendly restoration approaches such as assisted natural regeneration and mixed planting of native tree species. Adopting a landscape approach to restoration ensures planning of a biologically diverse productive landscape where conservation and production needs are balanced at the landscape level. In order to ensure access to quality planting material and climate resilience of restored forests, a national level system for forest genetic resources management should be established.

8) Adopting a multisectoral perspective

Forests and forest biodiversity are impacted to a great extent by larger socio-economic drivers outside the forest sector. In the past decades, agricultural landscapes have become substantially simpler across a range of spatial scales (Gámez-Virués *et al.*, 2015), pesticide toxicity loads have dramatically increased (Tang *et al.*, 2021), and road densities have increased (Laurance *et al.*, 2009, 2014). These changes have all had a significant impact on forest biodiversity. As such, it is important that biodiversity is mainstreamed across relevant sectors, such as agriculture, mining, transportation, energy and infrastructure development. It is also critical to enhance cross sectoral coordination so that the forest sector does not operate in isolation. Development of forest management plans should consider wider spatial planning objectives and strategies for biodiversity conservation. The decline and then recovery of ibis and stork populations in Japan, through changes in the management of *Satoyama* landscapes, illustrates the importance of an integrated large-scale approach to biodiversity conservation in production landscapes.

9) Providing economic incentives

Governments should incentivize SFM and high-quality forest biodiversity management through a variety of means, including: tax breaks for compliance with specific management objectives; issuing and renewing licenses and permits conditional on performance (and revoking licenses and permits in cases of serious non-compliance); subsidies and investments for achieving biodiversity outcomes; compensation for reduced production to promote biodiversity benefits; and grants for forest managers and owners to shift management objectives towards biodiversity conservation.

10) Facilitating market-based instruments

Governments can facilitate biodiversity mainstreaming in forestry by steering practices through various market-based approaches. Although a financial premium on certified forest products is limited, certification can provide market access and respond to stakeholder and consumer demands for sustainably and responsibly produced forest products. National governments can also require or incentivize certification, including through procurement policies and by providing tax breaks.

PES schemes can also be promoted through government policy and mechanisms, such as blended finance and public–private partnerships. In addition, PES schemes, including REDD+ and payments for carbon and watershed protection, can be further supported through national ecosystem assessments and national natural resource accounting.

Furthermore, governments can support sustainable value chain development through green purchasing policies that aim to reduce the environmental footprint of agricultural and forest products. The public and the private sectors should join hands in raising awareness of products that are produced legally and through sustainable practices without causing deforestation. CSR commitments made by companies seeking to mitigate reputational or operational risks should also be leveraged in support of SFM and biodiversity conservation through public–private partnerships.

11) Investing in knowledge and capacity development

Biodiversity mainstreaming is supported through enhanced knowledge and capacity development. Hence, outcomes can be improved through supporting research and training on biodiversity at higher institutes of learning, including universities, technical colleges and museums. Likewise, biodiversity information can be improved through national level surveys, especially for threatened species and habitats, and making information readily available through print media and online portals (e.g. maps of threatened habitat distributions). Governments and institutions of higher learning can support biodiversity mainstreaming through developing national databases (e.g. DNA barcodes for threatened species), mobile apps for identification and digital tools for incorporating local knowledge and citizen science. These new technologies should also be leveraged to improve law enforcement.

To guide forest managers and field practitioners, best practice guidelines for SFM, including forest management planning and biodiversity conservation, should be produced through a broad stakeholder consultation process, updated regularly, disseminated widely and supported with training programmes as required. Implementation of these forest management plans should be regularly audited and publicly reviewed, with penalties for non-compliance.

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17. Supplementary material

Country case studies
Weblink under preparation

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FAO FORESTRY PAPER

Mainstreaming biodiversity in forestry

Forests harbour a large proportion of the Earth's terrestrial biodiversity, which continues to be lost at an alarming rate. Deforestation is the single most important driver of forest biodiversity loss with 10 million ha of forest converted every year to other land uses, primarily for agriculture. Up to 30 percent of tree species are now threatened with extinction. As a consequence of overexploitation, wildlife populations have also been depleted across vast areas of forest, threatening the survival of many species. Protected areas, which are considered the cornerstone of biodiversity conservation, cover 18 percent of the world's forests while a much larger 30 percent is designated primarily for the production of timber and non-wood forest products. These and other forests managed for various productive benefits play a critical role in biodiversity conservation and also provide essential ecosystem services, such as securing water supplies, providing recreational space, underpinning human well-being, ameliorating local climate and mitigating climate change. Therefore, the sustainable management of all forests is crucial for biodiversity conservation, and nations have committed to biodiversity mainstreaming under the Convention on Biological Diversity (CBD). Mainstreaming biodiversity in forestry requires prioritizing forest policies, plans, programmes, projects and investments that have a positive impact on biodiversity at the ecosystem, species and genetic levels. In practical terms, this involves the integration of biodiversity concerns into everyday forest management practice, as well as in long-term forest management plans, at various scales. It is a search for optimal outcomes across social, economic and environmental dimensions of sustainable development. This study is a collaboration between FAO and the Center for International Forestry Research (CIFOR), lead centre of the CGIAR research programme on Forests, Trees and Agroforestry (FTA). Illustrated by eight country case studies, the report reviews progress and outlines the technical and policy tools available for countries and stakeholders, as well as the steps needed, to effectively mainstream biodiversity in forestry.

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