THE SECOND REPORT ON THE STATE OF THE WORLD'S FOREST GENETIC RESOURCES

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This report was prepared as a contribution to the FAO publication, *The Second Report on the State of the World's Forest Genetic Resources*.

Regional networks and international organizations were invited to submit written reports structured around the four strategic priorities of the Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources (FGR)– (1) improving the availability of, and access to, information on FGR; (2) conservation of FGR (*in situ* and *ex situ*); (3) sustainable use, development and management of FGR; and (4) policies, institutions and capacity building.

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CONTRIBUTIONS OF THE ALLIANCE OF BIOVERSITY AND CIAT TO THE IMPLEMENTATION OF THE GLOBAL PLAN OF ACTION FOR THE CONSERVATION, SUSTAINABLE USE AND DEVELOPMENT OF FOREST GENETIC RESOURCES

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Introduction

Bioversity International (currently the Alliance of Bioversity International and the Center for International Tropical Agriculture, Alliance for short) is an organization that delivers research-based solutions to harness agricultural biodiversity and sustainably transform food systems to improve people's lives in a climate crisis. The Alliance research agenda spans six key areas of focus: Food Environment and Consumer Behaviour, Multifunctional Landscapes, Climate Action, Agrobiodiversity, Digital inclusion, Improving Crops, and Gender Inclusion. Through interdisciplinary research conducted globally, the Alliance is focusing in building an evidence base, decision support tools and capacity to support safeguarding and sustainable use of diverse forest resources, as well as resilient restoration of degraded landscapes using tree diversity. In close partnership with collaborators and stakeholders, the Alliance carry out research to identify priority tree species, to generate information about their intraspecific diversity, the benefits that these can confer on users, to predict where these species are most likely to be threatened across their distribution range. It also provides an evidence base for practitioners and policy makers to set conservation priorities for forest genetic resources and support their sustainable management and use. Research on biodiversity and multifunctional landscapes support landscape restoration and the maintenance of inclusive socio-ecological systems, contributing to both reducing the pressure of agriculture on natural ecosystems, and to introducing better management practices for natural ecosystems. Research is increasingly focused on important food tree species, looking at their sustainable use within diets, and mapping threats to species that are important for nutrition security. Finally, the Alliance's research on gender and forests focuses on understanding and redressing gender and social inequalities related to forest management. Through research and action focused on women's and men's rights and participation in collective forest management, gender-equitable value chain development, gendered ecological knowledge, and social inclusion in landscape restoration, the Alliance is seeking to advance gender equality in its own right, and as a means to support sustainable forest management.

Priority Area 1: Improving the availability of, and access to, information on forest genetic resources

One of strategic activities of the forest genetic resources team at the Alliance has been to support the identify priority species at local, national and regional level, based on a combination of biological and socio-economic traits, and support targeted conservation actions through generation of information on the spatial distribution of threats to these key species and in particular to their intraspecific diversity. Numerous threat analyses have been conducted in the last 10 years, through different collaborative research projects.

Threat analysis to multiple threats was conducted for tropical and subtropical Asia's valued tree species (Gaisberger et al., 2022a). A region-wide, spatially explicit assessment of the vulnerability of 63 socioeconomically important tree species was conducted to assessed the threats posed by overexploitation, fire, overgrazing, habitat conversion, and climate change. Species-specific vulnerability maps were created

based on vulnerability to current threats and climate change, to identify priority areas for conservation and restoration. We pinpointed specific natural areas in Borneo rain forests as hotspots for in situ conservation of forest genetic resources, more than 82% of which fell outside designated protected areas. We also identified degraded areas in Western Ghats, Indochina dry forests, and Sumatran rain forests as hotspots for restoration, where planting or assisted natural regeneration will help conserve these species, and croplands in southern India and Thailand as potentially important agroforestry options. Our results highlight the need for regionally coordinated action for effective conservation and restoration.

Vulnerability mapping of 100 priority tree species in Central Africa to guide conservation and restoration efforts (Ceccarelli et al, 2022a). diverse biomes of Central Africa, which are globally important for biodiversity, carbon storage and people's livelihoods. The objectives of this paper were to: (i) map the vulnerability of 100 socio-ecologically important priority tree species in Central Africa to climate change, fire, habitat conversion, overexploitation, overgrazing and (ii) propose a spatially explicit strategy to guide restoration and conservation actions. We performed ensemble distribution modelling to predict the present and future distributions of the 100 species, assembled other anthropogenic threat exposure layers, assessed species' sensitivities to the five threats based on their trait profiles, and constructed species-specific vulnerability maps by combining the species' exposure and sensitivity. The results show that these 100 species are vulnerable to the five threats, with an average of 34% of their distribution ranges under high to very high vulnerability and 60% under medium to high vulnerability to at least one threat. Many species identified as most vulnerable in this study are not considered as threatened by the IUCN Red List, suggesting a need to update their conservation status, potentially through integration of the vulnerability mapping methodology we used here. We generated both species-specific maps and summary maps including all 100 species identifying priority areas for a) in-situ conservation, b) ex-situ conservation, and c) active planting or assisted natural regeneration. We present an online platform to enable easy access to the vulnerability and the conservation and restoration priority maps for decision makers and support conservation and restoration planning across Central Africa.

A spatial threat assessment to prioritize populations for conservation for 80 socioeconomically viable tree species in South America was conducted (Van Zonneveld et al., 2018). Ecogeographic Range Segments (ERSs) were identified and corresponded to groups of populations of a certain species in a specific ecological zone within a particular grid cell of a species' geographic occupancy. The threat status of each ERS was assessed. This methodology enable to assess the percentage of ERS threatened for species individually and jointly, with and without the expected effects of climate change, with and without considering an increased risk of extirpation of populations outside protected areas. Some species were recognized in need of greater attention, because all their ERSs are threatened across their whole distribution in South America: *Balfourondendron riedelianum, Cariniana legalis, Dalbergia nigra, Handroanthus pulcherrimus, Pachira quintana, Prosopis flexuosa,* and *Prosopis pallida*.

The effects of future climate change and four current threats (fire, habitat conversion, overgrazing and overexploitation) were identified and quantified for the 50 most common tree species of the tropical dry forests of north-western Peru and southern Ecuador (Fremout et al 2020). It was found that all 50 species face considerable threats, with an average of 46% of species' distribution ranges displaying high or very high vulnerability to at least one of the five threats. Our results suggest that current levels of habitat conversion, overexploitation and overgrazing pose larger threats to most of the studied species than climate change. A spatially explicit planning strategy for species-specific restoration and conservation actions was also proposed, with management interventions focused on (a) in situ conservation of tree populations and seed collection for tree planting activities in areas with low vulnerability to climate change and current threats; (b) ex situ conservation or translocation of populations in areas with high climate change vulnerability; and (c) active planting or assisted regeneration in areas under high current threat vulnerability but low climate change vulnerability, provided that interventions are in place to lower threat pressure.

Threats to 16 important food tree species occurring in agroforestry parklands of Burkina Faso (*Acacia macrostachya, Acacia senegal, Adansonia digitata, Annona senegalensis, Balanites aegyptiaca, Bombax*

costatum, Boscia senegalensis, Detarium microcarpum, Lannea microcarpa, Parkia biglobosa, Sclerocarya birrea, Strychnos spinosa, Tamarindus indica, Vitellaria paradoxa, Ximenia americana, Ziziphus mauritiana) was carried out to assess species vulnerability to six key threats (overexploitation, overgrazing, fire, cotton production, mining and climate change) and define priorities for conservation planning.

The threats posed by climate change to *Theobroma cacao* (Ceccarelli et al., 2021) were closely examined to determine potential future impacts on the species in Peru and identify areas where climate change-tolerant genotypes are potentially present. Based on the results from modelling, a contraction of suitable area for cultivated cacao is foreseen together, while a more positive future for wild cacao in Peru is envisaged. The results indicate that tolerant genotypes will be required to facilitate the adaptation of cacao cultivation under climate change. Target populations for collection missions were identified.

Other species-level threat analyses focused on the effects of habitat degradation on the socio-economically important Brazil nut tree (*Bertholletia excelsa*) in Peru (Chriboga-Arroyo et al. 2020), on the threats posed by changing habitat to sandalwood (*Santalum album* L.) in India and Indonesia, and on the impacts of habitat fragmentation on African locust bean (*Parkia biglobosa*) in Burkina Faso (Lompo et al., 2020).

Priority area 2: Conservation of forest genetic resources (*in situ* and *ex situ*)

A number of studies was conducted to identify conservation priorities for highly valuable tree species. A range-wide priority setting was carried out for the conservation and restoration of Asian rosewood species (*Dalbergia cochinchinensis*, *D. cultrata*, *D. oliveri*) to five key threats across their native ranges in six countries of the Greater Mekong Subregion (Gaisberger et al., 2022b). Based on our threat assessment, species-specific priority areas for conservation and restoration were delineated, subdivided by ecoregions as a surrogate for adaptive variation within species. Transboundary coordination has been underlined as critical to effectively address conservation threats. Based on a similar approach, priority conservation areas for *Juglans regia* L. populations in Central Asia were also identified (Gaisberger etal., 2020). A combination of georeferenced molecular marker data and climate data were used to identify priority conservation areas for the highly-valued medicinal species *Prunus africana*, optimizing selection conservation sites in terms representativeness of their genetic diversity found and distinctiveness of their climate with the aid of spatial analyses (Vinceti et al., 2013).

Further range-wide spatial analyses of genetic diversity were conducted for a number of species with the aim to guide targeted conservation in Africa (for *Parkia biglobosa* by Lompo et al., 2018; for *Khaya* spp., by Pakull et al; 2019), in Latin America (for *Enterolobium cyclocarpum*, Thomas et al., 2016; for *Ceiba pentandra* by Bocanegra-González et al., 2018).

Within species variability was also assessed through the lenses of local knowledge in the case of the shea tree (*Vitellaria paradoxa*) in Burkina Faso, where participatory characterization was used to understand how knowledge and preferences for shea ethnovarieties varied between gender and ethnic groups. Within species variability was also assessed regarding chemical composition of kernels (Guissou et al., 2020) and fruit pulp (Dao et al., 2021) and of *Parkia biglobosa*.

Some studies focused on resolving critical aspects for the correct taxonomic identify of species and consequent conservation action and susitanble use, such as phylogenetic relationships between African genera (Monthe et al., 2019) and origin of cultivated types including relationships with wild ancestors for mangosteen *(Garcinia mangostana* L. var. *mangostana*) (Yao et al., 2023).

The state of conservation and use of cacao (*Theobroma cacao* L.) genetic materials in six countries in South (Peru and Ecuador) and Central America (Nicaragua, Honduras, El Salvador, Guatemala) was evaluated through a survey of 176 gene banks and nurseries, reviewing also legislation for cacao genetic resources national and performing a review of breeding and selection programs. The study revealed strengths and

weakness, as well as the most appropriate investment areas for each country. In most countries gene bank collections did not have any characterization or evaluation data of the conserved materials and all countries had poor systems of certification, verification and traceability. The assessment also revealed that Breeding and selection programs had not fully exploited the potential of the cacao diversity available.

An analysis of traditional conservation strategies of cacao in Latin American countries (including intraspecific diversity of cacao preserved in gene banks as living collections, due to the species´ recalcitrant seeds, in wild populations and in farmers' fields) was carried out as a basis to develop an integrated approach based on local working collections to secure cacao diversity in the long term (Lavoie et al., 2023). The overview of resources being conserved across the region was obtained through a literature review. An integrated system linking the conventional conservation strategies was recommended as a significant improvement to the current conservation efforts. An integrated conservation system would require also a strengthened collaboration between all stakeholders involved.

Finally, the positive experience of converting non-native cacao plantations to fine-flavor cacao agroforestry in Peru through rejuvenation by grafting, the selection of high yielding and disease resistant native fine-flavor cacao genotypes, the organization of farmers in cooperatives to buffer the high market volatility were all presented as solutions offering promising socio-ecological perspectives (Tscharntke et al., 2022).

Priority area 3: Sustainable use, development and management of forest genetic resources

Research at the Alliance has focused on the use of forest genetic resources in forest landscape restoration, promoting the value of using native tree species in ecosystem restoration (Thomas et al., 2014). A freely available online tool, Diversity for Restoration (D4R: https://www.diversityforrestoration.org/), has been developed to identify suitable tree species and seed sources for climate-resilient restoration activities implemented in tropical forest landscapes (Fremout et al., 2021). The tool includes suitability maps of prioritized species, under, trait data that enables to carry out a selection of optimal species combinations for different purposes and conditions of the planting site, and seed zone maps that guide the sourcing of tree planting material adapted to present and expected future environmental conditions at the planting site. Catalogues of species for an increasing number of countries are being uploaded. The tool is now available for Colombia, Peru-Ecuador, Ethiopia (Oromia region), Burkina Faso, Cameroon, and Lebanon.

Genetic quality is an important prerequisite determining the success of forest restoration, however, due to a combination of different reasons, including market failures, the lack of appropriate guidelines, the lack of awareness about the importance of genetic diversity, it tends to be neglected in restoration initiatives based on tree planting (Jalonen et al., 2018), although the additional costs of integrating consideration of genetic quality in the supply of planting material may be negligible. These costs were assessed through the development of a cost model accounting for all relevant cost drivers of tree seed and seedling supply and integrating those into a single cost framework, representing components and interrelations in applied seed sourcing strategies, and their associated costs (Neff et al., 2021). The study showed that additional costs are incurred in at the beginning of restoration initiatives due to increased efforts invested in the collection of genetically diverse and suitably adapted seed lots. Nevertheless, overall costs of restoration decrease significantly, due to cost savings relating to replacement costs of replanting.

With regard to the impacts of forest management on individual species of value, a few studies were conducted for timber tree species in Africa. Selective logging can affect the demography, reproductive biology and evolutionary potential of forest trees, due to the reduction of population density and/or through determining environmental changes. The reduction of population density is particularly impactful for species naturally represented by few scattered and isolated individuals that may be subject to outcross pollen limitation and/or produce low-quality selfed seeds, showing inbreeding depression. Patterns of genetic diversity, mating system and gene flow were examined in populations of the self-compatible legume timber species *Erythrophleum suaveolens* with contrasting densities (Duminil et al., 2016a). In addition, the mating

system and gene flow of an emblematic timber tree species found in lowland rain forests of the Congo Basin, *Baillonella toxisperma*, were characterised (Duminil et al., 2016b).

In Latin America, the Alliance contributed to the development of genetic zones for *Nothofagus nervosa* and *Nothofagus obliqua* within their natural distribution range in Argentina (Azpilicueta et al., 2013). Genetic zones are considered as areas genetically homogeneous within which propagation material can be moved without excessive concerns regarding the possibility to cause changes in the genetic structure of a species. This information is useful to guide assisted migration programs under progressive climate change. A study conducted in the Maya Biosphere Reserve (Guatemala) assessed the effects of timber harvesting on the genetic diversity and viability of regeneration of a high-value timber species, the big-leaf mahogany (*Swietenia macrophylla* King). The results revealed that the genetic diversity of this species was not reduced by one cutting cycle under the practices of community forest management (Alarcón-Méndez etal., 2023).

In Central Asia, an important centre of origin for many globally valued tree species, a study was conducted on tree diversity maintained in home gardens, which play a key role in food supply, income generation and contribute to conserving diversity of fruit and nut trees (Vinceti et al., 2022). The research showed that the selection of species and varieties planted in home gardens is increasingly affected by market opportunities and availability of exotic material, particularly for apple and pear, while for other species (e.g., apricot, walnut, plum) traditional local varieties are predominant.

With regard to challenges posed by climate change, a study was conducted targeting forest owners and managers across 15 European to understand their perceptions of threats to forest ecosystems, knowledge of forest genetic resources and attitudes toward active management of intraspecific diversity of tree species to strengthen the resilience of forest ecosystems to climate change (Vinceti et al., 2020).

Within the OneCGIAR initiative on Sustainable Intensification of Mixed Farming Systems, ongoing research is focusing on the identification of priority tree species particularly suitable for silvpastoral systems, to be conserved and/or restored in selected target landscapes of five provinces of Northern Ghana (80 priority tree species occurring on farm identified) and in two regions of Laos (90 priority tree species occurring on farm identified): for these, species distribution models and seed zone maps have been developed and the information will be used to support conservation, restoration and tree seed supply.

Priority area 4: Policies, institutions and capacity-building

With regard to this strategic priority area, research has focused on understanding the functioning of the tree seed system in different countries, identifying needs for the development of policies, gaps in capacity and needs to strengthen institutions, in light of very ambitious forest landscape restoration objectives , which produced demand of huge volumes of tree planting material. A methodological approach has been developed to systematically assess the performance of the tree seed system against five key components (seed selection and innovation, seed harvesting and production, market access, supply and demand, quality control, and an enabling environment) through 15 detailed indicators, and tested in seven Latin American countries (Atkinson et al., 2021). The same approach ahs been also adopted to carry out a similar assessment of the tree seed systems in four Asian countries (Bosshard et al., 2021).

Furthermore, a comparative study based on dynamic system approach was carried out to understand the inter-related problems that affect the provision of good quality and site-adapted tree planting material in Burkina Faso and the Philippines, and to identify leverage points for intervention (Valette et al., 2020).

Contribution is being provided to strengthen the tree seed system in Burkina Faso through collaborative activities with the National Tree Seed Center (CNSF), focused on assessing quality and quantity of tree planting material provided by formal and informal suppliers across the country. It will also support the activities of the Sub-Committee for the Certification of Basic Forestry Materials.

Concluding remarks

The Alliance has been involved through different mechanisms in the maintenance of regional collaborations. The Asia Pacific Forest Genetic Resources Programme (APFORGEN) is a regional programme and network of 15 member countries to advance the conservation and sustainable use of the region's rich forest genetic resources. A separate report has been prepared to document the activities carried out in the last decade.

An equivalent coordination effort has been set in place in the Latin American region. The network LAFORGEN was set up officially in 2006 as a result of a consultation workshop for experts on Biodiversity and Conservation of Forest Genetic Resources in Latin America, held in Cali, Colombia. This workshop was part of a project collaboration between Bioversity International and INIA of Spain.

The main objectives of the LAFORGEN have been a) the promotion, support and execution of priority actions related to the conservation and the sustainable use of forest genetic resources in Latin America, through a greater collaboration between countries, b) the support and encouragement of exchange of information and experiences between scientists and professionals related to the issue of forest genetic resources in the region, c) the collaboration for the development of research activities on topics of common interest between institutions and countries of the region, d the execution of training activities on issues related to the network.

Different attempts have been made in recent years to revitalize this platform of experts. One opportunity for collaboration among experts on forest genetic resources involved in the regional network has materialized in the organization in April 2022 of an online training course with financial support of the Spanish Agency for cooperation (AECID) and the leadership of the Forest Research Center of the National Institute of Agricultural and Food Research and Technology. Ministry of Science and Innovation, Spain (INIA-CIFOR). A total of seven experts from the following organizations and institutions contributed: CIFOR-INIA (Spain), Bioversity International (Alliance), INTA (Argentina), INFOR (Chile), Ministerio para la Transición Ecológica y el Reto Demográfico (España), IIAF-UMSNH (México), UNAM (México). The course was focused on the importance of conservation and sustainable use of genetic diversity to adapt to rapid environmental change. Relying on the experience of teachers in Forest Genetic Resources (FGR) in Spain, Latin America and internationally, updated knowledge and case studies on the characterization, management and use of these resources was provided, as well as implementation of relevant efforts, within the Global Plan of Action, such as forest genetic resources conservation through strengthening coordination at the regional and national level. The course was aimed at forestry graduates with experience in research or forest management, willing to exchange experiences and broaden their training in the subject matter of the course.

The Sub-Saharan African Forest Genetic Resources Programme (SAFORGEN) was established in 1998 with an inception event held in Ouagadougou, Burkina Faso. The Secretariat of the initiative has been hosted by Bioversity International (formerly IPGRI). The regional programme involves institutions in 18 countries in sub-Saharan Africa and is focused on a) assessing dynamic processes that shape forest genetic diversity from a population to landscape level, b) developing strategies, methods and tools for the conservation and sustainable use of forest biodiversity, c) disseminating knowledge and information about conservation and sustainable use of forest genetic resources among both international and national fora. Research activities have centred around priority species groups: food tree species, medicinal and aromatic tree species, wood and fibre, and fodder tree species.

SAFOGEN has organized regional workshop on the "Conservation and use of forest genetic resources in Sub-Saharan Africa: Strengthening tree see systems' on 9-11 April 2019, in Kumasi, Ghana. The event has gathered delegates from 20 countries who took turns in presenting updates on activities in their respective countries relevant to the SAFORGEN regional strategy and/or the implementation of GPA-FGR. During the workshop, the structure of the network was revised. It was decided to rotate the hosting of the Secretariat on a biannual basis, across the different institutions involved. The establishment of a Steering Committee

was also recommended, and TORs defined. Furthermore, three main working groups were created: Tree breeding and seed production systems (WG1), Characterization of genetic resources and data systems (WG2), In situ and ex situ conservation of forest genetic resources (WG3). Lack of resources has been hampering progress so far.

Annexes – Key publications

Threat analyses

- Gaisberger, H., Fremout, T., Kettle, C.J., Vinceti, B., Kemalasari, D., Kanchanarak, T. et al. 2022a. Tropical and subtropical Asia's valued tree species under threat. *Conservation Biology*, 36(3): p.e13873.
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Conservation priorities - Within specie characterization of genetic diversity

- Gaisberger, H., Fremout, T., So, T., Thammavong, B., Bounithiphonh, C., Hoa, T. T., Yongqi, Z., Kanchanarak, T., Changtragoon, S., Sreng, S., Ping, H., Hung, T. H., Win, P. P., Hartvig, I., Theilade, I., Boshier, D., MacKay, J., Kettle, C., & Jalonen, R. (2022b). Range-wide priority setting for the conservation and restoration of Asian rosewood species accounting for multiple threats and ecogeographic diversity. Biological Conservation, 270, 109560. https://doi.org/10.1016/J.BIOCON.2022.109560
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Evaluation of complementary conservation efforts

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Tools

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