Chapter 2. The State of Forest Genetic Resources Conservation and Management

This chapter reviews the state of FGR conservation and management (C&M) strategies and programmes and their implementation as addressed and derived from country reports and regional syntheses prepared for the SoW-FGR. Starting with a summary of the values of FGR C&M, it presents a brief description of FGR C&M and its elements, and moves on to consider countries' progress in characterising their genetic diversity and in undertaking FGR conservation and management, both *in situ*, *circa situm* and *ex situ*. It also reviews progress in breeding and genetic improvement of forest tree species, and considers the systems for deploying and distributing forest genetic materials for application in the wide variety of activities and uses identified by countries, including by rural communities, on farms, in natural and planted forests. Themes emerging from the country reports have been identified, discussed and developed, particularly where these provide insights and methods for achieving more effective FGR C&M notably through identified strategic priorities (SPs).

2.1 FGR conservation and management

All countries contain trees within their borders– in natural and planted forests, rural areas, farms, orchards and gardens. Trees and forests are used by people for food, fuel, fibre, materials, medicines, and serve a myriad of other human needs, including social, cultural, aesthetic, religious, spiritual, as well as providing environmental services (biodiversity conservation, carbon sequestration, climate amelioration, protection of soil, and water catchments). The enormous range of goods and services provided by trees and forests is both a function of and testimony to the genetic variability contained within them.

Variation is continuously being generated through sexual recombination and mutations, and natural selection acts on this background of variability through the process of evolution, producing new variants that are better adapted to survive and compete, and cope with changing environmental conditions. Individual trees contain genetic variations that distinguish them from other members of their own species and other species. This variation provides the basis for selection of genotypes and varieties better suited to the provision of human needs, through providing trees and products better suited to purpose, or that produce goods and services in a more efficient manner, in a wider range of settings and against changing environmental conditions.

Whilst genetic diversity exists in almost all tree species, the extent to which this diversity is present in more important species (from economic, social or environment perspectives) and recognised, understood, documented, managed and utilized by humans will determine its value as a forest genetic resource. The future values of FGR will be determined by the way humans manage these resources and act, as the primary agents of environmental change in today's world. We are therefore impacting and altering FGR values whether we are aware of it or not, through our use of trees and forest resources and alteration of environmental conditions, just as much as through our conscious efforts to better conserve and manage them.

Conservation and management of FGR are inextricably intertwined – conservation of FGR requires implementation of well planned, scientifically-sound strategies, including management of FGR in breeding programs and in production populations. Provision of forest-derived goods and services depends on the presence of FGR and also has implications for their survival. As noted by countries, maintenance of FGR is partly being achieved through many and diverse activities in which FGR C&M is not consciously or explicitly identified as a goal. Indeed this growing awareness of how our actions, of lack thereof, impact on FGR is a recurrent theme in country reports and this chapter. However for the purposes of this report, and given the imperative to understand that the future of FGR is dependent on conscious, effective human intervention through deliberate management, we use the term 'management' to describe deliberate planned actions taken to conserve and protect FGR.

The national reports describe a vast range of actions by countries to recognise, understand, document, manage, and conserve their FGR, against a backdrop of diverse biological, environmental, geographic, economic, political, administrative, social and cultural contexts. Rates of progress have depended on political understanding and will, and resources made available. Collectively the reported actions describe a developing global movement towards the conscious stewardship and sustainable use of these precious resources, accompanied by the protection and maintenance of the evolutionary processes that has produced this irreplaceable legacy. The reports represent a vital contribution to global understanding and appreciation of FGR, and through the identified strategic priorities will help guide future international action, led by FAO Forestry Department with guidance from its respected Panel of Experts on Forest Gene Resources since 1969 (Palmberg-Lerche 2007).

2.1.1 Why FGR C&M is important: the social and economic value of conservation and breeding activities

Country reports listed a wide range of values of FGR and the resources derived from them, including economic, social, cultural, aesthetic, environmental values as well as biodiversity conservation and the maintenance of environmental and ecological services and processes. Economic/socio-economic values were the most frequently cited values used in most regions to prioritise species for FGR research, C&M with a large proportion of trees identified as priorities being of high commercial value, including widely planted, often exotic, industrial plantation species.

The economic value of forest industries recorded in the formal sector (such contribution to GDP, exports, employment) was provided in most country reports, but the values of forests and trees in the informal sector and contribution to rural livelihoods and poverty alleviation were not able to be addressed with precision. Whilst FGRs importance to the formal and informal forest economies; to social, cultural and environmental values, and for environmental services was noted in country reports, there were limited attempts to assign monetary values to any of its specific contributions.

Benefits from improved genetic materials **-** Planted forests, including agroforests, utilizing improved, better adapted and diverse germplasm directly contribute to improved economic well-being through increasing the output of superior forest products for lower inputs (e.g. labour, water and fertiliser), in a wider range of conditions and environments, with fewer losses to pests and diseases. FGR are the basis of tree improvement and improved forest plantation crops and countries in all regions reported significant gains in productivity and utility from improvement programmes and/or widespread use and adoption of improved materials. Increased yields of superior forest products generated at lower cost from genetically improved trees, can reduce the harvest pressure on natural forests, and allow them to be harvested in a less intensive, more sustainable manner better enabling them to fulfil service roles.

Forest ecosystem function, services and adaptation - Conserving and managing the variability of FGR *in situ* provides the basis on which selection and adaptation operates, and will better ensure continued ecosystem function and services. Indeed, adaptation to changing environmental influences requires a high degree of genetic diversity in tree species because of their immobility and perennial, long lived life forms. Forest genetic diversity helps ensure healthier, more resilient forests better able to deliver essential ecosystem service functions; e.g. well-forested catchments are better able to deliver a seasonally better-distributed supply of potable drinking water. Where forests have been degraded, the use of appropriate species and provenances, selected from the pool of natural variability maintained through effective FGR C&M, can assist with forest restoration efforts. Climate change is a major threat to agriculture, forestry, and biodiversity generally, through extreme climatic events, droughts, increases in temperature, more frequent and intense wildfire, and increased activity of pests and diseases. Climate threats to food security are already evidenced by an increase in disaster and famine response by international aid agencies. Under more extreme climatic conditions the use of trees and forests for food and fibre is likely to become even more important, e.g. due to increased risks of failure of rain-fed agriculture and annual crops. Effective FGR C&M takes on even greater significance against a background of climate change-induced drought and fire change and associated changes to forest structure and composition. It will be increasingly vital to provide the deepest possible reservoir of genetic variability on which natural and artificial selection can act, facilitating adaptation to the changed conditions

The role of trees in carbon sequestration and climate change mitigation are becoming increasingly recognised and valued. Recent estimates put the carbon storage of boreal forest at 703 gigatonnes, tropical forests at 375 gigatonnes and temperate forests at 121 gigatonnes. Mature, new and planted forests can sequester substantial amounts of carbon (see Ch 1). Eucalypt hybrids developed by Brazil with annual volume increments averaging 35 m^3 per ha and sometimes exceeding more than 50 m^3 per ha offer the potential for significant vegetative carbon sequestration. Brazil noted the likely importance of retaining healthy forests *in situ* (such Amazon forest) to maintain global climatic conditions that would maintain its competitive agriculture sector. The opportunities for simultaneously conserving FGR, reducing carbon emissions and generating income through the REDD+ schemes were noted by several countries.

2.1.2 Elements of FGR conservation and management systems

FGR conservation and management involves protecting a country's existing FGR, including in existing forests, landscapes or purpose-built facilities through *in situ*, *ex situ*, *circa situm* conservation measures and especially through sustainable forest management regimes. Breeding and tree improvement is central to FGR C&M, to improve the performance of selected species or forests for economic, social, community, environmental, conservation or other purposes, and the deployment of improved and adapted stock for a wide variety of end users, while ensuring that the benefits are equitably distributed. This involves a number of diverse and separate though closely interrelated activities, ranging from policy and legislation, research, sustainable forest management, private sector plantation development, to community management of FGR.

Country reports demonstrated different levels of FGR C&M in both extent and detail, and used a wide range of approaches. While the most detailed planning has been undertaken and implemented in northern European and North American countries that have well-established formal NRM and conservation institutions, each country has needed to address the task in the context of the resources available to it and the prevailing conditions. Nonetheless, most countries' FGR C&M systems shared a number of key elements, functions and features that were described in their reports.

Influences on the level of a country's FGR C&M effectiveness included the level of economic development, the nature of the forest resource (natural, managed native, or planted forest), the nature of the forest industry and patterns of forest use, patterns of land ownership, the type and quality of governance applied to the management of forests and biodiversity assets and natural resources more generally, and the resources available to undertake the task, including economic, expertise, institutional and logistical resources. Examination of the country reports indicated that a number of contextual features and characteristics influence and shape a country's system FGR C&M. The most important contextual features include:

a) biogeography

- biological resources – the nature of the FGR, for example, species, breeding systems, patterns and levels of diversity, area, type, location, distribution of forests and trees, species, diversity
- biogeographical characteristics – geology, topography, climate and soils

b) economy, industry and population

- human population – size, density, growth trajectory, income, how distributed and location with respect to FGR
- level of economic development – infrastructure, income, poverty level, industrial versus rural development models, maturity and diversity of economy
- economic importance of the forestry sector and demand for forest produce (wood products and NWFPs) – population, income, level of economic development, standards of living, expectations, preferences, use patterns
- nature of the formal forestry sector - level of development, type and level of investment, sawn timber, plantation versus natural forest, scale of activities industrial scale versus local production
- involvement of private sector – research, breeding, plantation development, utilisation and management of native forests
- nature of land-based industries including agriculture and forestry– produce types, methods, mechanisation

c) political system, policy framework and administration

- political system – centrally planned; democratic; market economies; relative strength of state, provincial, local and community government and governance systems
- legislative and policy systems – maturity, complexity, efficiency, level of integration
- development goals and trajectories – urbanisation, industrialisation, type of industries and economic activities desired, employment

- biodiversity and NRM legislation and policy
- administrative system – maturity of NRM agencies, degree of complexity, efficiency, transparency, accountability
- attitudes towards forests and forest conservation, protection of biodiversity, NRM amongst politicians, policymakers, administrators, private sector, communities, individuals, media, educators
- patterns of land ownership – size of holding, public, private and communal/traditional ownership
- system of land use planning and allocation to different uses; extent to which the state is willing and can regulate activities and use of non-state owned lands

d) research and education

- education and training system - availability and quality of education for various aspects of FGR C&M, development of expertise
- forest research capacity – number, quality of public, academic and private research institutes and the level of resources available to them, in key areas of FGR C&M

e) Society and community

- community traditions, customary law relating to resource use and conservation

These characteristics provide the context for further development of a country's FGR C&M programme.

Elements and features of effective and comprehensive FGR C&M systems

The main components of different countries' FGR C&M systems were described and analysed in the country reports, with deficiencies generally identified and highlighted. From this information, the key elements and features comprising an effective FGR C&M system have been identified as follows:

- a national strategy for FGR C&M, with a process for review and updating
- national strategies in other related and relevant areas incorporating goals and objectives of international agreements, including MDG, CBD, WTO, and harmonised with FGR C&M strategy; these include biodiversity, forestry, agriculture, land use, planning, economic development
- participation in international agreements which impact on FGR C&M
- legislation enacting the FGR strategy and international obligations
- a national programme for FGR C&M to implement the strategy, with adequately funded sub-programmes, including a process for identification and prioritisation of assets, analysis of constraints and barriers to effective FGR C&M, and the identification of issues, areas, approaches and programmes likely to most efficiently deliver improvement in FGR C&M
- administrative infrastructure and capacity to implement and administer the strategy and programmes, with appropriate budgetary allocations

- country-wide, comprehensive inventory of FGR assets in naturally regenerated and planted forests and in trees outside forests including agroforestry systems, and in dedicated FGR programmes and facilities; including assessment of threats to FGR and trends in the status of genetic variability
- process for prioritisation of assets identified in the inventory, consistent with national FGR C&M strategy, national development goals and international agreements
- established principles and practices for monitoring, evaluating, reporting, and improving activities and programmes
- coordination, including integration and harmonisation of strategies, programmes, administrations and sectors with relevance to FGR C&M including forestry, agriculture, biodiversity conservation, national development, industry, research and education
- participation in regional and international FGR networks and donor programmes
- consultation with all relevant actors and sectors of the economy and community in identification of priorities and development of FGR C&M strategies and programmes
- use of a number of mutually reinforcing approaches to FGR C&M in strategy, programmes and implementation.

Differences between FGR and biodiversity conservation.

. Biodiversity conservation focuses on conserving the whole spectrum of biological diversity *in situ*, from organisms through to ecological processes, and this simultaneously helps maintain and protect the variability of trees and forests within those areas conserved. Global activities to conserve biodiversity make an immense contribution to the conservation of genetic diversity in tree and woody shrub species, including species of potential importance, or that are lesser known or unknown and undescribed. This includes the contribution of protected areas and the implementation of sustainable forest management principles catalysed by the 1992 Convention on Biodiversity (CBD), a contribution acknowledged in country reports (e.g. Estonia p5), supported by the 1994 Montréal Process[1]. On the other hand, FGR C&M requires detailed and specific information about and protection of the genetic variability within and between socioeconomically important tree species and may also involve *ex situ* actions, and maintenance of FGR in breeding and production populations.

Whilst an ecosystem approach is the focus of a number of countries forest research programmes several countries noted important differences between conservation of biological diversity and FGR. For example, biodiversity conservation policy emphasises ecosystem and habitat protection rather than focusing on individual species; biodiversity programmes tend to focus on interspecific variation, while for FGR C&M, ‘changes below the species level can be critical for ensuring that the adaptive potential of the species is maintained…this is particularly important when considering threats such as climate change, invasive pests and pathogens, and the ability of species to adapt to these

[1] The Montréal Process countries are Argentina, Australia, Canada, Chile, China, Japan, Korea, Mexico, New Zealand, Russian Federation, United States of America, and Uruguay. These member countries contain 83% of the world’s temperate and boreal forests, 49% of the world’s forests, 33% of the world’s population, and are the source of 40% of the world’s wood production.

changing conditions'. The introduction of external genetic material into forests was suggested to confer climate change adaptability, a practice not hitherto widely considered in biodiversity conservation outside of enriching genetically impoverished inbred populations of threatened species. Furthermore, breeding and genetic improvement programmes in FGR C&M generally focus on particular economically important traits, which is much less common in habitat-oriented biodiversity conservation. For breeding and deployment of improved stock for commercial forestry, genetic variability in some traits will need to be deliberately reduced to achieve a consistency in genetic makeup and phenotypic expression of the desired characters, while for biodiversity conservation the emphasis is on maintaining processes, particularly evolutionary processes, likely to favour maximum diversity. The management requirements and regulations for strict protected areas may preclude some essential FGR C&M activities: (1) some conservation reserve provisions may prohibit actions necessary to ensure the regeneration or maintenance of FGR, (2) FGR conservation has not played a great part in countries' nature conservation measures, and (3) in management plans for strict nature conservation areas it is most often 'not possible to include genetic aspects'. Differences are summarised below:

- Activities for *in situ* conservation of FGR have many similarities to biodiversity conservation; most of the differences are between *ex situ* conservation and genetic improvement programmes versus biodiversity conservation activities; FGR focuses on intraspecific diversity in a smaller number of the most economically important tree species
- Interspecific, overall diversity focus of biodiversity conservation compared to greater focus on intraspecific variation for FGR C&M
- Some *in situ* conservation requirements may be satisfied by conservation of a small number of individuals of the target species in a small area, compared to the ecosystem, habitat and landscape scale protection approach of biodiversity conservation
- Genetic improvement for commercial and productive outcomes is a major component of FGR C&M compared to biodiversity conservation, employing a wide range of technical and financial resources, with activities such as breeding and use of provenance and progeny trials Conservation of biological diversity is largely a public sector activity, as it involves public goods for which markets are as yet poorly developed, and much of the natural biological estate occurs on public lands
- The private sector plays a significant role in breeding and commercial plantations establishment aspects of FGR C&M; by comparison this sector's participation in biodiversity conservation is much reduced, although there is increasing interest and attempts to harness private sector finance for biodiversity conservation, including through NGOs such as the Nature Conservancy and Conservation International
- *Circa situm* C&M is generally regarded as playing a lesser role in biodiversity conservation compared with its role in FGR C&M, where remnants in cleared agricultural landscapes may be extremely important as breeding stock: for example, teak has been nearly totally cleared for agriculture in parts of Thailand, and remnant trees may contain important genetic variability adapted to local landscapes. However, biodiversity conservation is increasingly focused on landscape approaches and reducing fragmentation by linking protected areas with vegetation corridors through agricultural landscapes.

- Breeding and widespread deployment of improved stock for commercial and utility purposes usually involves a reduction of genetic variability in the improved stock, and where plantations of improved materials replace natural forest, there are extreme reductions in total FGR and genetic variability and a curtailment of evolutionary processes. There is greater use of living gene banks such as planted gene conservation stands for FGR C&M compared to biodiversity conservation which is more focused on the *in situ* approach
- Genetic Interventionist approaches may contribute *in situ* conservation, for example reintroduction of lost alleles or gene infusion for genetically depauperate at-risk populations, or via breeding to introduce resistance to pests or diseases and allowing reintroduction of species to parts of their range where they have been eliminated.

Several countries remarked on the importance of communicating the specific requirements of FGR C&M to legislators, policy makers, managers and concerned communities involved in biodiversity conservation forest and land management, where these differed from standard biodiversity conservation activities, to ensure the requirements of FGR C&M were adequately addressed in law, policy, budgetary allocations, and management. Despite these differences, there is nonetheless a close alignment and overlap of many aspects of FGR C&M and biodiversity conservation and management. For example the genetic diversity and species implicit in of FGR C&M complements the habitat and ecosystem protection of biodiversity conservation. A high degree of integration and coordination between the two activities, in terms of strategies and programmes, is essential. There is an opportunity for mutual advancement and reinforcement of FGR and biodiversity conservation through closer alignment, for example to strengthen legislative, policy budgetary and programme support, and in coordinating activities where these are complementary.

The CBD notes that in article 8 (c) that countries are required to 'regulate or manage biological resources important for the conservation of biological diversity whether within or outside protected areas, with a view to ensuring their conservation and sustainable use…'. This points at the need to strengthen the contribution of primary forests and protected areas to *in situ* conservation of FGR. There is a need for FGR C&M objectives to be explicitly incorporated into national biodiversity conservation strategies and action plans, and to explore and identify opportunities for complementarities between FGR and biodiversity conservation.

2.1.3 National strategies and programmes for FGR conservation and management

In relation to FGR C&M, the term strategy may be used to describe conservation, improvement, breeding strategies from the biological, eco-geographical and technical points of view and is the subject of this chapter. , The term strategy is also used in country reports to refer to the setting of policy objectives, directions, approaches and 'agendas' in the development of high level public policy and this is addressed in Chapters 4. Planning, information and technical input requirements for national programs

Planning, information and technical input requirements for effective national FGR C&M programs, (see 2.1.2.1) include:

- Inventory and characterisation of FGR (national, provincial, forest, area, population, species or group of species; ecogeographic surveys and traditional knowledge) based on technical standards and protocols
- Information management systems, including databases and GIS for inventory and monitoring
- Prioritisation of FGR assets falling within programme scope for conservation and management, and including identifying marginal/range limit populations (see next section 2.2)
- *In situ* conservation and management of FGR, including strategies to identify and promote FGR conservation in primary forests and protected areas
- *Circa situm* conservation and management of FGR – identify options and potentials, and develop methodologies for improved on-farm management
- SFM approaches to maintain FGR while optimising production of goods and services,
- Community-based, participatory approach to sustainable forest management and FGR C&M, including roles and technical support for management by indigenous and local communities
- *Ex situ* conservation and management of FGR – review options and promote feasible *ex situ* strategies and technologies as back-up and complementary approach to other approaches
- Incorporation of gene conservation objectives into breeding and genetic improvement programmes
- Development of national seed programs to enhance role in dissemination of genetically appropriate and improved germplasm
- Roles for genetically appropriate and climatically-adapted germplasm, including to predicted new climates, in replanting and forest restoration programs
- Review and promote appropriate biotechnologies for FGR C&M
- Develop regional and international networks to conserve diversity in priority FGR species and access to germplasm for important planted exotics

2.2 Prioritising species for FGR C&M

Priority setting is an essential strategic planning tool to identify a country's most important FGR assets and fundamental to the effective FGR C&M. The values for which FGR require conservation and management at national and local levels must firstly be identified and prioritised, and taking into account international agreements which countries have signed and ratified. The process for developing national FGR strategies provides the context for identifying and priority values, and following this, prioritising species. Prioritising FGR assets for conservation, management and improvement facilitates allocation of scarce resources to the most important assets and programmes.

Country reports listed the tree species that they considered to be their national priorities for FGR C&M. They also identified the uses of the main trees managed for human utility, including those providing environmental services. These priorities are generally consistent with those set out in article 7 of the CBD for guiding information and monitoring, specifying 'components of biological diversity important for its conservation and sustainable use….paying particular attention to those requiring urgent conservation measures and those which offer the greatest potential for sustainable use', with country reports usually demonstrating a greater interest in economic outcomes than conservation.

Conservation – species and genetic diversity and scientific values

In country tabulations of priority species and their values, conservation purposes (biodiversity, threatened, endemic, genetic conservation, scientific) were nominated 735 times, about 24% of the total of nominated values for priority species. Biodiversity conservation value was the most nominated category in countries' listing of species used for environmental purposes, accounting for 27% of listings.

Assessment of the rate of genetic erosion and vulnerabilities of different species, subspecies, varieties and populations is important for determining their priority for conservation and management. Countries varied greatly in the number of tree species under threat. A Canadian analysis, which considered criteria of rarity, habitat under threat from alternative uses, decrease in range, and lack of viable seed sources showed that 52% of all Canadian tree species required some form of *in situ* or *ex situ* conservation . Biodiverse countries experiencing high rates of forest loss also reported the presence of often large numbers threatened species e.g. Brazil, Ecuador, Ethiopia, Indonesia, Madagascar, Philippines, Papua New Guinea) and Tanzania.

Invasives

Invasive trees species pose a significant threat to the integrity and conservation of FGR mainly through their capacity to transform ecosystems, with small island ecosystems especially at risk. Understanding the genetic makeup and variability of invasive trees and shrubs can be crucial to developing effective control and management strategies. Fourteen species nominated as priority for management were invasive, with implications for FGR C&M – these were mainly concerns in Africa and Europe (Judith tab 4a1). The vast majority of tree invasives have been introduced for ornamental purposes although several species introduced as afforestation or plantation species have become seriously invasive, e.g. *Prosopis juliflora* in several countries and *Acacia mearnsii, A. melanoxylon, Pinus patula* and *Populus canescens* in Zimbabwe, highlighting the need to consider the invasive potential of species developed and promoted for planting and ensure that risks are minimised.

2.3 Characterising genetic variability

Understanding the nature of and describing a country's FGR at both broad (geographic) and fine (among and within forest tree species) scales - is recognised as essential for effective conservation and management. Characterising genetic variability was used by countries for the following purposes:

1) Conservation planning and management, including sustainable forest management

- Identifying areas, forests, species or populations with high levels of variability for genetic conservation (*in situ* or *ex situ*)
- and/or whose variability is at risk
- Identifying populations or individuals with rare alleles for conservation (*in situ* or *ex situ*) or with high levels of variability for enriching genetically depauperate populations
- Characterising the variability within areas, forests, populations, stands to guide forest management and silvicultural practice
- Characterising relationships between genetic variability and environmental parameters to establish 'genecological' or seed transfer zones, within which transfer of genetic materials is considered most appropriate
- Monitoring the trend in genetic variability in species, populations, or particular areas/stands, for example in response to silvicultural and harvesting regimes, environmental changes and threats, in order to help guide conservation and management

2) Breeding and improvement

- Identifying species and populations with most potential for commercial development
- Characterising desirable productive, utility or adaptive traits in priority species and relatives for further development
- Identifying individual trees with desirable characteristics for breeding and improvement
- Identifying genetic markers, including developing linkage maps and ascribing function to genes, especially for characters conferring adaptive advantage or otherwise desirable traits
- Identifying stands and individuals for provision of propagation materials (seeds and vegetative materials))

Well-defined standards for work on FGR have been developed through the activities of IUFRO forest genetics working groups involving national forest research agencies from many different countries, (but predominately from Europe and North America in the first half of the twentieth Century). Indeed the IUFRO provenance trials of *Pinus silvestris* initiated more than 100 years ago are at the genesis of international action on FGR. FAO's Forestry Department and the work of its Panel of Experts on Forest Gene Resources, commencing in 1969, have been pivotal in developing a globally shared understanding, appreciation and modus operandi for FGR conservation and management. FGR work in tropical regions of Africa, Asia and Latin America has, been assisted by national forest agencies and institutes in developed countries, backed by their Governments and donor funding, , including for example Australia (CSIRO Australian Tree Seed Centre), Denmark (DANIDA Forest Seed Centre), France (Centre Technique Forestier Tropical) and United Kingdom (Oxford Forestry Research Institute). During the early 1990s forestry research was incorporated into the Consultative Group on International Agricultural Research, with three centres (IPGRI/Bioversity International; ICRAF and CIFOR) subsequently contributing in significant and complementary ways to FGR R&D. Article 7 of the CBD. Details priorities for information and data collection, requiring the identification and monitoring of components of biological diversity important for its conservation and sustainable use, as well as processes and activities which impact on these values and addressed through the strategic priorities identified through this SoW-FGR.

Recognition of the economic and ecological importance of genetic variability in tree species has steadily increased during the last 60 years, and has driven efforts to research, characterise and document this variation. There has been considerable research undertaken on commercially important planted tree species to document quantitative variation in growth rates, survival, wood properties, genotype by environment (GxE) interactions, and tolerance to different environmental stresses. An early example of this type of research, undertaken in the 1960-70's under the auspices of the FAO Forestry Department, was the investigation of provenance variation in *Eucalyptus camaldulensis*, the most widely naturally distributed *Eucalyptus* species and one of the most widely planted trees in the world [2]. The research demonstrated the substantial and economically important variation in performance of different provenances or seed sources, depending on their origin and the environmental (climate and soil) conditions under which the different trials were conducted. Since this time, there has been an ever-increasing appreciation in the forestry research community on the need to use well-documented, source-identified germplasm for the conduct of field trials. Series of international provenance trials of pines, eucalypts, teak, gmelina, pines, acacias, arid-zone species, and more recently casuarina and neem have been remarkably successful, making immense scientific contributions, and leading directly or contributing to major forestry plantation developments in the developing tropics. Hundreds of tree species and provenances (including many *Eucalyptus* spp.) were introduced in multi-locational arboreta in African countries to assess adaptation and potential use. These arboreta are now considered as *ex situ* conservation stands by some countries.

Approaches used by countries for characterising variability include investigation of morphological characteristics and the use of various biochemical and DNA markers, through field-based studies, provenance and progeny trials, and laboratory-based investigations; these are discussed below (and in more detail in Ch 5). The different methods of characterisation require different levels and types of resources, including funding, technical expertise, equipment, facilities and even land, and they are deployed by different countries in a manner consistent with the technical, financial and personnel resources available. The types of investigation and the information sought also influence the methods selected and the characters assessed.

Most methods of characterising genetic variability require substantial commitments of resources, and as the number of tree species and populations to study is considered impossibly high priority must be assigned to a limited number of the most important or model species. High value, widely-planted commercial species are generally accorded the highest priority as the economic benefits from improvement can be substantial: countries rated commercial value highest in their nominations of priority species values, at 46%, nearly five times the frequency of the next highest value, threatened conservation status at 9.5%. Economic returns from improvement programmes also allow the allocation of significant resources to the characterisation of the variability of these high value utility species. This includes field investigation, provenance and progeny trials, and end product quality considerations (e.g. timber and pulping properties, charcoal making properties, fodder properties, fruit and nut nutrient content for edible species, medicinal properties and essential oil profiles). This focus on economically important species has produced a great depth of information for high value globalised utility species and hybrids. For example tree species such as *Acacia mangium, A. nilotica, Cunninghamia lanceolata*, *Eucalyptus camaldulensis*, *E. grandis, E. globulus*), *Hevea brasiliensis*, *Pseudotsuga menziesii*, *Pinus* spp. (*P. caribaea, P. elliottii, P. massoniana, P. patula, P. radiata, P. sylvestris, and P. taeda*), *Populus* spp. and hybrids and *Tectona*

[2] *Eucalyptus camaldulensis* was nominated by 17 countries as a priority species in their country reports, and second only to teak with 20 priority listings

grandis, amongst of the thirty most widely planted trees in the world (Carle *et al*. 2009), have been the subject of intensive research into the genetic variability influencing expression of desirable characteristics. The majority of trees studied in depth are planted mainly as exotics[3], including many hybrids, with exotics comprising 83% of the priority species nominated by countries, for which data on origin is available. Historically, less effort has been expended on characterising a countries' own indigenous FGR, except in cases where the species are of high economic value and widely planted (e.g. *Cunninghamia lanceolata*, *Pinus massoniana* and *P. tabuliformis* in China, *Pinus taeda* and *Pseudotsuga menziesii*), or else are threatened and the subject of conservation management interest.

Where appropriate countries make use of existing information sources for their FGR programmes; for example some countries with advanced FGR C&M systems had not undertaken systematic or special inventories of FGR, rather making use of existing inventories and databases of forestry and biological resources.

Rare and threatened species requiring conservation are also considered to have high priority for characterisation of variability, and ranked second in values of species nominated for priority in country reports, at 9.5% of nominated values. They have been the focus of genetic investigations, especially for rare, threatened commercially valuable tree species (e.g. *Eucalyptus benthamii* in Australia; *Baillonella toxisperma* in Gabon; *Dalbergia cochinchinensis* in Thailand). Assessment of genetic variability plays a vital role in conservation planning and guides decision-making and management: as Germany remarks, '…knowledge will be used in decisions on natural and artificial regeneration of forest stands, in the provenance controls of forest reproductive material and in the choice of gene conservation forests'.

2.3.1 Methods for characterising genetic variability

As noted above, a number of methods for characterising genetic variability, both quantitative and molecular, are available. Use of these methods varied according to the nature of the country's genetic resources, whether the information sought is at the interspecific or intraspecific level, the country's priorities and the objectives being pursued (conservation, management, improvement), the resources and technology available for the task, the degree of advancement of their FGR C&M systems and the organisation undertaking the work. For example documentation of raw FGR in large protected areas may require taxonomic surveys to provide a broad assessment of variability at the interspecific level, while for detailed conservation planning or breeding programmes, information about the genetic variability between and amongst populations, provenances or progeny has been sought, involving investigation at the molecular level. A variety of parameters often need to be measured to provide the information necessary for conservation and management of a species' variability.

Characterising interspecific variability

[3] A classic example is *Pinus radiata* which is the most widely planted *Pinus* sp in the Southern Hemisphere, but restricted, rare and at risk of extinction from Pine Pitch Canker (*Fusarium circinatumin*) its native California (USA)

Characterisation of diversity at the species level is a key element and priority for FGR C&M. It involves the identification of tree species and mapping of their distributions through nationwide inventories; environmental and biogeographic information is also important for understanding and interpreting morphological differences. It requires botanical, taxonomic and biogeographic expertise, field survey, and GIS and data management systems for mapping, recording, storing and sharing information. Much of this level of genetic characterisation is being captured through biological and forestry inventories undertaken in the course of other resource management activities, such as biodiversity conservation and forest management.Such surveys often fail to capture and document the extensive genetic resources held in *circa situm* environments, ICRAF and African national partners have documented information for important agroforestry tree product (ATP) species through participatory rural surveys (e.g. Leaky *et al.* 2003), and SPRIG/CSIRO has done likewise with five Pacific Island nations (e.g. Thaman *et al.* 2000).

Countries with well-established biological and natural resource management administrations and infrastructure, including herbaria and well trained taxonomists, have a better knowledge of their tree species diversity and distribution, while countries with fewer resources have a greater need for further characterisation at the species level. Completion of biological inventories, including tree species resources, will be more challenging for countries with extensive areas of highly diverse tree flora distributed over a wide range of heterogeneous environments, particularly if forests are inaccessible and poorly known and/or with conflict related security challenges.

Interspecific diversity reported by countries varied significantly, and this has major implications for the FGR C&M systems. For example, Finland has only 19 native tree species; Germany has over 70 native tree species while Canada, with 10% of the world's forest cover accounting for 30% of global boreal forest, has 126 native tree species; this compares with China's 2000, Australia's 2500) and Brazil's minimum of 7880 species,. Countries with higher numbers of species will generally have greater reserves of genetic variability, and the task of documentation and characterisation is proportionally more difficult: country reports suggest that developed nations with lower interspecific variability generally had detailed knowledge of a higher proportion of their indigenous tree species, especially where these species were important commercially.

The level of endemism in countries' tree flora, especially at higher taxonomic levels such as family or genus, is an indicator of unique genetic variability associated with different evolutionary lineages. China has seven endemic families; of the 197 palm species in Madagascar nearly 100% are endemic at the species and genus level, and the country has 1676 endemic plant species considered threatened under IUCN criteria, many of which are trees. Monospecific families and genera may hold unique genetic diversity and are valuable for scientific purposes and their novel biochemical.

Where botanical inventories are lacking the area of forest or vegetated cover may be used as an approximate surrogate measure of genetic variability. As many countries do not have detailed information on variation among and within species, and are unlikely to in the near future, forested area is used as a primary measure of diversity of FGR, as a means of monitoring its trajectory or trend, is therefore critical to conservation and management decision-making in these contexts. For example, Ghana quotes the loss of most of its dry semi-deciduous forests as representing a serious threat to the genetic diversity of the woody species contained within it. Many countries reported significant deforestation rates – for example Madagascar lost 4.5% forest cover between 2000-2010

(FRA2010) – with the risk that 'many forest species may disappear forever, without ever being discovered' (Madagascar p20); similar risks were also noted by Indonesia and Thailand. Ethiopia recognises that 'the most important threats to genetic diversity come from deforestation and forest fragmentation, which can result in total loss of genetic information and disturbance in the genetic structure'. In summary forest cover can be a useful surrogate for genetic variability and as a basis for conservation and management decision-making until such time as more complete botanical and forest inventories have been undertaken.

Where area of forest cover is used a as surrogate for diversity, estimates of species richness and distribution per unit of area are required, to establish the relationship between forest or tree loss and the loss of diversity that this represents. Ground-truthing of GIS data may assist this process. Information on the likely levels of diversity within the species lost can also help inform this.

Area measures of forest tree species richness have also used to define biodiversity 'hotspots' and 'megadiverse' countries; are such delineations have been used in prioritising conservation efforts both internationally and within countries. Nonetheless, the identification and protection of areas particularly rich in FGR should not detract from efforts to conserve and manage these assets across the entire globe: a forest may contain relatively low numbers of species compared to other, more floristically diverse areas, however the species contained within it may be vital for local communities (e.g. atoll island communities in central and northern Pacific) or more genetically unique and have extremely high value for conservation of FGR(e.g. Seychelles., with only 93 indigenous tree species, which are nonetheless highly distinct with endemism of over 50% on its granitic islands).

For countries that lack comprehensive inventories of their forest species, completion of these is a high priority: for example, the Madagascar report states that it is indispensable to complete knowledge of the forests and the species they contain by undertaking new floristic inventories across the country. For assessing changes in forest cover, the use of GIS is vital, and constitutes one of the most important methods for broadly characterising genetic variability, particularly in the context of less wealthy, biodiverse nations subject to high levels of forest loss and degradation. International donor and partner assistance with conducting forest inventories can play a vital role in assessing diversity and monitoring these changes.

Characterising intraspecific variation

Environmental heterogeneity, breeding systems, the degree of biogeographic isolation from other populations or individuals, and the species evolutionary history all influence the pattern and level of intraspecific variation (Ch 1) . Its characterization and documentation is widely appreciated as a central component of conservation and management of individual species, including breeding for economic, genetic conservation and environmental applications, and for identifying provenances and seed transfer or genecological zones, enabling selection of germplasm best adapted to local conditions for use in planting programmes.

A thorough understanding of intraspecific variation is well-recognised in country reports as fundamental to the sustainable management of FGR, including in forests managed for multiple purposes; it is particularly important for forest types, species and populations containing valuable genetic resources with narrow or limited distributions which need to be monitored at the intraspecific level. Despite the great value of knowledge of intraspecific genetic variability, USA notes that, with current resourcing, there are ‘too many tree species’ to effectively assess genetic variability at this level. For example, China has genetic information on 100 species, a very high number compared to many other countries; however this represents only about 5% of its tree flora and highlighting the need to prioritise species for further investigation.

As plantation forestry in most parts of the world is focused on improvement of a small number of highly productive commercial utility species, genetic characterisation has similarly focused on these trees. For example, there is considerable study and information available on the variability of the most commercially important species in *Acacia*, *Eucalyptus, Populus* and *Pinus* which constitute four of the most widely planted genera globally. Efforts to characterise species which are less widely planted, but often important locally or in naturally regenerated forests are lagging and in urgent need of study.

Sharing information on intraspecific variability is essential for effective FGR C&M, and is particularly important for developing countries that lack the resources to undertake such studies on the exotic species on which their forestry industries may depend. Several key international networks share information generated in member countries and organizations; networks for *Pinus/*CAMORE, *Populus* and *Salix, Tectona*, *Eucalyptus,* neem, Bamboo and Rattan networks are particularly important for developing countries, as noted in country reports. It is also vital that public-goods FGR research is published in accessible formats, such as on line free or open-access journals and websites.

Methods used by countries to assess intraspecific genetic variation included well-established techniques such as identification of morphological differences in the field; provenance testing; progeny testing; genecological studies to ‘examine the variation of adaptive traits across the landscape that are likely to impart an adaptive advantage which may assist in delineating appropriate ‘seed transfer zones’; and increasingly laboratory-based approaches based on biochemical and DNA markers. Each method has its particular applications and advantages in different country contexts and applications. Of the species investigated by countries for intraspecific variation and for which testing methods were cited in country reports, DNA markers were used for 58% of the species, biochemical markers for 38% of species, and studies of morphological characteristics for 4% of species.

Genera and individual species vary greatly in the degree of variability within and between them as well as for regions and traits, and a species’ biogeographical and genecological distribution may be simple or complex, and may overlap provincial and national boundaries requiring cooperation between agencies in different jurisdictions and countries..

A brief description of countries’ approaches to intraspecific characterisation is given below.

<u>Use of morphological traits</u>

Morphological characters that may be assessed include bole form, branching pattern, height, wood and leaf characteristics, growth traits, as well as structures that show limited phenotypic variation, particularly reproductive parts such as seeds and fruits. Its relatively low cost and ease of use compared to laboratory-based approaches has led to its widespread application. However the observed differences cannot be attributed to genetic differences with certainty until further testing is undertaken, most commonly through provenance/progeny testing (see below) and increasingly coupled with molecular marker studies. Phenotypically-based selections and characters of trees in wild stands typically have very low heritabilities, especially for those traits showing continuous variation. Nevertheless, selected individual ‘plus’ trees or seed stands showing superior expression of desired traits is widely used for propagation materials for provenance, progeny or other trials and to produce seed or nursery stock for production plantings. The method may also be used to identify variants and guide selection of more diverse plant materials for conservation management when establishing *ex situ* genetic conservation stands for threatened species, although random sampling of gene pools, involving large number of selections (e.g. > 30 trees) of widely spaced and presumably unrelated individuals is generally preferred for both provenance trials and conservation measures. Morphological evaluation/phenotypic selection is one of the main characterization methods used by developing countries, even though its use was not recorded often in tabulations of countries' characterisation methods. Assessment of morphological and growth traits undertaken on same-aged plants growing under a common set(s) of environmental conditions generates higher heritabilities and accordingly are the first step in many traditional breeding programmes.

Provenance, progeny and clonal testing

Provenance testing involves growing trees selected from different locations or ‘provenances’ in the same field environment so that observed variation between populations or individuals can be attributed to genetic differences. These approaches have been and continue to be used widely in tree breeding and improvement programmes; Germany has provenance tests for 33 species underway, this approach being used as far as the 1800's; Zimbabwe's provenance testing programmes for indigenous species date back to the 1980's, and also forms the basis of its *ex situ* conservation programme. The results of provenance tests are typically only valid at half of the projected rotation age, and some characteristics of interest may not express themselves for many years. Accordingly provenance testing is time consuming and rather expensive, and may be subject to high levels of risk associated with natural disasters such as drought, fire, cyclones, and social, political and economic disruption. However, as provenance testing does not require high levels of technical infrastructure or facilities, it is used widely in tropical countries, where trees often have fast growth rates and shorter rotation periods, meaning that valid selections may be obtained as early as 5-10 years after planting for short rotation species.

Provenance testing, including GxE interaction studies and reciprocal transplant trials help identify provenances adapted to particular environmental conditions, including climate, drought, and fire – an increasingly important task given climate change. This contrasts with many molecular marker tests, which while evaluating genetic difference or similarity do not necessarily identify genes conferring adaptive or productive advantage. Several countries considered research to identify provenances better adapted to new climate change-induced conditions as a priority. More generally, the USA report notes:

> *‘Long-term provenance trials test different provenance collections over a variety of planting locations, and…in addition to documenting intra-species variation, can provide reliable information for determining the limits of seed movement and discern which seed sources suitable for planting locations because they evaluate seed sources over a long period of*

> *time...the wealth of provenance trials have demonstrated intraspecific variation for practically all timber species…'*.

Gene-ecology studies use provenance testing or environmental surrogates to examine the variation in adaptive characteristics related to traits such as growth rate, phenology, form, cold and drought tolerance, across a landscape gradient; the information is used to delineate seed transfer zones. This approach has been used to define seed transfer zones for conifers in southeast and north-western USA, for teak and *Pinus merkusii* in Thailand and for forest tree species in Denmark. It allows the best-adapted plant materials to be matched with appropriate locations and environmental conditions.

<u>Molecular markers</u>

Molecular marker approaches employ laboratory-based techniques to identify and describe genetic variation. Greatly reduced costs of gene sequencing and increases in computer processing speed and power, coupled with high labour costs in developed countries, have led to a proliferation of DNA studies, including whole genome sequencing and rapid progress in identifying the location and function of specific genes.

Isozyme and/or allozyme variation were widely used as molecular markers up to the 1990s to evaluate genetic diversity and breeding systems in trees, including for examination of variation within and between populations, using over 20 enzyme systems; the earliest research was mainly focussed on high priority plantation genera and species for production of timber and pulp, such as *Eucalyptus*, *Pinus* and *Populus*. However since the advent of more informative, accessible and cost effective DNA-based approaches, including direct DNA sequencing, single nucleotide polymorphisms and microsatellites, these isozyme studies have fallen out of favour although they are still useful for some purposes, and have a role as low cost markers for assessment of diversity and breeding systems.

Mexico notes that 'molecular markers have been the most popular [method of characterising intraspecific variability] for forest species [in] the last ten years'. This trend is reflected in country reports, where of 409 records of markers used to evaluate intraspecific variation, 58% were DNA markers, compared to 38% for biochemical markers. By contrast morphological markers were recorded used in 4% of evaluations. Europe reported the highest use of biochemical markers (65% of uses of this marker type), followed by Asia at 21%. Regionally, Asia and Europe reported the highest use of DNA marker, at 46% and 44% respectively. Africa reported the least use of DNA markers (3% of DNA marker uses), possibly reflecting the limited resources available for applying these techniques.

Molecular techniques offer the opportunity to rapidly identify genetic variability. This can circumvent the long time periods and risks involved in provenance and progeny testing, which is a constraint on the development and production of improved germplasm for general use. Germany points out the time available to develop climate change-adapted planting stock is extremely limited, highlighting the importance of developing techniques able to deliver results more quickly than traditional methods.

Although these methods are highly effective in identifying variability and evaluating similarity or difference between individuals or populations many of these techniques use ‘neutral’ markers, ie markers where the genetic variation identified does not necessarily confer an adaptive advantage or contribute to improvements in productivity, performance, or utility. Many countries involved in research at this level identified the need to develop molecular markers for adaptive and productive traits as a high and urgent priority. For example, Germany stated that *‘It is essential that future international research projects also provide more information about the genetic variation to adaptation-relevant gene loci. This would provide important information on the adaptation potentials of tree populations.’*

There are constraints on the use of molecular techniques in developing countries with limited resources, including cost, lack of expertise, equipment and facilities; Zimbabwe noted the high cost of molecular characterisation constrained its use. Nonetheless it is recognised that these techniques offer great potential – Ghana, for example, identifies development of expertise in biotechnological approaches and upgrading of existing facilities as key capacity requirements for advancing its characterisation agenda. Further, many developing countries already use these techniques, even if their use is limited. However, as noted earlier, there are many opportunities for cooperative arrangements with international or regional partners and donors to provide molecular-based characterisations for developing countries which lack these resources, or to assist in the development of in-country facilities and expertise. Research facilities able to undertake these studies may exist in a country outside of the institutions charged with FGR C&M, such as universities, agricultural institutes, research organisations, and the private sector. Effective collaboration between such groups can deliver mutually beneficial outcomes: in the USA, much breeding and improvement work involving the use of these facilities takes place through cooperative arrangements between universities, public land management agencies, and private companies. Ethiopia noted that while no dedicated facilities existed for molecular characterisation of FGR, facilities did exist in the country but were engaged in agricultural crop research; molecular characterisation of the few intraspecific studies of trees (using ISSR, AFLP and chloroplast microsatellites) were outsourced internationally. Burkina Faso similarly outsourced its characterisations based on molecular markers: ‘…sophisticated methods have been used through a partnership with Western universities in Denmark, France, Great Britain and the Netherlands.’ This suggests there is an opportunity for coordination and sharing of research interests and facilities in related fields, potentially for the benefit of both sectors. Germany noted that some government department offered consulting services in FGR; adoption of this approach more widely may allow the procurement of skills, expertise and access to facilities on an ‘as needs’ basis.

On the other hand there can be advantages in developing these capacities within countries, both to facilitate the integration of national strategic priorities for FGR with research capacity and function, and to allow the country’s own FGR C&M interests to be pursued without having to accommodate external demands.

The potential benefits from greater integration, coordination and cooperation in areas of common interest is ilustrated by the Ethiopian case quoted above, in which in-country capacities and facilities exist but are not available for use in FGR research. This also underscores the importance of integrating FGR objectives at a national level, for example through harmonisation with national strategies and programmes in related fields.

Measures

Various methods are available to analyse the data collected in studies that use the techniques described above. These were rarely referred to in the national reports, although a number of countries such as Mexico and China detailed the analytic methods used in evaluations of their FGR data. For example in China evaluations and analysis of inter-population variation used variance components, genetic distance and phenotypic differentiation coefficients, while intra-population variation was evaluated using standard deviation, coefficient of variation, variance, and Shannon information index. Common parameters used for isozyme and DNA analyses 'include allele frequencies and their distribution, variance of genotypic frequencies, average number of alleles per loci, effective number of alleles, percentage of polymorphic loci, Wright's inbreeding coefficient and Nei's diversity index, Shannon information index, coefficient of genetic differentiation and genetic distance.'. In studies of the variability of Mexican tree species, genetic diversity was inferred through calculation of expected heterozygosity, observed heterozygosity, number of alleles per locus and percentage of polymorphic loci.

Characters investigated in studies of intraspecific genetic variability

Investigation of commercial plantation forestry species focuses on characters delivering economic benefit, such as growth rate, form wood characteristics or industrial processing qualities. This differs somewhat from investigation of the level and distribution of variability within a species, required for the design of effective genetic conservation programmes; in this case, documenting particular productive characteristics is less important than assessing overall variability (provenance and progeny testing may however be used in conservation management to establish variability, including when selecting materials of threatened species for *circa situm* conservation measures). Characterisation of variability contributing to adaptation and survivability under future environmental regimes (climate change, human-modified landscapes and invasive species), though recognised as crucial by some countries, needs further work.

Countries reported the individual characters that were assessed in the course of evaluating genetic variability; twenty-seven characters were reported as used in 692 characterisations. The most studied were morphological characters least subject to phenotypic variation i.e. seed, fruits, cones and pods at 17.5%; next was disease and pest resistance, accounting for 13% of characterisations (adaptive and/or productive character); leaf anatomy (morphological) at 7%; and bole/stem diameter (productive) at 7%; growth rate (productive) at 5.5%; productivity/biomass/fodder (productive)at 5%; height (productive) at 5.5%; drought resistance (adaptive/productive) at 5%; phenology (adaptive) at 5%; bark (morphological) at 5%, and chemistry/exudates at 3%, as well as a 17 other less used characters. These data indicate that purely morphological characters remain widely used in the evaluation of variability, despite the increasing focus on molecular markers. It also highlights the importance for countries in identifying trees and genotypes for breeding for pest and disease resistance, e.g. despite a limited intraspecific evaluation programme, Ghana (p20) notes that 'all objectives and priorities for…understanding…intraspecific variation are geared towards identification of planting stocks resistant to insect and disease infestation under forest plantation conditions'.

It was noted that the variables and measures used in evaluating genetic diversity are indicators that are often used to represent and infer the general variability of target organisms (e.g. Mexico p3).

This process relies on assumptions about the relationship between the variation observed in the variables tested and the variation in the target character or organism under study. Several countries observed the need for continued research into the methods for characterising diversity. In particular, recent molecular techniques have allowed genetic variability to be rapidly characterised. However, as mentioned above, many of these studies use ‘neutral’ markers, i.e. for genetic variations that do not confer selective advantage, the need for identifying molecular markers for adaptive and productive characters was noted as a priority by Germany. Adaptive traits include drought tolerance, fire and wind resistance and pest and disease resistance, while productive characteristics include growth rate, form, and wood processing qualities.

The importance of identifying adaptive markers is considered especially significant with respect to climate change, which is widely recognised in country reports as the major challenge to the integrity of forest ecosystems and the survival of individual tree species. A number of countries pointed to the need to identify breeding stock for both productive and environmental purposes that is better adapted to the expected conditions, for example with respect to phenological responses (reproductive phenology and deciduousness), or drought, fire, pest or disease resistance. Germany stressed the high priority for identifying markers for characters that confer survivability under the expected modelled altered climate regimes, to facilitate the selection of climate change-adapted plant materials.

2.3.2 Monitoring forest genetic resources

Monitoring the state of a country’s genetic resources and its trajectory is an essential requirement for effective FGR C&M and decision-making, assisting in identifying the extent, severity, location, and nature of the genetic erosion of species and forests; informing decision-making, and evaluating conservation and management actions. Article 7 of the CBD requires signatory countries to ‘monitor, through sampling and other techniques, the components of biological diversity…paying particular attention to those requiring urgent conservation measures and those which offer the greatest potential for sustainable use’. The rapid rate of forest loss, high levels of genetic erosion and impending climate change highlight the urgency of establishing effective monitoring programmes. A number of countries recognised the need for an effective forest genetic resources monitoring and evaluation system as required by the CBD; Canada noted inter- and intra-specific monitoring is a priority for tracking FGR status of species and for threat status, level of genetic erosion, and vulnerabilities of species, and identified the need for ongoing investment including in field and laboratory personnel, information management for inter- and intra-specific monitoring including consistency across jurisdictions. Germany noted the importance for ongoing monitoring of available genetic resources and silvicultural activities to deal with climate change.

As it is impossible to measure the genetic variation and monitor changes in all or most tree species, two approaches may be applied. Firstly, measure and monitor the genetic variability in only of the highest priority or model species. This approach is adopted by Germany which monitors genetic variation of five species in response to forest management regimes and silvicultural practices. The second approach involves identifying and monitoring surrogates for FGR; for example, particular species or populations, or the area of forest or tree cover, in combination with GIS, ground-truthing, biogeographical interpretation and species richness-area Effective monitoring of genetic variability will often require several measures to be used and assessed in combination.

The current level of FGR monitoring varies enormously between countries. For example, Thailand has a network of 1285 permanent plots as part of its national forest resources monitoring information system, with sampling commencing in 2008; which is expected to provide valuable input for updating information on forest cover, genetic resources and deforestation. It also has a strategic framework for surveys and database establishment for biodiversity and FGR in protected areas.At the other end of spectrum, the Solomon Islands currently has no systems in place to monitor and report on FGR erosion.

Monitoring needs to be a requirement of all FGR C&M programmes, and specified in a country's national FGR strategy or programme with endorsement at the national level helping to secure budgetary allocations. Several countries pointed out the need for increased and consistent, harmonised monitoring across jurisdictions, regions and national boundaries. Existing cooperative multi-jurisdictional administrative arrangements, where they exist, can provide a vehicle for integration of this FGR C&M function. For example, in Europe, an integrated European forest convention addressing SFM is currently being negotiated, and this may provide a suitable avenue for harmonisation.

Global trends in FGR

Major cause of FGR losses include conversion to agriculture and other land uses, forest degradation and ecosystem simplification, selective removal of high-value timber and NWFP species, fire, and increasingly, invasive species, pests and diseases aggravated by climate change. The high rates of forest loss and degradation in some countries resulting in irretrievable erosion of FGR have been noted above (see also Ch 1). . FRA 2010 has documented forest losses in the period 2000-2010 which show that most forest loss in occurring in more biodiverse rich tropical forest regions and countries, with primary forest shrinking by 0.37% per annum globally. These data also show that forest loss in tropical areas is relatively stable on a % basis from the period 1990-2000 and 2000-2010. In western and central Africa and in South America the rate of forest loss was the same for both periods at 0.66% and 0.45% per annum, respectively. In eastern and southern Africa the rate of forest loss increased from 0.62% to 0.66% per annum over the two periods, while annual forest loss in south and southeast Asia dropped substantially from 0.77% to 0.23%. Annual forest loss also declined substantially in central America from 1.56% to 1.19%. Globally the area of forest designated primarily for conservation of biodiversity continues to increase substantially, by 1.92% per annum from 2000-2010. A major concern is that most forest loss is occurring in biodiverse tropical countries: the ten countries with largest annual net loss of forest area, from 1990–2010 are in order Brazil (-2, 642,000 ha; -0.49%), Australia (-562,000 ha; -0.37%), Indonesia (-498,000 ha; -0.51%), Nigeria (-410,000 ha, -3.67%), Tanzania (-403,000 ha; -1.13%); Zimbabwe (-327,000 ha; -1.88%), DR Congo (-311,000 ha; -0.20%), Myanmar (-310,000 ha; -0.93%), Bolivia (-290,000 ha; -0.49%) and Venezuela (-288,000 ha; -0.60%). Such extensive losses in biodiverse forest cover are likely to be accompanied by loss of genetic diversity in socio-economically useful and potentially useful tree species. Gross losses of undocumented and poorly documented FGR in many tropical countries are of extreme concern, and this dire situation requires urgent action involving inventory and conservation measures, that are adequately funded and prioritised at both national and international levels.

On the other hand, areas of forest in a number of countries were being increased or maintained, due to establishment of reserves and protected areas, controls on logging and over-harvesting, implementation of SFM, planting of trees and plantations and the natural regeneration of abandoned farmland. Between 1990-2100 major replanting has occurred in both China (1,932,000 ha per year) and the USA (805,000 ha per year) (FRA 2010). Countries with constant or increasing forest cover tended to be developed countries with highly developed forest management and administration institutions, although India has achieved an increase of 3 M ha in the decade to 2010, partly through plantings (India p16). Denmark (p4) describes the long-term increases in its forest cover from 2-4% at the beginning of the 19th century to 13.5% in 2010.

Due to its monitoring systems, Germany was well-placed better document and describe changes in FGR cf. most other countries. Forest genetic diversity has been increased through prevention of overcutting and forest loss, the application of silvicultural techniques favouring multipurpose mixed hardwood stands established from a wider genetic base over monospecific coniferous plantings, and through an increase in forest area including the targeted introduction of rare tree species into natural forest ecosystems; evidence from intraspecific research suggests there is little or no loss of diversity in productive forests so it is assumed that diversity is stable (Germany p26). However, it is noted that repeat inventories are required to definitively assess whether genetic erosion has occurred.

While maintaining and expanding forest cover and genetic variability may be easier for developed, temperate and boreal zone countries given the lower number of species, more effective administration of forests and less poverty-driven unregulated harvesting, they nonetheless offer examples of how maintenance and expansion of FGR may be achieved, for instance through sustainable forest management, silvicultural techniques, and policy mechanisms such as incentives for sustainable management of FGR.

2.3.3 Differences between countries and regions in characterisation of FGR

The wide divergence between countries in the level of knowledge of genetic variability has been noted earlier. From the country reports, the degree to which FGR have been characterised, and the methods employed evidently vary with:

- Level of economic development and resources available for characterisation (financial, technical, institutional and personnel),
- Level of development of conservation and forestry organisations and services and accompanying information and management systems,
- Importance of the forest sector in the economy, and the method of production and forest management (e.g. dependence on planted forests versus naturally regenerated forests),
- Nature of the forest industry – production profile with respect to output types, structure of the industry including development of private sector capacity in genetic improvement,
- Degree of engagement with regional and international networks,
- Support and contribution of international donors,
- Organisation within the country carrying out the study
- Involvement and inputs of relevant research organisations, including institutes, and universities,

- Supporting legislation and regulatory frameworks valuing FGR C&M
- National FGR strategy or programme
- Area of natural forest remaining, and the degree of diversity within the country's flora and the heterogeneity of its genecological zones,
- Numbers of priority tree species identified for conservation and management

Several other variables influencing the characterisation of genetic variability by countries are worth noting. Firstly, developing countries particularly in tropical or subtropical areas, often have very high levels of tree species diversity and FGR variability, such as the 17 'megadiverse' countries including Brazil, Colombia, DR Congo, Ecuador, Indonesia, India, Madagascar, Malaysia, Mexico, Papua New Guinea, Peru, Philippines and Venezuela and these require greater survey effort to document their FGR, in terms of identifying and mapping distribution of species, identifying areas of high interspecies diversity, and investigating genecological relationships. Secondly, developing countries generally have fewer resources available for survey, characterisation and data management, and consequently their FGR resources were generally not as well documented as developed nations. Thirdly, developing countries generally experienced much higher rates of uncontrolled forest clearing, meaning they had a greater requirement for inventories of FGR variability at the species level. Given the resource constraints in these countries, GIS provides an extremely important tool for assessment and monitoring. Fourthly, tropical developing countries relied heavily on the use of exotic utility species for plantation development, for which extensive characterisation work had already been undertaken but for which access to germplasm remains critical.

By contrast, developed countries tended to be in colder climate zones and had generally lower levels of species diversity and correspondingly lower requirements for interspecific survey. There is generally less uncontrolled forest loss and degradation through human action; indeed forest levels were often static or in some cases increasing. Developed countries generally had well-developed, long-established forest and conservation services, with comprehensive biological and forest inventory and information systems, and generally had better documentation of FGR at the area, species, and population levels. Examples include Australia, Canada, Denmark, Finland, France, Germany, Japan, Norway, Spain, Sweden, and the USA.

2.4 Strategies and approaches

Strategies addressed in the country reports fall into two main categories. Firstly, there are the strategies that countries develop at the national level that set broad overarching directions for the conservation and management of FGR. These are the appropriate place for harmonising national agendas with regional and international objectives, and identifying opportunities for coordination and integration between the various sectors within government, the economy and the community that impact on or influence FGR C&M. These are discussed above. Secondly, there are the technical strategies or approaches that are used to achieve FGR C&M, These may involve *in situ*, *ex situ*, *circa situm*, sustainable forest management and community/participatory approaches to conservation and management of FGR. The second category of strategies is the subject of this section.

In their reports prepared for this SoW-FGR, countries adopted a suite of different strategies or approaches that best suited their particular conservation and management needs, consistent with their own development goals, and the requirements of their economies, communities and their particular biogeographical and socioeconomic contexts.

Comprehensive and mutually reinforcing strategies need to be employed, across the entire range of activities relevant to FGR C&M and may operate through the public sector, private sector or community sector, or any combination of these; public sector strategies include the use of regulations and/or incentives.

2.4.1 *In situ* FGR conservation and management

In situ conservation of FGR is often considered to be the core activity of FGR C&M, as it starts out by maintaining the existing natural pool of genetic variability whilst at the same time permitting natural selective processes to operate, and secondly, it maintains the typically wide range of variation required for effective selection for breeding and genetic improvement of trees with high commercial and utility value.. An example of successful long term *in situ* conservation was provided by Thailand, with assistance from the Danish government during the 1970s, and demonstrates the need, challenges and expected outcomes:

The natural stands [of Pinus merkusii], especially in the northeast of Thailand, have been heavily exploited by local communities, primarily as a source of resin and fire sticks. In addition, many good stands are fragmented and declining as a result of the widespread conversion of forest to farmland and frequent fires. The lowland stands that showed the best performance in provenance trials… are even threatened with extinction… [conservation] of genetic variation within the species by selecting a number of populations from different parts of the distribution area…will serve as a source for protection, management and maintenance of genetic resources by providing a basis for future selection and breeding activities as well as for seed sources with a broad genetic base

In situ conservation is often considered the first course of action in both FGR and biodiversity conservation; it has been noted that alternative methods such as *ex situ* measures should normally only be considered once it is established that *in situ* conservation is not feasible and where species are at serious risk of extinction in the wild, or for safety duplication purposes. Advantages of *in situ* conservation are that 'simultaneous conservation of ecological, aesthetical, ethical and cultural heritage values are enabled'; and that large amounts of FGR may be efficiently conserved through simultaneously conserving multiple species' diversity. In indigenous production forests where SFM is practised and FGR variability is maintained, *in situ* conservation is fully compatible with harvesting of timber and forest produce.

In situ conservation ensures that the genetic variability contained in the target species is, in the absence of catastrophe and genetic bottlenecks, is maintained at a high level, and is the foundation on which selection pressures operate to direct adaptation to the new conditions. *In situ* conservation therefore allows for changes in the genetic variation contained in population or species to take place over time, and is thus referred to as dynamic (e.g. Sweden pp21-23). It is distinguished in this regard from *ex situ* conservation which predominantly uses 'static' techniques, which generally preserve a 'snapshot' of the variability present at the time of conservation of the germplasm. The following comments from country reports illustrate these points:

Although the great majority of *in situ* conservation assets are managed as open, dynamic breeding systems, a small number may be subjected to controlled pollination or other reproductive manipulations, for specific breeding outcomes.

In situ conservation involves a wide range of activities, and every *in situ* programme will include a combination of these measures, initiatives and features. Measures mentioned in country reports include:

- Process for prioritising areas, species and populations for *in situ* conservation action
- Research to understand the nature and distribution of genetic variability within the area, species or population, and to identify threats to variation and management actions to protect it, to guide conservation programme design (for example, determining the location and number of populations and individuals, area of reserve required to maintain variability at a desired level, and management actions to minimise threats)
- Protection of an area containing target FGR or priority FGR species through dedication as a protected area, reserve, population or individual, with accompanying restrictions on activities that threaten FGR;
- Legislation and/or regulation enabling conservation of the area or species, including ability to control access and use, for example through gazettal or listing on an official threatened list
- Enforcement capacity and action to control threatening activities in line with legislation and regulations
- Preparation of a management plan and active management of the forest or species, through a) controlling activities that degrade the genetic resource, by managing access, use and harvesting, and b) maintaining conditions necessary for survival and regeneration of the species or forest being conserved, e.g. through maintenance of ecological processes, control of invasive plants and animals, management of wildfire, maintenance of pollinators and dispersers.
- Participation of forest users and adjoining communities in management, access and benefit sharing, including for example incentive payments for stewardship, sustainable employment based on activities undertaken in accordance with SFM principles
- Education and awareness-raising for forest-using communities and industries, regarding appropriate uses and activities and implementation practices that minimise impacts on FGR.
- Preparation and implementation of sustainable forest management plans, that ensure genetic variability is not diminished in areas subject to harvesting and use.
- Preparation and/or implementation of guidelines or codes of practice governing the conduct of activities that may be permitted in reserves or areas providing FGR benefits, to minimise impacts on variability; for example a code of forest practice, guidelines for reduced impact logging, harvesting of firewood, NWFPs including seeds or nuts.
- Provision of alternative livelihood opportunities for forest users, for example rural, traditional or subsistence communities who rely on forest produce for fuel, housing materials, foods, medicines and income but who may be displaced or disadvantaged by change in landuse; this may include the development of plantations or better forest management to counter any shortfalls in supply of forest products.

Protected areas provide significant *in situ* conservation initiatives for most countries. For the past 20 years, protected areas have mainly been created for biodiversity conservation purposes to meet country obligations under the CBD, which states: '… the fundamental requirement for the conservation of biological diversity is the in-situ conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings'. The contribution of the CBD to the conservation of forest genetic resources cannot be underestimated. Countries consistently reported conservation *in situ* in a wide range of forest reserve categories and ownerships, ranging from strictly protected areas through to forests used for wild harvest and timber production through to private property. For Brazil, with 286 M ha of permanent, public forest estate, 'the conservation of FGR...involves a large scale *in situ* scheme', with protected areas playing a central role. In India, protected areas cover nearly 16 M ha, nearly 5% of the land area; China reports 149 M ha or 15% of the country is managed as some form of nature reserve providing *in situ* conservation of FGR. Seychelles noted that 48% of its land is protected area; Canada has 9.8% of its land area protected.The security of conservation tenure and the type and level of management are major factors in determining conservation outcomes for *in situ* FGR.

In order to better assess the contribution of protected areas to *in situ* FGR conservation, countries were asked whether they had evaluated the genetic conservation of tree species within their protected areas. A standard response was to list the number of species, threatened species, and detail any specific programmes for priority species. In general, there was little information available on the actual FGR benefits of protected areas, in relation to populations, genecological zones represented and intraspecific diversity conserved. This is indicative of the gap between the detailed information required to evaluate the effectiveness of *in situ* FGR conservation for species, and the immense task that this represents for those countries which include many hundreds or even thousands of tree species distributed over vast areas.

Although reports detailed the vast areas and amounts of FGR conserved *in situ* in protected areas and other public lands, many countries noted that they had few if any formal, designated *in situ* conservation reserves for priority species. For example, India lists only 18,481 ha in dedicated reserves for *in situ* conservation of target species, but points out that nearly 16 M ha is conserved in protected areas. Similarly, Finland states '..valuable genetic resources exist also on strict nature conservation areas, but…these areas are not considered to be part of the gene conservation programme', due to differences in management approach. The Solomon Islands with 80% forest cover amounting to 2.24 M ha, has a tiny fraction of forest (0.017%) under formal protection in two locations. This is of concern given that logging is occurring at four times the sustainable rate with serious impacts on FGR: 'the latest update on logging concession areas… provides evidence of forest cover loss on logged over areas which [is] also associated with significant loss of natural and ecological value…some endemic forest species that are unable to adapt to new environments face possible extinction'. The report notes *'While most agree that the creation of a conservation estate would be in the national interest there is no functioning institutional framework for its advocacy, creation or management. Even if such a framework existed then there would be problems in funding it. For these reasons none of the conservation areas identified… have been reserved and in fact many have already been logged.'*

The value of the protected area approach to conservation of FGR is exemplified in the reports from Brazil and India:

*In situ conservation of genetic resources is the more effective strat*egy*, especially when the main goal is the conservation of entire communities of tree species, as the Brazilian tropical forests. In these cases, trees of other species than the target ones must be included in the genetic conservation scheme, including their pollinators, seed dispersers and predators…The conservation of forest genetic resources in Brazil involves a large scale in situ scheme, and for that purpose a national scale strat*egy *had to be implemented. [This involved] the creation of a significant amount of conservation units, as well spread over the national territory as possible, synchronized with a national strat*egy *for biological diversity…'* (Brazil)

'…when the whole habitat or ecosystems are protected, whole plant genetic resources also enjoy the protection.' (India).

In situ conservation of FGR in forests under some form of protection involves diverse designations and categories, and subject to widely-differing associated regulatory regimes. Although these designations vary significantly between countries, systems tended to be shared in regions with historical and political affinities. Brazil lists 12 categories of protected area providing *in situ* conservation benefits; Canada notes it has 'numerous categories of protected areas established by multiple organizations at the federal and jurisdictional levels and through non-governmental organizations that either directly or indirectly have the intent to conserve tree species *in situ*.' The wide range of protected area designations providing FGR conservation values includes: dedicated FGR conservation reserves, protected areas, nature reserves, protection forests, national parks game management areas and bird sanctuaries, Ramsar sites, scenic parks, ecoparks, forest reserves, watersheds, mangrove forests and UNESCO biosphere reserves. IUCN protected area categories are useful in standardising country reserve categories and some countries 'translated' their designations allowing comparison with IUCN categories. Regulations governing permitted activities and guiding management varied widely and differed in the extent to which they were compatible with and/or facilitated *in situ* conservation of FGR. Thailand noted that its forest reserves provide *in situ* conservation benefits for FGR, but have less strict laws and regulations governing activities compared with protected areas. In many countries the integration of *in situ* conservation objectives and requirements with a multiplicity of designations and body of regulations presents a significant harmonization and coordination challenges. Closer integration of the aims, selection and design criteria for biodiversity conservation and other reserve and public land categories, including productive designations, with the objectives and requirements for *in situ* FGR conservation could achieve significant synergies.

In many parts of the world *in situ* conservation is mainly taking place in forests outside of protected areas. Major *in situ* conservation benefits may be provided by forests on public land used for production of timber or other forest products, depending on intensity of use and the management approach. Forests operating under sustainable management regimes and that take full account FGR management principles and practices provide major FGR conservation benefits in contrast to forests that are heavily exploited and/or subject to uncontrolled extraction. For a number of countries, sustainably managed native production and multiple-use forests are central to their *in situ* FGR conservation efforts, especially where native tree species are also major commercial timbers. Private and communally-owned and managed forestry land (e.g. in many African and Pacific Island nations) may also provide important *in situ* conservation of FGR (see below).

Ownership of natural forest lands will influence a country's approach to *in situ* conservation of FGR; the level of government control and ability to make land-use decisions depends largely on whether the land is in public, private or communal ownership. Where significant forested areas are in public ownership, the state can create protected areas and reserves for *in situ* conservation of FGR, consistent with national strategies and priorities. Conversely, the ability of governments to influence land use and protect FGR on the private estate is generally much less, and varies considerably. Regulations governing protection of FGR on private land will be more effective in countries where state power is strongest, administration effective, incentives available, and where community support for conservation is well accepted.

Forest areas on private and communally owner or customary lands also provide significant FGR conservation opportunities especially where important FGR may occur outside of protected areas. Lands under indigenous or customary ownership and/or management are extensive in some countries e.g. almost all land (85-100%) in Melanesia the area of private land subject to conservation and SFM regulations is more than twice the area in public protected areas; in Finland the area of privately owned forests is 15 M ha, more than double the area of publicly owned forests; Sweden similarly has high levels of private ownership - over 75% of its productive forest is privately owned; in the USA the majority (57%) of forests are also in private ownership but with great variation regionally. By contrast Canada, with 10% of the world's forest area, has 7% of its land in private ownership. Various levels of conservation regulation apply to private and customary lands, for example Zimbabwe notes there are differing laws and levels of control relating to different categories of private and communal land ownership in that country. Government regulation ranges from strong to practically non-existent both within and between countries. On the other hand there are large areas of private lands held under strict conservation tenure and management regimes, including under conservation covenants by NGOs including the Nature Conservancy; private forestry lands managed under SFM principles or dedicated as reserves; and other private lands subject to conservation management or vegetation retention regulations. Where lands under indigenous or customary ownership and/or management are managed under SFM principles, e.g. as protected areas or under customary regimes consistent with conservation of FGR, they can provide significant *in situ* conservation benefits. In Vanuatu, all forests are under customary ownership, with benefits flowing from the direct involvement of landowners in forest utilization and reforestation, but a downside is the convoluted arrangements required for approving Government management plans and disruptions from land ownership disputes.

The following example from Sweden demonstrates the importance of private ownership and its potential for achieving *in situ* FGR conservation outcomes:

> *'Sveaskog, the largest forest company in Sweden, owns 3.3 M ha of productive forest land, which is 14 % of Sweden's total productive forest land. Sveaskog´s nature conservation strategy includes the ambition to focus on conservation on 20 % of the company´s productive forest land. 650 000 ha are assigned to nature conservation land using production forests, nature conservation forests and Ecoparks.'*

Achieving *in situ* FGR conservation on private and customary land can be problematic, as it may be difficult to secure long term or permanent conservation tenure over the land and to achieve an adequate level of FGR conservation management. Securing *in situ* conservation of FGR in these contexts may involve a combination of regulation, SFM, education, provision of income and employment from sustainable forest-based industries, and incentives to reward landholders for stewardship of FGR. *Ex situ* conservation will often be required in cases where FGR assets are outside of publicly protected and managed areas.

In relation to achieving *in situ* FGR conservation outcomes on private land, the use of legislation and regulation to control land use and activities leading to losses of FGR have been noted above. However, while legislation and regulation are important, they are limited in their effectiveness, particularly in the private estate, with many countries noting that regulation failed to control activities leading to forest clearance. Under the Brazilian Forest Code, in the private estate forest along rivers, hills and slopes must be preserved as permanent protection areas (PPAs); and in addition to this, minimum percentages must be maintained under native vegetation (legal reserves) depending on the biome: 80% of rural properties located in forest areas in the Legal Amazon; 35% of rural properties located in savanna areas in the Legal Amazon; 20% of rural properties located in forest or other vegetation in other regions, and in native grasslands in any region. Legal reserves or LR may be harvested for timber and other products under sustainable forest management plans. PPAs cover 12% and LRs 30% respectively of Brazil, twice the area of designated protected areas on public land; however, 42% of the PPAs and 16.5% of the LRs were subject to illegal deforestation, as were 3% of protected areas and indigenous lands, and the extent to which the SFM plans are adhered to is unknown.

The Solomon Islands illustrates the difficulties of achieving conservation of FGR on customary lands: 'In the Solomons any moves to limit a landowning group's ability to dispose of its forests as they see fit, would be regarded by them as interfering with their rights of private ownership. The Land and Titles Act and other statues, including the proposed new Forests Act, have mechanisms that provide for the State to impose limits on the use of private land; however where this is in the national interest the understanding is that the owners will be compensated for any rights foregone. In the current economic conditions the State is in no position to make such compensation.'

To counteract illegal clearance of FGR on private land and encourage protection and active conservation management of FGR, some countries offer incentives and stewardship payments; for example, Brazil, Finland and Sweden. However, in the USA 37 M ha in the private estate is protected through voluntary conservation covenants entered into by individuals, land trusts and NGOs, significantly supplementing the public reserve system. Such voluntary private land conservation initiatives mentioned are oriented towards the protection of areas, taxa (species, varieties) and ecological processes. Their contribution to *in situ* conservation of FGR would be substantially enhanced if FGR C&M objectives were incorporated in reserve selection criteria and subsequent management.

The importance of the public-private land issue for FGR C&M can be illustrated by the following example. In some cases significant priority FGR assets exist largely or completely on privately owned land and outside the public estate. For example, Brazil's landscape-scale *in situ* programme is guided by the identification of Priority Areas; however, many of these fall outside the public estate, in which case conservation of FGR relies on the actions of private landholders. In some Brazilian biomes, such as Mata Atlantica, Pantanal and Pampa biomes, there is minimal overlap between Priority Areas and public land, with almost all the genetic resources occurring on private land.

An important point regarding the protected area approach for *in situ* conservation of FGR is that although the wide range of protected areas, reserve and land category types were nominated by countries as their primary *in situ* conservation initiatives, most had not been designed or selected or had management plans implemented with reference to the provision of *in situ* conservation of priority FGR and their particular needs. While landscape scale biodiversity conservation as currently practised fulfils many requirements of *in situ* conservation of FGR, failure to consider the particular needs of formal *in situ* FGR conservation protocols will inevitably result in losses of genetic variability, especially for species which are more dependent on ecological disturbance. The Canadian report points out that although programmes for the protection and management of threatened species also provide *in situ* FGR conservation, they do not necessarily address 'silent' extinctions which are 'associated with loss of genetically distinct populations, or loss of locally adapted gene complexes, [which] are not considered in [threatened species] legislation, yet may have devastating consequences for tree species faced with increasing environmental change'. It is therefore important to integrate *in situ* conservation FGR requirements into the full range of biodiversity conservation initiatives carried out by countries, to maximise outcomes for both.

To further this, integration of FGR objectives into a wide range of land-use designations and regulations governing the use and management of forested land should be considered, for both public and private land. Where legislation and regulation relating to reserves providing *in situ* conservation is inadequate, Germany suggests increasing the legislative backing for FGR conservation management actions by including the protection purpose 'conservation and sustainable utilization of forest genetic resources' in the relevant legal provisions for designated *in situ* gene conservation assets. This may be extended to other public land reserve categories and designations providing *in situ* conservation benefits.

A further example of the need to specifically address the requirements of *in situ* FGR conservation is provided by the many countries listing of their natural or near-natural seed stands and seed production areas as *in situ* conservation areas and reserves. While seed stands clearly have *in situ* conservation value, several countries noted that they were rarely selected by a formal *in situ* conservation programme design to provide *in situ* FGR conservation outcomes. Their value as *in situ* conservation resources for priority species may be correspondingly limited. This again demonstrates the need for addressing the particular requirements of *in situ* FGR conservation and integrating them more widely into management practices of all categories of forested lands. However, for countries lacking the resources for identification and management of formal *in situ* conservation reserves, seed stands are vital components of their *in situ* conservation efforts.

Formal *in situ* FGR conservation programmes

In contrast to the multi-species landscape-scale protected area approach to *in situ* conservation, dedicated programmes for *in situ* conservation of the genetic diversity of priority trees requires quite specific provisions. Specific programmes are based on knowledge of the targeted species' pattern of genetic variability, including variability within and between populations across the species' range, its distribution, ecological and regeneration requirements, physiological tolerances, genecological zones, reproductive biology and associated pollinators, dispersers and symbionts.

Based on specific information available, or in its absence through reference to general guidelines (such as FAO 1993; FAO, DFSC and IPGRI 2001), a dedicated programme for FGR conservation of a priority species may specify the proportion of variability to be preserved, the number of trees to be protected, the area required for conservation, and which populations need to be represented. The majority of variability can generally be preserved through maintaining a selection of genetically representative populations although some loss of low frequency or rare alleles may occur (e.g. USA p46); to maintain rare alleles additional populations and/or many more trees, over a wider area need to be conserved and the additional expense may be difficult to justify. Measures to protect the population's variability and viability by managing threats and ensuring regeneration of the stand must also be specified (e.g. disturbance regimes such as fire). FAO, DFSC and IPGRI (2001) guidelines suggest that between 150 and 500 interbreeding individuals are required for each population to be conserved *in situ*.

Pertinent information is required for dedicated scientifically-sound FGR conservation programmes for particular species. The Thailand report states that '….genetic resources must be selected mainly based on the available knowledge of spatial patterns of genetic variation… The combination of marker-aided population genetic analysis and information about adaptive and quantitative traits as well as forest ecosystems would allow comprehensive conservation programs for individual species in each forest type' . While some countries had sufficiently detailed information to guide *in situ* conservation planning for priority species, there was nonetheless a widespread concern at the lack of genetic or other pertinent information for the majority of species, with some countries having little information on which to base *in situ* conservation programmes. Even well-resourced countries noted the impracticality of surveying all populations of all tree species; for poorly resourced countries with high levels of tree diversity distributed over wide areas the task is impossible with current technologies.

Ideally, priority species need to firstly be thoroughly investigated for genetic and ecological diversity and then genecological zones identified and delineated, with conserved populations selected to represent the full suite of genecological zones across the entire range, resources permitting. Thailand's conservation of *Pinus merkusii*, for example, includes all eight genecological zones identified; similarly, the country's *in situ* conservation programme for teak covers all five genecological zones identified on the basis of topography, climate and vegetation, in different 15 locations. China similarly describes its process for designing *in situ* FGR conservation for priority species: 'The number of populations or stands of target species, the size of area and effective number of trees for in situ conservation were determined according to the result of genetic diversity analysis, combined with data obtained from field surveys'.

Where detailed knowledge is lacking, guidelines based on established principles may be used to design *in situ* conservation programmes. Parameters that may be considered in the preparation of guidelines for a species' *in situ* conservation include:

- Breeding system – e.g. obligate outcrossing cf. self-fertile species; vegetative propagation; animal vector cf. wind pollinated (latter assumed to have a more even distribution of alleles)
- Range – localised cf. widespread, disjunct cf. continuous (e.g. fragmentation), edge of range
- Isolating factors – greater breeding isolation between populations cf. less isolation
- Environment – homogeneous cf. heterogeneous environmental factors (e.g. geology, soils, aspect, moisture, climate)

- Population size – small in number, limited in area cf. numerous and extensive
- Level of natural variability occurring within the species and its populations – high diversity within and between populations cf. low diversity within and between populations
- Patterns of distribution of a species – e.g. clustered versus dispersed, continuous versus disjunct

Guidelines for establishing *in situ* conservation reserves for particular species have been prepared for use in some countries or regions: for example China has developed technical standards and codes for *in situ* conservation sites: these address selection of species, number of populations, area, number of trees and management requirements. EUFGIS provides information for use in European countries, for defining the minimum number of individuals required for *in situ* conservation of a species. The preparation of guidelines that can be used regionally is particularly useful for shared species and environmental conditions, and where conservation and management priorities are similar. The use of the EUFGIS guidelines is demonstrated by the following description of minimum *in situ* conservation programme requirements from the Swedish report:

- '500 trees per gene conservation unit are sufficient for species with large and continuous populations which are extensively used in forestry. These species are subjected to extensive forest tree breeding and import of forest reproductive material. In Sweden, *Pinus sylvestris*, *Picea abies* and perhaps also *Betula pendula* and *B. pubescens* belong to this category

- '50 trees per gene conservation unit are sufficient for species with populations of varying size and structures and with no or limited use in forestry. In Sweden, several tree species such as *Acer platanoides,…Fagus sylvatica, Fraxinus excelsior, Populus tremula,…Quercus robur, Salix caprea,*…and *Ulmus glabra* likely belong to this category

- '15 trees per gene conservation unit are sufficient for species with (very) small and isolated populations, which may be situated in the edge of the species geographic distribution area. These species may be redlisted or their populations have recently decreased due to forest damage. In Sweden, for instance *Acer campestre, Carpinus betulus, Juniperus communis, Prunus avium,…*and *Ulmus minor* belong to this category of tree species.'

Finland also lists some general rules: 'A basic requirement for a gene reserve forest is that it is of local origin and has been either naturally regenerated or regenerated artificially with the original local seed source. The general objective is that a gene reserve forest of a wind pollinated species should cover an area of at least 100 hectares, in order to secure sufficient pollination within the stand, but smaller units have been approved in particular for birch-species. The *in situ* -units for rare broadleaves are much smaller as a rule.' The Thailand report (p 31) offers these guidelines for outcrossing species: 'After the genetic variation within and among populations of any species has been investigated, the most variable populations with relatively high outcrossing rates (for outcrossing species) should be chosen as the sources for gene conservation.' Although general principles can be used to design *in situ* conservation programmes, guidelines are best prepared with reference to the species and conditions existing in the particular country or region. Guidelines may already exist or at least a high level of information may be available for well-studied genera and species, and there are opportunities to update and/or prepare guidelines through regional associations or networks focused on particular taxa. In order to facilitate *in situ* conservation, the preparation of guidelines should be considered, for countries, regions, genera/species that lack them and the work of EUFGIS is a useful model for other regions.

Dedicated FGR conservation programmes for priority species, whether based on detailed species knowledge or guidelines, generally seek the most efficient design to conserve the optimal amount of variability required to meet the objectives of the conservation programme, for example through identifying the number and location of populations, and the number individuals and the area required, to conserve the majority of genetic variation in the target species. Establishing, managing, and monitoring *in situ* conservation units at the fine scale necessary is resource intensive and expensive. Accordingly, programmes strive to conserve the minimum number of individuals and populations and the smallest area possible, consistent with the conservation outcomes sought. Thailand's *in situ* conservation of *Pinus merkusii* which includes two reserves of 100 ha and 960 ha, while Denmark conserves 56 species in 2880 ha of genetic conservation reserves, while the average size of *in situ* conservation units in Bulgaria was 6.3 to 6.8 ha for conifers and hardwoods. While these reserves meet the genetic requirements for *in situ* conservation, it must be noted that reserves of limited size and individuals will rarely if ever be adequate by themselves to conserve the full range of ecological and evolutionary processes needed for the long-term viability of the population. In order to remain viable, conserved populations need to be embedded in a healthy landscape matrix including the pollinators, seed dispersers, microbial associations, and the myriad of other organisms and processes that comprise a viable ecosystem. The matrix and its ecological processes must be properly managed together with the designated *in situ* conservation units.

Consistent with this approach, target conservation populations of priority species are almost always located within existing designated protected areas, forest reserves or production forests. These may be subject to further specialised conservation and management, such as monitoring, stricter control of use or access, or stimulation of regeneration. Therefore a landscape scale approach to conservation of FGR that encompasses ecological processes must be implemented at the same time as smaller, well-sited and dedicated reserves for priority tree species.

The provision of biological corridors to facilitate gene flow may assist in reducing risks of inbreeding and genetic drift in situations where *in situ* conservation units are functionally and reproductively isolated. Examples include The Greater Mekong Subregion Core Environment Programme and Biodiversity Conservation Corridors Initiative, and recommendations and plans and to link fragmented landscapes in Australia and Sri Lanka. In situations where FGR *in situ* conservation values are extremely high and the conservation of reproductively isolated, small populations is considered essential, then population viability analysis needs to be undertaken to assess feasibility and inform conservation management options.

Selecting areas for *in situ* FGR conservation

The importance of the landscape scale, protected area approach to *in situ* FGR conservation has been noted above: areas may be selected as a means of preserving the entire range of species, including trees, contained within them, as well as ecological processes and many other functions. Conserving large areas of forest in reserves serves well in the absence of detailed genetic information on priority species. Criteria for selection may include high levels of tree species diversity; presence of tree species with a high level of endemism or threatened status; a high threat level for the particular forest association/vegetation community; ability to support ecological processes, and viability of populations and processes. Brazil's FGR conservation "…involves a large scale *in situ* scheme, and for that purpose a national scale strategy had to be implemented'; it has undertaken extensive survey of the country which identified 3,190 priority areas for biodiversity conservation and sustainable use, using the criteria of representativeness, environmental persistence and vulnerability. Ethiopia has defined 58 National Priority Forest Areas and prioritised five vegetation classes containing priority species in conjunction with other protected areas as the basis for its *in situ* conservation programme, which cover about 14% of the country. Ethiopia's Forest Genetic Resources Conservation Strategy sets the general criteria for establishment of *in situ* conservation sites as follows:

- Availability of viable number of genotypes of the target species,
- Number of priority species existing in the forest,
- Presence of unique/endangered/endemic species within the population,
- Accessibility of the forest,
- Degree of disturbance (threat) of the forest,
- Species richness of a given site/population, and
- Attitude of the rural community/local people towards conservation.

The Republic of Korea has a vast system of 432 FGR reserves covering a total area of 126,868 ha. These are areas warranting special conservation measures and classified into seven categories, viz. primeval forest, rare plant natural habitat, rare forest type, useful plant original habitat, alpine plant area, wetland forest and valley stream, and natural ecosystem conservation.

A variety of approaches were used by other countries to identify and prioritise areas for *in situ* FGR conservation. Zimbabwe uses level of threat to the genetic diversity of economic species as a criterion for establishing 'strict natural reserves': these are areas containing 'commercially harvestable indigenous hardwoods whose genetic integrity could potentially be altered by over-exploitation'. To identify areas where genetic diversity may be eroding most seriously, the USA assesses range contractions amongst forest species as a surrogate for genetic loss: the mid-Atlantic region extending into New England shows the greatest loss of forest-associated vascular plants; Sweden also notes the importance of range criteria for conservation; this is particularly important with respect to adaptation to climate change in situations where there is clinal variation along a climate gradient, e.g. latitude, altitude, aspect and rainfall. Gap studies and analysis are being used by to identify FGR that are not adequately conserved through existing measures, and to identify vulnerabilities and guide C&M decision-making.

The distribution of natural forests serving as repositories of FGR may vary significantly across a country. The most extensive forest clearing has occurred in areas of longest settlement and highest population density and highest agricultural productivity, such as Brazil's Atlantic Forest biome; much of Thailand's teak resources have been lost to agriculture. Differential rates of clearing of agricultural areas results in the loss of species and associated variability adapted to these highly productive areas. This suggests that a very high priority should be placed on conservation of any remnant FGR remaining in sites of high productivity and fertility. While highly degraded, over-exploited forests in rural areas may provide opportunities for replacement with more productive plantations (e.g. Ghana p47), their current and future value as potential sources of genetic variability for conservation and the development of improved varieties for use and planting in these areas should not be overlooked.

Priority species for *in situ* conservation

The first step in preparing an *in situ* conservation programme is make explicit the conservation objectives to be achieved: '…a sound strategy for the conservation of genetic resources of a species should begin with the identification of clearly defined conservation objectives'. This is consistent with the process of prioritising species for *in situ* FGR conservation. Although the prioritisation of species for general FGR C&M has been discussed above in section 2.2, there are several issues worth noting in relation to prioritising species for *in situ* conservation of FGR in particular.

Many countries nominated priority species for *in situ* conservation in their SoW reports; a total of 743 species were nominated by countries globally. Of the responses where stated purposes could be ascribed to the categories: 50% were for genetic or biodiversity conservation, 34% for seed production and 16% for economic reasons. The breakdown for the conservation category was 24% for non-specified reserve or conservation purposes, 16% because the species was threatened, with only 10% specifically for genetic conservation.

Firstly, it is interesting to note the discrepancy between the relatively small number of tree species nominated for *in situ* conservation, and the protected area approach that many countries reported as their primary means of conserving FGR *in situ*: the numbers of species and populations maintained in protected areas and other forested lands far outweighs those in dedicated *in situ* programmes for priority species. This is likely to be due to a) the high cost and difficulties in undertaking the research, planning, implementation and management of dedicated *in situ* conservation programmes for priority species, b) the lack of information available for priority species on which to base dedicated situ conservation programmes, c) the efficiency of the protected area approach, in conserving the FGR of a wide range of species and ecological processes simultaneously, which is the only option for countries lacking the resources for dedicated *in situ* FGR programmes. As an example, Sweden states it 'has hitherto very few *in situ* genetic resources for the approximately 30 native forest trees to enter into the EUFGIS Portal. Obviously, there is a clear need to improve the *in situ* conservation of forest genetic resources in Sweden.' On the other hand, it has 4.7 M ha in nature reserves and national parks providing at least some level of *in situ* FGR conservation.

Secondly, only 16% of nominations for *in situ* conservation of priority species were for economic reasons, which contrasts with the much higher weighting of 46% when priority for general FGR C&M is listed by countries (section 2.2). This is due to the fact that 85% the economic species used in forestry globally are exotic species (section 2.2), and are therefore ineligible for *in situ* conservation in the countries where they are widely planted as exotics. These globally important, exotic industrial plantation forestry species are usually well documented and conserved in through *in situ* FGR programmes in their countries of origin and in *ex situ* FGR conservation programmes around the world. The leadership and coordinating efforts of the FAO Forestry Department since the 1960s, coupled with various agencies and programs operating in international mode such as DANIDA Forest Tree Seed Centre, France's CIRAD-Forêt (and its predecessors), CSIROs Australian Tree Seed Centre, CAMCORE and donor programs of several European countries, Canada, USA and Australia have been vital in this regard and are widely acknowledged in country reports to the SOW-FGR. Naturally, where commercial species are indigenous to countries they were nominated for *in situ* FGR conservation; for example, Thailand's teak (*Tectona grandis*) and Siamese rosewood (*Dalbergia cochinchinensis*) are both the subject of *in situ* FGR conservation programmes to ensure high quality genetic material is available for improvement, and in Germany, one of its common and most important commercial species common beech (*Fagus sylvatica*) accounts for 43% of its in designated *in situ* conservation stands under its Forest Act on Reproductive Material, with other important commercial indigenous species English Oak (*Quercus* robur) and sessile oak (*Q, petraea*) at 18%, Norway spruce (*Picea abies*) at 13%, and Scots pine (*Pinus sylvestris*) 8%; 29 other tree species account for the remaining 18% of *in situ* conservation stands. Several reasons for prioritising species for *in situ* may apply simultaneously e.g. Siamese Rosewood is prioritised for both its commercial value and its threat status. In several reports it is apparent that indigenous tree flora have been poorly investigated for their economic and productive potential, a point noted by Tanzania: 'the [indigenous] gene pool has more to offer…'. This is partly being rectified through the work of ICRAF and national partners and others, e.g. during the period from1996-2005 the AusAID-SPRIG (South Pacific Regional Initiative on Forest Genetic Resources) project assisted several Pacific Islands to simultaneously research, conserve and develop their own indigenous species which has resulted in much greater planting of native species such as sandalwood (*Santalum*) species in Fiji and Vanuatu, whitewood (*Endospermum medullosum*) in Vanuatu and malili (*Terminalia richii*) in Samoa.

Thirdly, while general conservation purposes comprised 50% of the reasons for nominating priority species, only 10% specifically mentioned gene conservation, with general conservation and conservation of threatened species accounting for the remaining 40%. It appears that some countries correlate threatened species conservation with *in situ* FGR conservation; whereas this is seldom the case. Improved understanding and promotion of the methodology for formal *in situ* FGR conservation is required to increase its application.

Finally, 34% of priority species nominated for *in situ* conservation were nominated for seed production purposes. However, as noted above, selection criteria for *in situ* seed production stands may differ from those used to select populations for *in situ* conservation of FGR; for example, ease of access may influence seed stand selection, while these are generally not considerations in formal *in situ* FGR conservation programmes; conversely, the conservation of populations growing in marginal and extreme environments and/or uncommon alleles may be a consideration for *in situ* FGR conservation of a species but less important for seed stands providing germplasm for commercial forestry.

A further point is that priority species nominations only reflect existing knowledge of utility and threatened status – where the potential economic utility or the threat status is unknown, species are neither nominated nor dealt with as priority. By contrast, landscape scale approaches, such as protected areas and sustainably managed multiple use forests, provide the benefit of maintaining a large number of species and populations regardless of the level of knowledge, and for this reason are more appropriate where species information is scant or lacking.

Nevertheless, the process of prioritising species for *in situ* conservation is an essential task, given that the particular requirements of dedicated *in situ* FGR conservation programmes for priority species are unlikely to be fulfilled by the ecosystem conservation approach alone. Both coarse-grain, landscape scale and fine-grain, species-specific *in situ* FGR programme approaches are required, and these must be treated and managed as essential and complementary.

Some country reports described the criteria used to set priorities for *in situ* conservation of FGR. For China, 'priority species for *in situ* conservation was determined by the existing quantity of the species, the socio-economic value and the depletion of FGR', while Thailand's three priorities were: '…species with socio-economic importance, both the commercial importance and the importance for maintaining ecosystem functions and services; species with higher levels of genetic diversity; and species with populations at risk or under threat from any cause e.g. critically endangered, endangered or vulnerable species' (Thailand p38).

In situ conservation programs will aim to conserve genotypes and populations with desired adaptive, production and quality traits and also variation more generally in target species. For breeding programmes seeking improvement in a species' commercial or utility value, productive traits such as growth rate or form may be sought in populations or stands identified for conservation; pest and disease resistance and adaptation to climatic extremes are other economically important traits. *In situ* conservation programs that seek to maintain genetic variability for biodiversity conservation purposes, such as for threatened species management, or in the interests of general conservation of FGR, will seek to preserve the widest range of variability possible within the resources available to the programme. Many countries stressed the importance of maintaining the widest genetic base possible through *in situ* and dynamic conservation measures to facilitate adaptation to climate change for all forestry and tree planting programmes, whatever their objectives.

Management of *in situ* FGR conservation areas

In situ conservation of FGR cannot be achieved by merely legislating for a protected area; 'the populations maintained *in situ* constitute part of ecosystems and both intra- and inter-specific diversity must be maintained over time at appropriate levels'. Where a country's forest management regulation and administration lacks the capacity to manage extensive areas of natural forest *in situ*, or where sustainable management is lacking, uncontrolled and non-sustainable harvest and use pressure and serious loss of genetic variability may result, as noted by Ethiopia; the most valuable and highest utility species are at the greatest risk. Risks to genetic variability, both species and within-species, are greatest in countries with high levels of diversity, such as Brazil which has lost 42 M ha of its forest cover in the 15 years to 2005, averaging 2.84 M ha annually. Where biodiversity inventories are incomplete, lack of information on the value of the assets may result in complacency, lack of action and subsequent loss of genetic variability. Country reports, particularly in developing countries, noted serious losses of FGR resulting from inadequate management and lack of oversight of protected areas, conservation reserves, and dedicated FGR *in situ* conservation stands; outcomes included illegal logging and harvesting, mining, clearing, poaching, growth of invasive species, damage from unmanaged wildlife and uncontrolled wildfire, failure to enforce regulations, and pests and diseases, often amplified through interactions with climate change. Sometimes these activities impacted on the last remaining natural stands of high value timber species, e.g. *Tectona grandis* and *Dalbergia cochinchinensis* stands in Thailand, and both significant and threatened species that hold extremely valuable genetic resources.

In response, countries all noted the paramount importance of managing the forest estate, and in particular protected areas and *in situ* FGR conservation sites, to ensure the maintenance of the genetic resources, species and ecological processes contained with them. Iran remarks the requirement for 'management plans to monitor the changes in target populations over time and ensure their continued survival. Responses identified and implemented by countries include improved and strengthened forest management, better legislation and regulation, more effective enforcement, preparation of management plans and guidelines, better funding, inventories including conservation trajectories of threatened species and vegetation communities; expertise; and community education. Providing incentives for improved management of FGR were identified as well as methods of generating financial returns from sustainable management, such as the development of game-based tourism facilitating the creation and management of wildlife parks, and the sustainable harvest of forest produce by local communities

The need to better understand the risks faced by individual species and how to manage these was noted by Canada. This requires research on species' vulnerabilities through a systematic analysis of the species, habitats, or ecosystem at risk; information on a species' sensitivity, adaptive capacity and exposure to threats such as climate change; and understanding the species' habitat, physiology, phenology, biotic interactions, and genetic parameters such as the species' ability to respond to threats such as climate change, for example its capacity to adapt in place or to migrate.

The importance of maintaining genetic fitness and regeneration of conserved stands was noted by several countries. In its report Sri Lanka noted that for outbreeding species, large areas of contiguous forest are required to avoid loss of diversity through genetic drift and inbreeding. It also noted the value of re-establishing 'gene corridors' to reduce the risks to fragmented, isolated populations, and proposed conversion or enrichment of monoculture plantations surrounding isolated native forest patches using mixed indigenous species with appropriate levels of variability.

The preparation of well-considered and comprehensive management plans for *in situ* FGR conservation areas was identified by many countries as essential (e.g. Thailand):

> *'Natural stands in each zone were selected and conservation measures and management options were proposed specifically for each zone based on the available information on its population size,* leg*al protection, social aspects, commercial interest, and management costs…'*
>
> For teak, implementing a '*conservation plan comprising a number of activities [has] been recommended: field survey and selection of the populations; demarcation and protection; monitoring; and management guidelines.'*

There is also a need to ensure regeneration occurs in the conserved stands, and Thailand observes: 'silvicultural practices and management are essential to promote the natural regeneration of the existing conservation areas'. There may be particular needs to research the regeneration requirements of threatened species.

This issue is addressed in more detail in the section on sustainable forest management.

Rehabilitation

Many significant FGR assets including threatened, high value timber and NWFP species and forests with high genetic diversity have been seriously degraded through a failure of management to regulate and prevent overharvesting. These areas must be brought under management and rehabilitated at the earliest opportunity to prevent further decline, and to improve their condition and viability and economic utility. This approach is consistent with CBD Article 8 (f) which refers to the need to 'rehabilitate and restore degraded ecosystems and promote the recovery of threatened species…through the development and implementation of plans or other management strategies'. Reafforestation and rehabilitation initiatives under the Low Forest Cover Countries (with less than <10% forest cover) programme may provide impetus for action. Knowledge of species requirements and techniques are essential, and China identified the need for improving knowledge and practice of restoration and rehabilitation of endangered populations *in situ*. In Iran 'restoration of degraded forests is carried out by native species and plantation of native pioneer species…the main objective of rehabilitation is to achieve ecosystem sustainability in forest area and increased biological diversity'. Ghana undertakes rehabilitation of degraded 'convalescent forests' through cessation of exploitation and undertaking management.

Enrichment planting, whereby threatened tree species are propagated from local germplasm, and reintroduced into areas in which they have been depleted, is an important element of *in situ* conservation consistent with article 8f of the CBD. Reintroduction into the wild subjects the species to natural selection, allowing the continuation of evolutionary processes. It is vitally important to ensure an appropriately high level of genetic diversity is represented in enrichment plantings; this will reflect the objectives and scope of the project and the genecological characteristics of the enrichment site. Zimbabwe has species believed to be extinct in the wild that are conserved in *ex situ* and *circa situm* contexts - home gardens – and it has identified the opportunity to reintroduction back into natural settings. Ghana uses artificially propagated stock to enrich forests that have been depleted by over-exploitation and that lack adequate natural regeneration. Denmark has re-established the previously locally-extinct *Pinus sylvestris* to its former range in the country, using germplasm from adjacent countries. These examples demonstrate the value of adopting multiple, integrated and complementary approaches to FGR conservation, successfully combining *in situ*, *ex situ*, *circa situm* conservation and site management.

Enrichment and reintroduction plantings require a supply of plant materials, and for some species with particular reproductive requirements, such as a number of threatened taxa, propagation may prove difficult. China noted the importance of developing propagation techniques for threatened species, especially where they may be resistant to standard techniques, for *in situ* enrichment plantings as well as for *ex situ* and *circa situm* conservation; research may be required to identify the best and most efficient propagation techniques for less well-known species. Ethiopia notes a need for promoting tissue culture for mass propagation; this may assist *in situ* enrichment plantings as well as 'inter circa' plantings described below.

Opportunities from climate change initiatives: restoration and connectivity for *in situ* FGR

Planting and regenerating trees over extensive areas has been proposed as a means of sequestering atmospheric carbon and mitigating climate change, and a number of country reports referred to such programmes. With thoughtful planning these may also offer significant opportunities to improve the viability of fragmented landscapes suffering reproductive isolation and genetic erosion, and to restore local vegetation to its former range. Examples of such programmes in country reports include India's National Mission for a Green India, under the National Action Plan on Climate Change, aims 'to double India's afforested areas by 2020, adding an additional 10 M ha', and the

Sustainable Landscapes programme. Indonesia notes 'there are 40 REDD Plus pilot or demonstration projects across Indonesia being implemented for ecosystem restoration concessions for carbon sequestration and emission reduction….[and a] massive campaign programme to plant one billion trees nation-wide annually is launched for greening Indonesia.' In Australia, Federal and State Governments and NGOs (such as Bush Heritage Australia, Greening Australia and Landcare Australia) are supporting multipurpose, biodiverse and carbon sequestration planting programmes that also restore and promote ecological and evolutionary processes, through reconnecting fragmented landscapes. With appropriate selection of species and planting materials these programmes could provide significant FGR conservation benefits, for example by restoring using locally-sourced planting stock incorporating depleted or threatened species or genetic variability. In Niger farmer–managed natural regeneration (FMNR) has restored over 5 M ha of barren land into productive agroforests through protecting tree coppice and seedling regrowth, simultaneously sequestering vast amounts of carbon, restoring degraded FGR assets and farm productivity and resilience (Tougiani *et al.* 2009). FMNR program also gave farmers confidence to protect trees and respect the integrity and value of trees as property of the landowner.

Where these plantings involve reintroduction of trees grown from local, genecologically appropriate genetic sources back to their former range, they are referred to as 'inter situ' plantings, where 'inter situ is the collecting of germplasm and re-establishing it in field trials or plantations located within the same geographical areas, allowing it to continue to undergo natural selection under prevailing climate conditions'. There are particular benefits where these extend into or connect with existing natural vegetation, to reduce fragmentation, increase gene flow, support ecological processes, and increase the viability of remnant forest patches or isolated FGR assets. At the same time, these plantings may be used to provide a range of timber and NWFPs and employment to rural and traditional communities, especially where access to forests is reduced through conservation management.

Constraints, needs, priorities and opportunities for *in situ* FGR C&M

Constraints, needs and priorities and opportunities for *in situ* conservation of FGR were identified in almost all country reports. A number of the more common ones identified by countries are listed below: Canada's report provides more detailed information on a number of issues in various areas.

Constraints

The constraints on *in situ* conservation were all too evident to countries, who listed barriers as indicated in the following non-exhaustive listing:

Land use pressures, encroachment and land ownership

- High levels of exploitation, land clearing and deforestation with a variety of causes including poverty arising from population growth and degradation of natural resources, expansion of agriculture, including grazing pressures, and market demand for timber and fuel; illegal logging
- Encroachment on *in situ* conservation areas, including as a result of poorly delineated boundaries

- Private or customary ownership of land on which FGR assets occur, over which there is limited control (Cyprus , Solomon Islands), which may be in small fragmented parcels (Japan), and/or for which long-term conservation cannot be assured (Finland)

Resourcing and capacity

- Lack of expertise and capacity typically associated with insufficient funds and resources for training, survey, identification, management and monitoring as reported by many countries

Public awareness and support

- Resistance to expansion of protected areas and conservation reserves due to community concern over loss of use and access and increased human-wildlife conflicts
- Loss of traditional knowledge and beliefs leading to decrease in valuing of conservation and traditional species and forest management
- Low participation or lack participation of communities, and lack of benefit sharing arrangements for communities adjoining forests resulting in conflict over forest resources
- Lack of public awareness, interest and/or support , including lack of political awareness and/or support
- Lack of alternative livelihood options for local populations

Policy, Legislation and enforcement

- Lack of coordination between policies, laws, government departments and sectors impacting on *in situ* conservation of FGR, including insufficient policy support
- Legal uncertainties and shortcomings including lack of adequate legal framework, lack of knowledge of relevant policies, laws and regulations on the part of stakeholders, including those charged with law enforcement, lack of legislative protection for designated areas, inadequate enforcement of regulations and laws and monitoring
- Lack of policy on how to increase benefits of trees on farms and *circa situm* conservation
- Concentration on charismatic, priority species at expense of conservation of other indigenous and traditional species or undue emphasis on a small number of rare species and conservation of saprophytes

Technical and operational issues

- Lack of FGR strategy, coordinated national plans and integrated approaches to FGR conservation linking *in situ* and *ex situ* strategies
- Important ecosystems underrepresented in protected area networks, e.g. lowland, primary forests in Indonesia, Gangetic plains forests in Nepal and lowland dipterocarp forests in Philippines,
- Lack of inventory and knowledge on natural distributions and genecological zones, genetic resources and processes, including FGR assets already conserved *in situ*
- Management issues of *in situ* conservation areas including exotic/invasive weed species suppressing growth of species conserved *in situ*, inappropriate fire management, and minimalist or close-to-nature management approaches limiting opportunities to conserve light-demanding/disturbance-dependent species in more strictly protected areas.

- Climate change reducing regeneration of conserved species; causing range shifts of species and vegetation communities due to shift in climatic zones
- Threats to FGR in protected forests from invasive species (including insects), fire and climate change.

<u>Needs and priorities</u>

Countries identified a wide range of needs and priorities to improve *in situ FGR* conservation including:

Resourcing and capacity

- Increased, more secure, long-term funding
- Capacity building – including education, training, expertise, resources,

Public awareness, involvement and support

- Ensuring sustainable livelihoods, sustainable access arrangements, benefit sharing for communities and forest users adjoining FGR *in situ* conservation areas
- Expanded use to increase valuation by community of indigenous FGR and complement *in situ* conservation
- Greater focus on indigenous and traditional species in use, research, documentation, evaluation of potential, promotion of values in rural communities, and *in situ* conservation
- Payments to compensate traditional forest users where access to forest revenues is denied; incentives for stewardship of FGR.
- More education and awareness for forest owners and users through extension and general public
- Communications strategy, including media campaigns, to raise awareness of FGR conservation matters in general public and youth

Policy and enforcement

- Strengthen legal framework for FGR *in situ* conservation, including review and revision of policies and legislation and addressing FGR currently on unprotected lands
- More effective enforcement of regulations and laws
- Poverty alleviation and employment creation strategies

Research Priorities

- Increased knowledge of and monitoring genetic variation and its distribution in priority FGR, including threatened species, breeding systems and levels of outcrossing, gene flows between conserved populations and introduced/planted materials, and population viability
- Inventory and GIS mapping of FGR in protected areas, including to identify centres of diversity, and in non-protected areas
- More knowledge of effective *in situ* conservation techniques including selection, establishment, monitoring, restoration and rehabilitation and management
- Prioritisation of species

- More knowledge on species importance in maintaining ecosystem function and services as a focus for *in situ* conservation
- Research on autoecology, and species genetic diversity, including monitoring, to inform and assess effectiveness of FGR conservation strategies and activities,
- Development of low cost control technologies and better controls for invasive species
- Research for methods to improve participatory forest and FGR management, including to reduce deforestation
- Research into socio-economic aspects of *in situ* conservation
- Impact of predicted climate change on effectiveness on *in situ* conservation reserves

Technical and operational issues

- Better planning including national network, better defined guidelines for designation and management of FGR conservation reserves and preparation of *in situ* conservation strategies and action plans,
- Rehabilitating and restoring degraded ecosystems and promoting recovery of threatened species
- Assessment and monitoring of existing FGR conserved *in situ*
- Protection of identified high priority species including rare species, and endangered populations
- Conservation of marginal range populations as part of integrated gene conservation efforts
- Better management of *in situ* sites, including silviculture and actions to ensure regeneration , management plans for and demarcation of protected areas
- Better knowledge sharing, coordination and networks at national level e.g. between government agencies, researchers, parks managers, forest and local authorities and farmers
- Improving connectivity of the protected area network and reducing fragmentation

<u>Opportunities</u>

Various opportunities were identified in country reports to enhance *in situ* conservation of FGR and activities and suggestions which might be extended included:

Land use pressures, encroachment and land ownership

- Reduce pressure on *in situ* conservation areas, e.g. Develop alternative renewable energy sources to fuelwood from native forests, including energy plantations and improvement of production forestry, through identification and delineation of areas for forest development, improvement of germplasm quality to boost plantation industry and restoration; better natural resource management.
- Involvement of private sector in *in situ* and gene conservation reserve systems, funded through environmental service payments or with Government assistance; with long term security through purchase and incorporation into public estate

Resourcing and capacity

- Involve and better coordinate efforts of Universities, training schools, NGOs and others in conduct of FGR inventories

- Increase involvement of donors and NGOs in *in situ* conservation
- Information exchange and participation in regional and international networks and collaborations

Public awareness and support

- Greater and continued involvement of local communities in management
- Sustainable and equitable use of natural resources and benefit sharing by local communities

Policy and enforcement

- Development supportive policy regimes for protected areas
- Legislative protection for threatened, ecological keystone and cultural species, including iconic trees and populations
- Better land use planning policies and tenure systems

Self-financing, adding value and improving functionality of protected areas and landscape matrix

- Increased use as seed stands for priority FGR, including development of 'forest gene bank' concept whereby genetically diverse material of priority economic and threatened species is planted as mixture in one (or more) locations
- Use to raise living standards of local people
- Ecotourism to generate income from non-consumptive uses of *in situ* conservation areas
- Enrichment planting and regeneration of high priority and threatened FGR in protected areas, including restoration of degraded areas
- Restore connectivity of protected forest fragments
- Promote on-farm/*circa situm* conservation of priority FGR including fruit trees and their wild relatives
- Payments for environmental services such as carbon sequestration, e.g. REDD+, watershed protection, and bioprospecting licences
- New employment opportunities including from NWFPs, such as increased market for specialist organic forest produce

Technical issues

- More wider use of gap analysis to identify priority areas for FGR conservation
- Translate research findings into practical conservation plans and actions
- Assessment of existing forest reserves for synergetic use as *in situ* FGR conservation units for main tree species.

2.4.2 Sustainable forest management

The majority of *in situ* conservation of FGR takes place outside of protected areas on a range of public, private and traditionally-owned lands, especially in multiple-use forests and forests primarily designated for timber/wood production. It is vital that these forests are managed through sustainable forest management (SFM) principles and practices. There are numerous SFM strategies, approaches, initiatives and programmes undertaken by countries to ensure that adverse impacts on FGR are minimised whilst forest productivity and other uses and services are maintained if not enhanced. These include SFM certification schemes for forest operations, identifying and protecting high conservation value stands, promoting the use of indigenous species, ensuring natural and artificially regenerated stands contain sufficient genetic variability, replacement of monocultures with mixed species plantations, and promoting community participation in forest management, thereby maintaining traditional valuation, knowledge and management of forests.

While almost all extant forests and trees provide some level of *in situ* conservation of FGR, these values may be quickly lost or diminished through forest destruction or degradation. Secure *in situ* conservation of FGR requires security of appropriate tenure over the area, for example through gazettal as a protected area or conservation reserve, or as a production forest permanently subject to FGR-appropriate SFM. It also requires continuing application of dynamic management regimes that address and maintain genetic diversity of the tree species. The importance of the SFM approach is illustrated by considering that forests subject to harvesting and use under SFM regimes will offer more effective conservation of FGR than poorly managed or uncontrolled protected areas subject to threats such as illegal incursions, unsustainable harvesting, wildfire, grazing and invasive species.

Prior to the modern era, and associated unprecedented population growth, sustainable utilization of forest resources was able to be practised in most areas under traditional and customary management. Forest management approaches have been progressively developed and institutionalized over the past three centuries with SFM described in German forestry texts as early as 1713 and forest management introduced to the Sudetes region, central Europe in 1742. In many national policies and programs and at international level, including through the CBD and the UN's 2007 Non-legally Binding Instrument on all Types of Forests (NLBITF) SFM is widely recognised as a means of achieving conservation outcomes simultaneously with multiple productive uses. The requirement for the sustainable use of forests is enshrined in CBD Articles 8 (c) (*in situ* conservation) and 10 (sustainable use of components of biological diversity). Germany notes that the NLBITF provides a definition of SFM that applies globally: 'sustainable forest management, as a dynamic and evolving concept, 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 role of FGR C&M is crucial to the achievement of these aims and needs to be explicitly recognised and steadfastly incorporated into SFM.

This UN instrument also sets out general objectives for SFM:

Global objective 1: 'Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation'

Global objective 3: 'Increase significantly the area of protected forests worldwide and other areas of sustainably managed forests, as well as the proportion of forest products derived from sustainably managed forests'

In developed countries, various SFM approaches has been applied to forestry and timber harvesting operations, particularly involving a sustained yield principle. However, forests are utilized for other extractive purposes and these similarly require management through sustained yield and other SFM principles. Wood products (timber, roundwood, pulp and energy) accounted for the largest category (42%) of reported values for species currently used by countries; the remaining nominated values included in order from most cited were: food security and production, non-specific NWFPs, medicines, agriculture and agroforestry, fodder and artisanal uses. Non-extractive forest uses also need management plans that take into account FGR, as these can also have negative impacts; e.g. poorly managed tourism can lead to introduction of invasive species or pathogens, changes to regeneration patterns, and increased fire risks. Therefore, to achieve effective *in situ* conservation of FGR, SFM plans incorporating FGR goals and objectives need to be prepared and implemented for all forests subject to use, both consumptive and non-consumptive. The following discussion adopts the expanded meaning and application of the term SFM, as applying to all activities and uses of forests and trees.

Production forestry remains a major focus of SFM, given that 39% of the world's forests are primarily used for production of wood and NWFPs, with an additional 24% of forests are designated for multiple use, which in most cases includes the production of wood and/or NWFPs (FRA 2010). The proportion of native forests subject to timber harvesting shows extreme variation between regions and countries. Whilst several countries have legislated to discontinue logging of native forests or limit it to small areas, other countries maintain large areas of native forests for production (notably in Europe and Africa) or multiple use (notably in North America), but often with timber production as a major objective. In Indonesia 60% of total forest area is managed as production forest, while Germany manages most of its forests jointly for production forestry and conservation.

While protected areas make an essential contribution to FGR, they make up a minor proportion[4] of forests worldwide. Productive uses may occur in various categories of protected areas. Many countries' protected areas include multiple land use designations that allow for a range of uses and activities to take place, such as limited timber extraction, harvesting of NWFPs, grazing, hunting and tourism. A number of countries also noted that protected areas were subject to encroachment and illegal occupation, use and harvesting activities, despite their conservation designations. SFM involves both ensuring that approved activities within protected areas are conducted in ways that minimise impacts on the genetic resources, as well as preventing uncontrolled, illegal uses; and if prevention is not possible, to manage these illegal activities to reduce their occurrence and minimise impacts.

SFM, as sometimes currently practised, does not always adequately address the requirements of *in situ* conservation of FGR. This may occur in situations where there is an overly focus on maximising

[4] The area of forest in protected areas and/or where conservation of biological diversity is designated as the primary function account for 12.5% of the total forest area or more than 460 M hectares (FRA 2010).

ongoing production of timber at the expense of genetic and ecological outcomes that are important components of SFM. Therefore it is essential to ensure that SFM protocols address the requirements for conservation of FGR, both of major commercial timber species as well as the other forest tree species, especially those providing NWFPs, whose continued presence and variability may be impacted by timber utilization. Nonetheless, for countries where logging currently takes place with inadequate controls and at unsustainable rates, applying the basic forest management principle of sustained yield can be a significant tool for achieving FGR conservation.

China has identified that population growth, increasing wealth and consumer demand for timber and wood products will result in a significant shortfall between national demand and supply, and these factors also hold for other diverse fast growing Asia-Pacific economies such as Australia, India and Thailand. Traditional timber exporting countries in Africa such as Ghana have faced major declines in exports and may eventually become net importers of timber products. The long-term challenge of meeting rising global demand for wood products will necessitate adoption of SFM, including *in situ* conservation of FGR, in all forms of production forestry. There is also an increasing demand for NWFPs and environmental services from forest and these uses can usually, with proper management, be made fully compatible with FGR conservation. However, highly valued and sought-after NWFPs may be rapidly depleted, especially if harvested in a destructive unsustainable manner. SFM plans require regular updating to meet new circumstances including changes in demand and production for diverse NWFPs, e.g. cork, honey, mushrooms, venison; essential oils; bamboo for fish traps and coco de mer; and various environmental services, e.g. biodiversity conservation; faster growing forests for the purpose of sequestering CO_2 as part of climate change mitigation; and restoration of degraded soils.

Country initiatives in SFM for maintenance of genetic variability and evolutionary processes

Countries addressed SFM for timber production forests in a variety of ways. The following SFM approaches and initiatives, detailed in subsequent sections, contribute to the maintenance of genetic variability and evolutionary processes:

<u>Reducing use and harvest pressure on natural forests through SFM strategies</u>

Application of SFM to increase the production of timber and NWFPs from natural forests can reduce the harvest pressure on other forests conserved for biodiversity and FGR purposes, and free up production forest for other uses. SFM can deliver sustained increased timber production from the same or reduced area of natural production forest. Indeed, a number of countries reported increased annual increment of forests and/or increase in the standing volume of timber in production forests, through the application of SFM principles and techniques. In Sweden for example, the standing wood volume of its forest has increased by 86% over the past 90 years, associated with a doubling in the annual increase in standing volume over the same period. In Finland although the forest area has remained constant, the volume of timber is 40% greater than 50 years ago and 45% more volume is added annually than is harvested. Legislation and implementation of strong SFM principles and management, including for FGR, has resulted in increases in the area of forests in Germany. The USA reported an increase in timber production with the forest base fairly constant and standing volume increasing. Sustainable increases in timber and NWFPs may be achieved through application of SFM practices such as selected seed sources and improved genetic materials, altering rotation length, species-specific minimum diameter cutting limits, enrichment plantings of preferred timber species, thinning operations, retention of mother or seed trees, retention of preferred NWFP species during clearing, and ensuring that the principle of sustainable yield is applied, where the amount of harvest does not exceed the annual increment. The possibility of increasing production from existing natural forests through better management was also noted by Ghana, which proposed increasing investment in natural forest management to relieve the harvest and use pressure on forests with FGR and conservation values. Sweden remarked that more intensive forestry to increase forest growth requires an increased effort in gene conservation to balance production and environmental objectives. In Japan national forests, other than protection forests, are also managed sustainably through long-term regional forest management plans which contribute to FGR conservation.

Another strategy is to increase the area of forest available for productive uses and FGR conservation through planting and facilitation of regeneration. This is indicated in FRA 2010 with a number of countries recording large annual net gains in forest area between 1990 and 2010: in some cases this is the result of deliberate reforestation programs especially in Asia, while in southern Europe and USA there may be a large component of natural regeneration on abandoned, marginal agricultural lands. Ghana has also proposed intensive forest plantation development to reduce pressure on natural forests. Solomon Islands identified an urgent need to rehabilitate logged areas that had failed to regenerate, as a step to restoring such areas to productivity. This strategy may extend to increasing farm and landscape plantings and expanding plantation areas to meet the demand for forest products and services without adding to utilization pressures on native forests; these plantings may include tree species and populations under pressure *in situ*, thereby providing *circa situm* FGR conservation benefits.

Increasing plantations to reduce pressure on native forests is an important adjunct to SFM strategies. Indonesia is one of several countries adopting this strategy: ‘to reduce pressure from natural forest exploitation, the Ministry of Forests has increased permits for Industrial Plantation Forest…from 4.5 M ha in 2000 to 8.97 M ha in 2010.’ Myanmar, Solomon Islands and Vanuatu similarly identified this approach as vital to reducing unsustainable logging of natural forests, including particular high-value species. From an FGR C&M and longer term sustainability viewpoint is essential that existing, genetically diverse natural forests are not replaced with exotic monocultures of limited genetic variation. In many locations abandoned or marginal agricultural land may be suitable for plantation establishment, thereby avoiding loss of natural forest. Other strategic measures adopted by countries to facilitate plantations, include provision of low-interest loans for plantation programmes particularly of multi-purpose tree species as well as for forest-related cooperatives, and ensuring land for plantation establishment is affordable.

Applying basic forest management principles such as sustained yield is essential for conservation and management of FGR, as its focus is on maintaining a long term flow of products and benefits from the forest – a process in which FGR play a central role. It requires guidelines, inventory and FGR survey, preparation of plans, and effective administration. The Solomon Islands demonstrate the need for application of such basic principles – log exports account for over 70% of export earnings, providing 18% of total government revenue, and are a major source of income and employment in rural areas as well as generating royalty payments to landowners. However, logging is occurring at an unsustainable rate with the resource likely to become substantially exhausted by 2018, with potentially destabilising effects on the economy and society. Gaining administrative control of forest harvesting and subjecting it to a sustained yield regime is a critical step in improved forest management, and provides the basis for a rational approach to utilisation incorporating conservation of FGR. Sustainable forest management of Vanuatu's resources is enshrined in the constitution, and backed by a Forestry Act, National Forest Policy and Codes of Logging Practice, but struggles to be implemented due to lack of land use plans, an updated forest inventory and Government resources, and there is a gross imbalance between forest utilization and reforestation.

Another important approach in relieving harvesting pressure on natural forests is to establish alternative use-values and income generation from these forests, such as ecotourism, conservation, water production and environmental protection. The Seychelles has ensured that this strategy and the alternative uses are adequately addressed in policy and field management by incorporating the relevant objectives into high-level government policies and programmes. This is consistent with the UN's 2007 NLBITF (part V 6 (j)), which suggests encouragement of 'recognition of the range of values derived from goods and services provided by all types of forests and trees outside forests, as well as ways to reflect such values in the marketplace, consistent with relevant national legislation and policies'. Markets for alternative goods and services may be already available or developed, through mechanisms such as production under forest certification schemes; stewardship payments; payments for carbon sequestration or credits for biodiversity, land or environmental management.

Providing alternative goods and services to replace natural forests products is an SFM strategy used by some countries. Demand for fuelwood and charcoal, which in a number of countries contributes to unsustainable levels of harvesting, may fall when alternatives are provided: in the Seychelles, 'the demand for fuelwood appears to be rapidly dwindling due to rural electrification and expanding use of kerosene also in the rural areas', and in Zambia rural electrification and greater efficiency of wood and charcoal burning are proposed to reduce the demand for charcoal, the production of which is currently partially responsible for unsustainable rates of destructive exploitation and loss of FGR. On the other hand Norway has a policy of providing more wood for uses in which it has less negative environmental impact than alternative products. The Philippines report mentions extending the life of construction materials to reduce the requirement for wood for repairs and replacement.

Value-adding to forest produce is a strategy that is being increasingly applied to counter unsustainable, high volume/low return forestry based on extraction and export of round logs. Gabon has prohibited round log exports since 2009 to encourage domestic processing, while Papua New Guinea and Solomon Islands have downstream processing targets and projects to add value to logs and increase financial returns to the population, government revenues and to provide greater employment. Solomon Islands has a requirement for 20% of timber logged under licence to undergo further processing, as a mandated policy implemented as a regulated condition of logging licences, may facilitate further value adding.

Boosting imports of forest products while reducing logging on vulnerable native forest resources is another high level SFM strategy that has been used to reduce pressure on indigenous; this may be facilitated by reducing or eliminating tariffs on wood imports. Certain countries are highly effective at producing forest products with minimal impact on FGR, and importing from these sources and reducing a country's own production pressures on its natural forests may be a viable strategy for better conserving FGR whilst not impacting on FGR conservation at global level. For example, Brazil is extremely efficient at producing pulpwood for manufacture of paper from its 1.1 M ha of pulpwood plantations, representing just 0.2% of the country area: 'the wood necessary to produce one M annual tons of pulp in Brazil is harvested in 100 thousand hectares…in other parts of the world, like Scandinavia and the Iberian Peninsula, 720 and 300 thousand ha would be respectively necessary to obtain the same amount'.

Zoning – identifying and protecting important areas for increased protection and management

As for more targeted *in situ* conservation approaches, SFM for maintenance of FGR requires that key tree populations or areas containing priority or threatened tree species or other essential elements for maintaining FGR need to be identified, demarcated and given extra protection and appropriate management. This approach is practised by many countries, including Finland, which identifies and protects valuable habitat areas within production and other forests; Thailand, which in 1989 gazetted National Forest Reserves as three zones (conservation, economic and agricultural) and Seychelles. Nonetheless there are reports of failure to protect significant areas for conservation of FGR and biodiversity once they are identified even though protocols were set out in codes of practice and other programmes, through administrative failure, lack of political will, and inadequate funding; the Philippines also noted lack of will as a contributor to failure to adequately protect forests.

A number of countries apply land-use planning to allocate production forestry and plantation expansion activities to areas where these deliver the maximum benefits with the least impacts. This approach is also used to the identify areas suitable for agricultural expansion. It is essential that conservation of FGR is taken into account during land-use planning.

Adopting multiple use approach to production forestry areas

Adopting an explicitly multiple use approach to production forests better facilitates the incorporation of FGR C&M objectives into their management. Multiple uses may include timber and NWFP harvesting, conservation of genetic resources and biodiversity, catchment management and water production, environmental protection and CO_2 sequestration, and recreation. The various multiple uses must be compatible, and able to be conducted in the same area without significant impact on the other uses. Germany's forest management approach is based on the multiple use model, particularly achieving production simultaneously with genetic and biodiversity conservation, through a 'protection through utilisation' approach. To achieve multiple uses simultaneously with FGR conservation, detailed information about the genetic resources and their management requirements are required, as well as a high level of organizational capacity. A multiple use approach enables integration of FGR conservation and management objectives into the management of areas designated as timber production forests. In many cases multiple uses may be complementary to FGR C&M; indeed, management for a particular use may help in the conservation and management of FGR assets. For example, allowing honey production in protected areas in the Seychelles promotes the suppression of damaging fires through the actions of beekeepers protecting their hives and nectar sources.

Opportunities exist to integrate FGR conservation with plantations, including through protection of forest buffers along watercourses and planted corridors of native forest species linking up retained native forests to minimize fragmentation. Indonesia notes a failure to integrate FGR conservation objectives into new plantation establishment through total elimination of all regeneration on proposed plantation sites prior to planting. By contrast, mahogany established through enrichment planting in logged over forest in Fiji has allowed regeneration and continued growth of many native tree and understory species, including important FGRs such *as Endospermum macrophyllum* and *Atuna racemosa*. Where productive utilization of a forest can be undertaken through SFM with minimum environmental impact including on FGR and associated processes, it may be appropriate to allow such activities in protected areas or conservation reserves. This may be the case where protected areas are subject to uncontrolled access, harvest and utilization by neighbouring, impoverished rural communities; many of whom may have previously lived in and utilized protected areas in accordance with customary, sustainable-compatible management regimes. Providing controlled access under FGR-appropriate SFM plans can reduce negative impacts on FGR and may even provide positive conservation benefits through informal surveillance by neighbouring communities and reduction in illegal and detrimental activities.

<u>Adopting 'Close to nature' forestry practices</u>

Adopting management techniques that rely on or mimic natural forest processes is an important SFM approach. Natural regeneration of logged coupes is one such approach: countries' most commonly utilised species were predominantly regenerated using natural regeneration (61% of species), more than double the number regenerated through plantation establishment (30%) based on those countries reporting on regeneration methods for SoW-FGR. For some countries relying on forest production based on indigenous species this figure can be high, e.g. In Canada 85% of logged forests are allowed to regenerate naturally.

European countries are increasingly applying 'close to nature' approaches to forestry management, with emphasis on natural regeneration, while elsewhere the approach is also under investigation. Denmark's 2002 National Forest Programme recommends a conversion to the 'close-to-nature' approach to forestry management with the Forest Act of 2004 providing the legal framework for this transition. Germany proposes that 'protection through utilisation' by promoting 'close to nature' forestry is the most effective approach for simultaneous production from and conservation of its forests, with the result that 'due to the strict legal provisions and largely practiced close to nature forestry, overexploitation and clear-cutting are no real threat to the state of the forests' genetic diversity in Germany'.

<u>Using local species</u>

Country reports to the SoW-FGR indicate that there is a global trend to make increasing use of indigenous tree species for afforestation and environmental plantings. The use of locally indigenous species in forestry plantings for activities such as timber production, fuelwood and afforestation can assist in maintaining genetic variation, especially where planting stock is developed from 'genecologically appropriate' and genetically variable germplasm, and management regimes do not excessively deplete variability in non-target species. This can yield major FGR benefits where indigenous species are used as an alternative to commonly planted exotics. Nonetheless consideration must be given to reducing the risks of genetic material from improved indigenous species entering local populations of the same or hybridizing species, and attendant loss of local genetic variability. Using local species has the added benefit of raising awareness of the value of local tree species. Tanzania recommends further use of its valuable, high performing indigenous species such as *Antiaris usambarensis* and *Khaya anthotheca* whose growth rates 'compare closely with industrial plantation species raised in the country, [and] ...should be included in afforestation programmes…the gene pool has more to offer…' However where the use of high-performing exotic species yield a more valuable crop than local species and with minimal impact on FGR, their use may be not only commercially preferable but can also lower utilization intensity pressures on a country's natural forests. This approach may form part of a high policy level SFM strategy that addresses FGR C&M.

Codes of practice

The development and application of codes of practice for forest harvest and utilisation activities is crucial to achieving SFM. Codes of practice for SFM provide guidance for conduct of operations according to SFM principles, and where relevant complying with government legislation or regulations. They may apply to the operations of state, parastatal and private companies or individuals engaged in utilisation of forest species or areas on public land, and may extend through legislation to timber extraction activities on private land. They may be imposed as a condition of access licences to public forest resources by government authorities thereby forming part of the regulatory system, or they may be voluntary industry codes of practice. Some codes may be further developed as certification schemes and used to demonstrate production best practices in the marketplace. It is vital that codes of practice for SFM incorporate measures to ensure the maintenance of FGR and the ecological processes that support them. To be effective, compliance of forest operators with SFM codes must be monitored, and there must be mechanisms to ensure compliance such as enforcement of breaches, 'make good' provisions for damage, lodgement and potential forfeiture of bonds, fines, cancellation of licences or permits to operate, or denial of access to the forest resource. Codes must have legislative or legal backing to be enforceable. Several state jurisdictions in Australia have codes of practice governing forestry operations on both private and public land; these include various provisions for maintaining ecological assets and conserving non-target species.

Codes of practice require effective forest and natural resource administrations to achieve SFM and FGR C&M. Instances were reported of a failure to implement SFM and FGR C&M protocols contained in codes of practice due to lack of resources, administrative and technical capacities, or lack of jurisdiction over important conservation resources. They may only be effective in the private forest estate where the government has jurisdiction over forest protection activities and private-land harvesting, including through granting of permits. Where codes of practice exist for activities potentially impacting on FGR but lying beyond the normal purview of forest operations, these also need to address the requirements of FGR C&M. Harmonising a national FGR strategy with relevant cross-sectoral programmes will facilitate FGR integration into codes of practice for related activities.

Preparation and implementation of SFM plans incorporating FGR C&M

The preparation of SFM plans incorporating FGR C&M objectives and actions is a primary component of SFM, just as they are for protected areas and *in situ* conservation reserves. Information is required on the genetic resources and associated evolutionary processes, the impacts of use on these, followed by selection of appropriate SFM approaches to minimise impacts. Written plans facilitate accountability through providing objectives and benchmarks against which outcomes and performance can be measured; plans are vital for monitoring, auditing, evaluation and improvement, and central to 'adaptive management' approaches. Some countries remarked on the difficulties of implementing SFM plans. Reasons included lack of funding, lack of organizational capacity, lack of political support and/or jurisdiction over forests under customary or private tenure.

Ensuring that SFM plans are adequately financed is integral to SFM. This may involve government and departmental budgetary allocations for example as endorsed in national forestry and FGR strategies; raising of revenue from forestry activities (e.g. license or royalty payments); adopting a system of valuing FGR and paying for stewardship or otherwise rewarding FGR conservation. Building capacity for effective administration capable of implementing SFM programs incorporating FGR is essential, but often lacking in developing countries.

A number of countries reported supporting community participation in preparation of SFM plans to facilitate sustainable outcomes (e.g. Iran p109e/Ch5), in line with recommended principles for SFM (IPF/IFF UNFF 2005).

Harvesting

To achieve effective conservation and management of FGR, SFM must implement harvesting regimes that address the genetic characteristics of the particular target species and other woody species potentially impacted by harvesting including any other priority species, as well as associated evolutionary and ecological processes. Areas to be conserved for their FGR values must be identified, and if necessary protected from harvest; the harvest intensity and techniques must minimise impacts on non-target species, and the harvest and regeneration practices must ensure that the genetic variability of the target species are retained as much as possible. Monitoring the impacts of forest utilisation and applying appropriate management are essential elements of the SFM process. A number of countries noted negative impacts of harvesting regimes and techniques on their FGR: the most significant is harvesting at unsustainable levels resulting in depletion or extermination of the target and other forest species. Iran reported a research programme to investigate the damaging impacts of silvicultural practices, while Sudan has banned the harvest of selected endangered, economically important tree species.

Maintaining germplasm variability in regenerated production forest stands

Ensuring that regeneration of harvested stands is adequate and contains sufficient variability for adaptation and continued evolution is crucial to SFM for FGR C&M. This is particularly important for countries with significant forestry industries that rely heavily on native forest logging, and with limited strictly protected areas. The majority of commercial timber tree species are regenerated naturally. This requires that sufficient numbers of trees contribute to the reproductive materials used for stand regeneration, to maintain variability in the target and other impacted species. Monitoring of regeneration is essential, and may need to be supplemented with artificial seeding or planting if stocking rates are inadequate. Where artificial regeneration is the preferred method of restocking then genetically diverse germplasm is essential. For example, Germany mandates the minimum number of seed trees to be used; along with the large number of seed stands available and the system of private certification of germplasm suppliers, ‘sufficient amounts of reproductive material with high genetic diversity are available for artificial regeneration of most provenances.’ Its report also notes that incorporating the regeneration of non-commercial tree species into natural regeneration regimes and cultivation of ‘adapted populations with great genetic diversity’ are particularly beneficial for *in situ* conservation. In order to maintain the variability of germplasm in the 15% of production forests in Canada which are artificially regenerated, criteria and indicators for SFM requirements state that:

> *'Under criterion 1, Biological Diversity, indicator 1.3.1: genetic diversity of reforestation seed lot, addresses the variation of genes within a species by ensuring that seed used to regenerate harvested areas has sufficient genetic diversity to respond to changing environmental conditions…The genetic diversity of seed used for reforestation is a result of both the number of areas where seed is collected and the parental composition of those areas. Most of the seed used in reforestation programs across Canada is collected from natural stands where the number of parent trees is typically in the hundreds to thousands (Canadian Council of Forest Ministers 2006). This seed likely has genetic variation that is representative of the natural populations where it was collected. [However] in some jurisdictions, a significant portion of the seed for reforestation also comes from seed orchards'*

Ideally seed would be collected from the area to be harvested and regenerated beforehand. However, where this is not possible, germplasm of local provenance or from the same genecological zone may be used to maintain variability and ensure the stock is well-adapted to local conditions. Guidelines based on knowledge of the target (or closely related) species may be used to guide collection and use of germplasm for artificial regeneration to maximise variability in situations where genetic variation patterns are incompletely or else unknown. Germany recognises the need to monitor the genetic impacts of its silvicultural practices on its priority species, and is developing a methodology to facilitate this: early work suggests that losses to date are not excessive. Solomon Islands noted a failure of natural regeneration and failure of management to undertake remedial measures as a threat to the survival of forests, their FGR, and a sustainable forest industry.

There is a growing recognition of the need to provide for higher levels of genetic variability (both more species and greater intraspecific diversity) in production forestry, especially for traits associated with adaptability to changing climatic and environmental conditions. Some countries have identified this as a priority for their breeding and forest management programmes, and seek to incorporate variability conferring adaptation to climate change into germplasm used for regeneration of harvested areas, plantations and other plantings. There is also increasing recognition of the role of FGR in providing sufficient variability in protected or forest reserves to facilitate adaptation to climate change, and associated management requirements.

Increasing variability in plantation establishment

In Indonesia land preparation practices for forest plantation or agroforestry in logged-over conversion forest areas may involve removal of all residual species and regrowth; part retention of advanced growth and natural regeneration, including especially economically valuable local tree species, will assist in maintaining diversity with minimal economic losses.

To increase variability, several countries are considering or have undertaken conversion of monoculture plantations to mixed species plantings. Reasons for conversion included to provide opportunities for adaptation to climate change, and to increase genetic connectivity between isolated remnants. Germany (p29) has identified that climate change may necessitate the transformation of pure spruce stands in many parts of the country to mixed stands of putatively adapted tree species. Increasingly, mixed species plantations serving multiple purposes are finding favour, for example, under initiatives for reafforestation of low forest cover countries such as Iran.

Other practices to minimise losses of FGR during plantation development may include documenting and conserving *ex situ* any threatened local FGR, avoiding conversion of native forest to plantation, and ensuring genetic diversity within plantation stock across a range of adaptive traits whilst maintaining uniformity for desired production and quality traits.

<u>Certification and demand management: increasing market share for sustainably produced products</u>

There are several certification schemes for sustainable forest management in operation. These specify management protocols which are in accordance with accepted SFM principles. Organisations involved in forest management and harvesting, whether public or private, may apply for certification; this requires initial proof of compliance with the protocols and regular auditing to ensure ongoing compliance. Certification of a product under these schemes may confer a marketing advantage. This approach to SFM is consistent with the UN's NLBITF: which encourages '…the private sector, civil society organizations and forest owners to develop, promote and implement…voluntary instruments, such as voluntary certification systems or other appropriate mechanisms, through which to develop and promote forest products from sustainably managed forests…' (NLBITF Pt V (x)).

A number of countries reported achieving certification under several of these schemes, but forest area certified may vary considerably between countries. Canada remarks that '…independent certification of forest management may be one of the most important changes in forestry during the past 50 years…Canada is a world leader in forest certification, with about 150 M ha of forest certified by one or more of three globally recognized certification standards…the principal driver for certification is the ability to sell wood products on the global market.' Estonia reported that a number of Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) full or chain of custody certificates have been issued for forest operations in the country; all state forests are FSC and PEFC certified.

The predominant FSC certification system has as one of its principles the 'Maintenance of high conservation value forests' (Principle 9). This entails that management activity in high conservation value forests maintain or enhance the attributes which define them. It is desirable that explicit mention be made of FGR values for assessing high conservation value forests, as forest certification systems need to integrate the requirements for effective conservation and management of FGR into their schemes.

<u>Community and participatory management, poverty, reducing pressure on conserved areas</u>

Indigenous or traditional ownership, use rights and management may play significant roles in conservation management of *in situ* FGR in many countries. For example in Canada, aboriginal people own or control around 3 M ha of land, and play a major role in the management of FGR; other countries where indigenous peoples feature in ownership, use and management of FGR include India and Brazil; customary tenure dominates land ownership profiles in many regions, particularly in the Pacific Islands, and in parts of Africa including Zambia which has 46 M ha or 61% of the country under traditional ownership, and Swaziland.

A suite of causes of deforestation related to the failure of conservation management to address indigenous/traditional ownership, knowledge, use and management were identified in country reports: a) uncontrolled access to protected areas and *in situ* FGR conservation sites by neighbouring rural communities sourcing fuel, food, housing materials, forest produce, b) decrease in value placed on trees and sustainable management due to loss of traditional knowledge of indigenous forest food and produce plants and traditional management systems; c) poverty-driven increased use pressure amplified by climate change including encroachment of agriculture and pastoralism, and d) conflict caused by loss of access to forests designated as 'no-take' protected area resulting in loss of informal control over illegal harvest and uncontrolled and unsustainable utilisation.

Such causes of deforestation and genetic erosion is being increasingly addressed through use of the community or participatory management approach. This involves the participation of communities and harnessing traditional valuation and knowledge of use of traditional forest trees, and customary management practices that are compatible with sustainable management of FGR. In Madagascar local communities are increasingly directly involved in management and utilization of native forests through licensing and implementing agreed management and harvesting plans.

In summary FGR C&M considerations need to be better integrated into SFM planning and practices, including undertaking an inventory of FGR, prioritizing the FGR for conservation and management, characterising their variability, defining a management strategy for maintenance of variability, integrating this into utilisation protocols and plans, monitoring the impacts on variability, and adjusting the SFM regime as appropriate.

2.4.3 The state of *ex situ* conservation

Ex situ conservation can take various forms and, typically serves to capture and maintain species genetic variation in field gene banks or seed banks outside their native or original environment. *Ex situ* conservation by means of germplasm storage includes the maintenance of seeds, pollen and *in vitro* cultures often at low temperatures for extended periods of time. *Ex situ* field plantings can be in semi-forestry or forestry settings and include clonal archives, provenance and progeny tests, arboreta and botanical gardens.

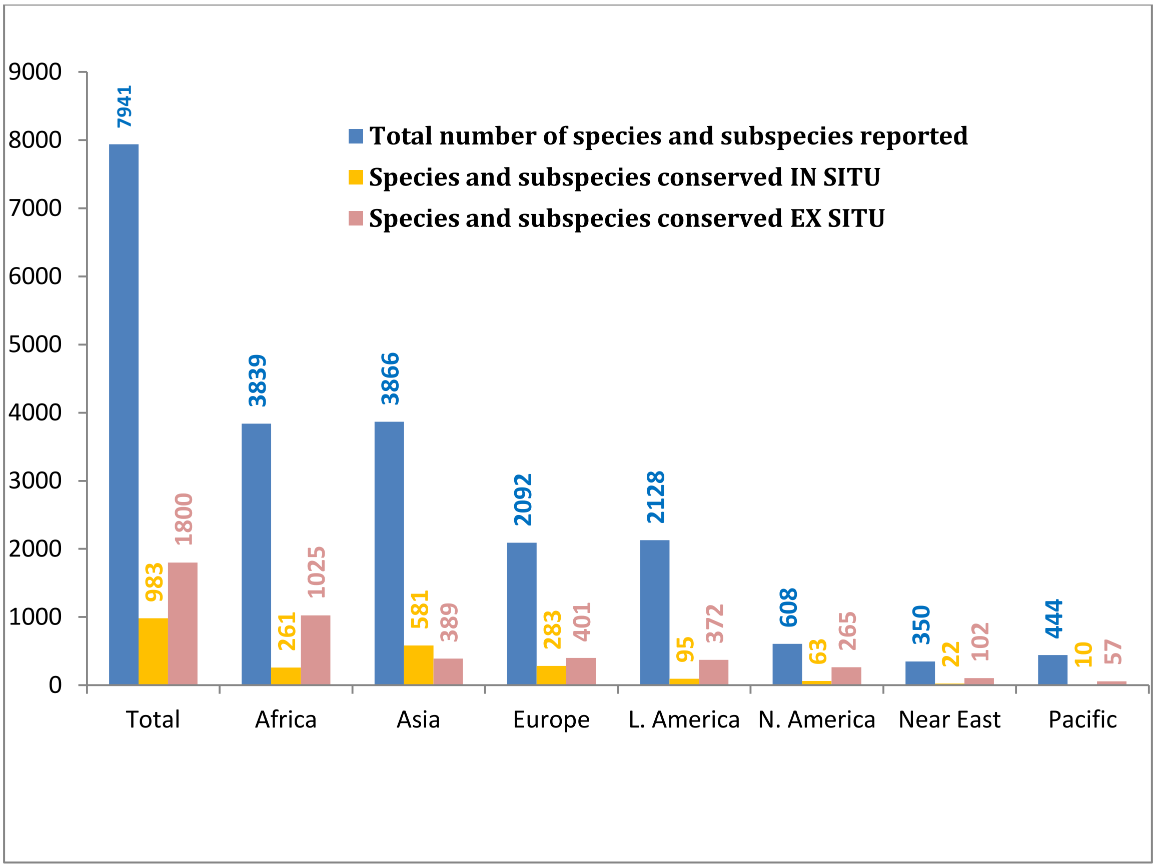
Internationally, there are strong commitments by governments and non-governmental agencies to *ex situ* conservation. The Convention on Biological Diversity's (CBD) Global Strategy for Plant Conservation, 2011-2020 promotes efforts at all levels - local, national, regional and global - to understand, conserve and use sustainably the world's immense wealth of plant diversity while promoting awareness and building the necessary capacities for its implementation (CBD 2013). The 2011-2020 Strategy includes 16 outcome-oriented global targets set for 2020, with Target 8 specifically addressing *ex situ* conservation "to conserve at least 75 per cent of threatened plant species in *ex situ* collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes" (CBD 2013).

Global infrastructure commitments can be best depicted by, for example, the Svalbard Global Seed Vault in Norway, which was built in 2007 to provide insurance against the loss of germplasm from seed banks, as well as a refuge for seed in the case of long-scale regional or global crises (Global Crop Diversity Trust 2013). The Millennium Seed Bank Project (MSBP) of the Royal Botanic Gardens, Kew, UK, an expansive global partnership with countries such as Australia, Burkina Faso, Botswana, Chile, PR China, Kenya, Lebanon, Madagascar, Mali, Mexico, Jordan, Saudi Arabia, Republic of South Africa, Tanzania and the United States of America (Kew Botanical Gardens, 2013), and agencies such as the Food and Agricultural Organization (FAO) of the United Nations (UN) and Bioversity International, was developed in part to enable countries to meet international conservation objectives set by the Global Strategy for Plant Conservation of the Convention on Biological Diversity and the Millennium Development Goals of the United Nations Environment Programme. The MSBP has banked 10% of the world's wild plant species and has the goal to conserve 25% of species by 2020. Both the Svalbard Global Seed Vault and the MSBP store tree seed.

The Botanical Garden Conservation International (BGCI) is a global network with one of their mandates to ensure the world-wide conservation of threatened plants, the continued existence of which are intrinsically linked to global issues including poverty, human well-being and climate change (BGCI 2013). The BGCI network currently has 700 members in approximately 118 countries. BGCI supports *ex situ* conservation through many of its activities, in particular, through the establishment of regional networks that strengthen and support botanical gardens such as the African Botanic Gardens Network (ABGN).

Based on data obtained from the Country Reports submitted to the FAO, the total number of species conserved *ex situ* is 1800 and, 95% of these species are native and 8% are exotic. Assessing the total number of species with *ex situ* reserves by region, Africa reported 1062 species in *ex situ* reserves, 372 species reported as conserved in Latin America, 389 species in Asia, 401 in Europe, 265 in North America, 57 in the Southwest Pacific and 102 in the Near East (see Figure 5). In all regions the majority of species conserved by *ex situ* means were native species.

Figure 6: Number of species conserved *in situ* and *ex situ*



Considering globally priority genera conserved *ex situ*, *Pinus* is the genus with the largest number of species conserved with 65 species, followed by *Eucalyptus* with 28 species conserved, *Albizia* with 24 species, *Acer* with 15 species, *Quercus* with 13 species and, *Acacia* and *Terminalia* each with 10 species conserved. Globally the total number of accessions reported is 159,579 and for a number of species there are multiple accessions. The majority of these accessions are as field collections with 49 % of these accessions residing in clone banks, 40% are as field collections (e.g. provenance trials), 14% are as seed collections and 7% are as *in vitro* collections.

Regional *ex situ* conservation activities

Africa

Ex situ conservation in African countries is primarily achieved through arboreta and botanical gardens, but does include other means such as provenance trials, plantations, seed orchards and seed banks. Short- and long-term storage of germplasm is not available in all African countries and where that capability exists it varies in capacity. Examples of *ex situ* seed storage include Morocco, which has four facilities for production and storage of tree germplasm and these facilities are equipped for conditioning, conserving, organising and managing those seed lots. Burundi has a capacity for medium and long-term cold storage of seed. Madagascar has one seed bank, functional since 1986 that collects seed from rare, threatened and valuable tree species. Burkina Faso has one of the most operational seed centers, established in 1983, that serves as a seed bank for medium and long-term storage. They participate as a Millennium Seed Bank partner focusing on research, seed and herbarium specimen collections and conservation of duplicates of their collections. Other countries with *ex situ* conservation infrastructure include Tunisia with two genebanks; their largest has a capacity to store 200,000 accessions, while the Zimbabwe Tree Seed Centre has approximately 23,000 accessions. Other countries such as Burkina Faso and Cameroon have infrastructure for storage but frequent power outages and lack of funds for maintenance have rendered them either non-functional or unreliable. Countries such as Malawi work in collaboration with the Millennium Seed Bank for backing up their *ex situ* conservation collections.

The types of tree species conserved in African countries are highly variable and includes indigenous and exotic species from many genera and families. The main genera conserved and propagated for multiple reasons are *Acacia* spp., *Eucalyptus* spp. and *Pinus* spp. A few countries such as Benin and Burundi value species based on their medicinal uses. Mauritania's main driver for *ex situ* conservation is mitigating the impacts of desertification and the restoration of degraded ecosystems.

In addition to traditional *ex situ* conservation methods such as seed and live field collections of all kinds, many countries, including Burkina Faso, Cameroon, Ethiopia, Gabon, Kenya, Republic of South Africa and Zimbabwe, have genetic improvement programs to select plus trees for different purposes such as seed orchards although several countries, such as Ghana and Tanzania, reported that their improvement programs are moribund or in decline due to lack of funding. In many sub-Saharan African countries The World Agroforestry Centre (ICRAF) has partnered with national Government agencies, Universities and others to implement a wide array of domestication and improvement programs for indigenous multipurpose tree species. A small number of countries, including Algeria, have tried *in vitro* propagation methods such as somatic embryogenesis and axillary bud inductions for some of their priority species.

Limitations and constraints are numerous and most revolve around lack of monetary and human resources, proper equipment or facilities to effectively store and manage the germplasm for short- and long-term safekeeping. Another common limitation is a lack of technical knowledge and training for the proper management of *ex situ* conservation programs such as knowledge of reproduction, propagation and storage, data logging and management. Future priorities for many African countries involve the need to develop a national strategy and research programs for the management of *ex situ* conservation to identify priority FGRs and finding ways to fund, develop, and maintain proper infrastructure and collections for the safekeeping of their FGRs.

Asia

Reported *ex situ* conservation activities in Asia are diverse ranging from provenance trials, seed orchards, clonal repositories, botanical gardens and arboreta, and seed and pollen gene banks with multiple native and exotic species targeted.

Community-based *ex situ* conservation programmes are emerging in a number of Asian countries. For example, in Nepal the government has been endeavouring to entrust the management responsibility of seed orchards to the local communities by providing the mechanism by which communities receive direct benefits from these resources. However, as yet adequate benefits have not been generated which is identified as being due to poor market linkages. While Central Asian countries, such as the Kyrgyz Republic, noted studies under Bioversity International and the UNEP-GEF, that are establishing demonstration sites and forest reserves where wild fruit species are preserved in accordance with the various State's legislation. These efforts aim to support local farmers through on-farm (*ex situ*) conservation and use of local tree species (primarily fruit and nut) in agrobiodiversity.

Country efforts are variable with common trends emerging pertaining to constraints which include a lack of resources to support *ex situ* conservation activities. In particular, limited infrastructure and a lack of trained personnel were common themes. The need for national cooperatives to promote FGR conservation and to enhance the ability of various countries to be self-sufficient with regard to seed supply were examples of country priorities for future *ex situ* conservation activities.

Europe

Reported *ex situ* conservation activities in Europe are diverse varying from those that are extensive including provenance trials, seed orchards, clonal repositories, botanical gardens and arboreta, seed and pollen gene banks through to no activities. A number of European countries, such as Bulgaria and Sweden, have noted that ex situ conservation is of secondary importance compared to in situ conservation because it is a static conservation approach, and therefore does not provide for adaptation to a changing environment.

Northern European countries, such as Norway, have identified the need for long-term seed storage, as seed years are scarce at northern latitudes and high altitudes. The Nordic Genetic Resource Centre (NordGen), a collective meeting place for researchers, managers and practitioners from Nordic countries in the fields of forest genetics, seeds, plants and methods for regeneration is assessing the possibility of utilizing the Svalbard Global Seed Vault as a long-term seed storage option for forest seed banking activities. Other countries such as Cyprus are considering the establishment of national seeds banks for forest species. Some countries such as Russia have extensive *ex situ* tree seed collections. The Russian Forest Seed Warehouse in Pishkino, Moscow Region, currently stores 10 tonnes of seed, focusing on *Larix* spp., *Picea* spp. and *Pinus* spp.

Multiple *ex situ* conservation priorities are identified by European countries including the conservation of rare and endangered species, those populations that are genetically unique, and with ecological and economic importance. Many European countries reported that *ex situ* conservation activities has been negatively affected by the current fiscal and economic situation

<u>Latin America and Caribbean</u>

There are similarities in the *ex situ* conservation activities in Argentina, Brazil, Chile, Costa Rica, Ecuador and Peru. All countries have multiple seed banks, botanical gardens or arboreta, seed orchards and most have the capacity for germplasm storage in other forms such as DNA banks, pollen and cryopreservation of tissue. Germplasm sources ranged from non-native commercial species with economic impact to native species with unique medicinal and unknown impact. Gene banks were set up as a network within a country and therefore were mainly controlled at local level. The infrastructure for storage in the form of facilities, technology and equipment was present in all countries.

Most countries with *ex situ* conservation programs have identified priorities to guide their respective programs. These include conserving and improving FGRs important to the specific country, contributing to and promoting their sustainable use and support the value of conservation of FGRs in the scientific and general population. This entails determining an appropriate representative sample of a species based on geographic or genetic variation, and the future use of the material such as for breeding, plantation, and other R&D and conservation programs.

The constraints were similar within the region with a lack of permanent financing available for long term projects. Knowledge and the in depth research needed to characterize the material being conserved is often lacking. With respect to this a critical area of research that needs to be addressed is the nature of recalcitrant seed and protocols for handling seeds of species with this storage behaviour. There was also a need to have clear strategies and policies for conservation.

<u>Near East</u>

There were similarities in the priorities and constraints of FGRs among these countries namely Egypt, Iran, Iraqi Kurdistan, Jordan, Lebanon, Sudan and Yemen. All wanted to establish, enhance or continue the scientific research and education in forest genetic conservation such as propagation of trees and protocols for storing seed. There was a definite need to improve the infrastructure and technical capacity with respect to provenances tests, seed orchards, arboreta, gene banks and seed centers. Promoting partnerships with local communities and the forest to manage the resource and improve livelihoods need to be prioritised.

Lack of funding, trained personnel, research and equipment were constraints. Climate change and its impact on this region are severe given the current stage of desertification that exists. Habitats are degraded and depleted with the impact of logging, grazing and harvesting of fuelwood, highlighting the importance of protecting the forest through reserves, botanical gardens and arboreta. National policy to support and create a strategy for FGR conservation and management was urgently needed in most countries. Some countries (Iraq, Iraqi Kurdistan and Jordan) don’t have the capacity to develop comprehensive GIS surveys to identify areas and species that require conservation or protective management measures to be established.

North America

In Canada, 30 species are conserved in 549 trials/plantations and clone banks. This does not include provenance trials or clone banks for breeding programs. There is a national and several provincial seed banks where 15,000 accessions from 75 species are conserved. Territorially, the United States includes Hawaii, Puerto Rico and US Virgin Islands where 48 of the 57 officially listed species are native. Therefore, conservation activities are conducted on many species that are not native to continental United States. *Ex situ* conservation activities are conducted by over 80 arboreta and botanic gardens with 77 species of trees and shrubs in the collections. There is a national and a number of regional seed banks that store over 120,000 seedlots from over 200 species In Mexico there are 54 forest gene banks with medium to temporary storage with the goal to supply nurseries for the government reforestation programs with some being used for conservation. Mexico is working with 74 tree species with the majority being native and equally divided between conifers and hardwoods. There are 57 arboreta and botanical gardens which harbor germplasm for scientific research, nutrition, medicine, ornamental, and species at risk. Mexico, along with Canada and the United States, is a member of the North American Forestry Commission through which the exchange of training and knowledge pertaining to *ex situ* conservation, among other areas, has achieved significant results. Personnel capacity, financial, inter-agency communication, priority at the political level, limited knowledge on genetic variation of non-commercial species and knowledge and stability of long-term conservation methods such as seed banks are all constraints to improving *ex situ* conservation in North America. Future priorities include: mitigating the impacts of climate change through conservation and deployment strategies; prioritizing federal and provincial listed species and those at risk from invasive alien species; focus on non-commercial conifer and deciduous species; GAP analyses to optimize sampling; preserve improve and promote the sustainable use of forest genetic resources.

Southwest Pacific

Reports were reviewed from six countries: Australia, Cook Islands, Fiji, Papua New Guinea, Solomon Islands and Vanuatu and three French territories (French Polynesia, New Caledonia and Wallis and Futuna). Conservation activities have been conducted for about 60 species and include species and provenance trials, clonal seed orchards, seed production areas, clone banks and cryogenic storage. In Solomon Islands 30,000 plant specimens transferred from the National Herbarium to Fiji during civil unrest in 1999-2000 have not yet been returned. Papua New Guinea has a national tree seed centre that stores seed for research, reforestation and export. CSIRO's Australian Tree Seed Centre maintains a national *ex situ* seed collection of more than 900 tree species, while the Southern Tree Breeding Association contributes significantly to *ex situ* conservation in the form of provenance and progeny trials for multiple tree species. An Australian Seed Bank Partnership, which developed out of the MSD project, has a mission is to safeguard Australia's plant populations and communities by developing a national network of conservation seed banks. This Partnership unites the expertise of fourteen institutions, including universities, herbaria, botanic gardens, non-government organisations and state environmental agencies. One member of the partnership is the Western Australian Department of Environment and Conservation's Threatened Flora Seed Centre. This Seed

Centre was established to safeguard a geographically diverse range of seeds from threatened plant species, and has successfully stored seeds from three-quarters of WA's threatened plant species, many of them trees and woody shrubs, and has also reintroduced more than 50 threatened species back into the wild. New Caledonia has developed a small number of clonal archives and seed orchards of unique endemic species of Araucariaceae (France Volume 5 - p 19). In 2011 the Secretariat of the Pacific Community developed a Pacific Islands Tree Seed Centre, which aims to help research, conserve and disseminate seeds of socio-economically important tree species to its 22 island member countries and territories.

Constraints for *ex situ* conservation consist of a lack of research; no national policy or strategy, limited funding, poor facilities; public education; training for staff; land tenure. Future priorities include: staff training; involvement and engagement of rural communities; funding commitments; assessing the state of endangered species; developing and upgrading facilities; expanding collections and field trials. Papua New Guinea pointed out that external collaboration with funding agencies has to be pursued in order to achieve their priorities.

Ex situ conservation priority species by region

Asia

In Asia, no significant trends were evident between countries concerning which native species were conserved *ex situ*. Nepal and India both had *Dalbergia sisso*, a deciduous rosewood tree, as a main species for *ex situ* conservation in field collections (e.g., provenance and progeny trials). A few Central Asian countries have *ex situ* collections that focus agroforestry species. For example, Kazakhstan's largest *ex situ* collection is for *Malus sieversii*, the sole wild ancestor to most cultivars of domestic apples and Uzbekistan's largest collections are for nut bearing trees, *Juglans regia* and *Pistacia vera*.

Ex situ conservation field collections in China include progeny and provenance tests for multiple native and exotic tree species. For four native tree species, *Cunninghamia lanceolata, Larix olgensis*, *Pinus massoniana* and *Pinus sylvestris* var. *mongolica,* there are over 1,200 accessions in one or more stands, and there are also extensive clone banks for these species. Sixteen native tree species are stored in seed banks with six species (*Pinus bungeana*, *Pinus massoniana, Pinus sylvestris* var. *mongolica*, *Pinus tabulaeformis*, *Sophora japonica* and *Melia azedarach*) each having over 1,000 accessions. For exotic species, China identified nine *Eucalyptus* species and *Tectona grandis* as having 62 – 646 accessions for each species in field stands. Sri Lanka's *ex situ* collections focus on field collections for similar exotic species (e.g. *Tectona grandis*, *Eucalyptus grandis* and *E. microcorys*) and also *Khaya senagalensis*. *Tectona grandis* has the largest number of field collections, with 200 accessions in five stands. Sri Lanka reported no *ex situ* collections for native tree species.

Japan's *ex situ* conservation activities are for native species and focus primarily on clone banks and seed storage. Collections for some species are extensive; *Cryptomeria japonica* has 7,812 clones in field collections and 2,298 seed accessions, *Chamaecyparis obtusa* has 2,452 field clones and 1,515 seed accessions, while *Larix kaempferi* has 2,450 accession in clone banks and 508 seed accessions.

India has numerous species in *ex situ* conservation field collections, with the majority of species being native including *Acacia nilotica*, *Azadirachta indica*, *Dalbergia sissoo*, *Tectona grandis* and bamboos. For exotic species, India has a few extensive collections. For example, there are 3,122 accessions in field stands for *Acacia auriculiformis* and 4,548 accessions for *Hevea brasiliensis* in clone banks. India's *ex situ* germplasm storage collections focus primarily on native species and these collections are not as extensive as their *ex situ* field banks. The largest seed storage collection is for a native species (*Prosopis cineraria*) with 453 accessions, while their largest *in vitro* collection is for an exotic species (*Jatropha curcas*) with 145 accessions.

Nepal has identified 36 native species under some form of *ex situ* conservation. Twenty-four of these species are in field stands, 14 species are maintained in *in vitro* collections and there are no *ex situ* seed collections reported for any of the 36 species. Under *ex situ* field collections, *Dalbergia sissoo* has seven stands, while *Cinnamomum tamala* and *Leucaena leucocephala* each have three stands. The remainder of the species have two or one stands per species.

In Kazakhstan, seven native species (*Berberis karkaralensis*, *Malus sieversii*, *Corylus avellana*, *Alnus glutinosa*, *Juniperus seravschanica*, *Aflatunia ulmifolis* and *Quercus robur*) are conserved *ex situ* in field collections and these species also have *ex situ* seed stores. Uzbekistan has 4 native species in *ex situ* field collections (*Juglans regia*, *Pistacia vera, Amygdalus* spp. and *Haloxylon aphyllum*) and has no other *ex situ* collections.

Europe

There is significant diversity in the native species conserved *ex situ* in the 15 European countries reporting data. There are large accessions for *Pinus sylvestris* and to a lesser extent *Picea abies* and for many hardwoods including *Quercus* spp. and *Populus* spp. in a number of countries. In seven countries, *Pseudotsuga menziesii* is a common exotic species conserved *ex situ*.

Bulgaria has identified 36 native and exotic tree species conserved *ex situ* primarily in field collections and in a few seed bank accessions. The largest *ex situ* field stands for native species are for *Quercus petraea, Q. frainetto* and *Fagus sylvatica* each with at least 49 accessions, while *Populus spp.* and *Pinus sylvestris* have the largest number of field stands and accessions. For exotic species *Pseudotsuga menziesii* has the largest number of accessions, with 55 accessions in one field stand. Seed is stored *ex situ* for two species (*Picea abies* and *Pinus sylvestris*).

Cyprus has reported that the majority of *ex situ* collections are for stored seed, where seed is stored for 16 native species, the majority of which are trees and the number of accessions range from 3 to 15, with the largest accession for *Astragalus macrocarpus* spp*. Lefkarensis*, a small shrub present in evergreen mixed forests (IUCN 2013).

In Denmark, *ex situ* conservation is in the form of seed storage with ten tree species having accessions. *Abies nordmanniana* has the largest number of accessions, followed by the native species *Pinus sylvestris* and the exotic species *Pseudotsuga menziesii*. Estonia's *ex situ* conservation activities are also in the form of seed storage, with two native species, *Populus tremula* and *Populus tremula* f. *gigas*, and the exotic species *Populus* x *wettsteinii* having multiple accessions.

Finland has *ex situ* field collections for eight native tree species (*Acer platanoides*, *Fraxinus excelsior, Juniperus communis*, *Quercus robur*, *Sorbus aucuparia*, *Tilia cordata*, *Ulmus glabra* and *Ulmus laevis*). Germany has 59 species represented in *ex situ* field collections, with the largest collections for native species such as *Taxus baccata*, *Picea abies* and *Fagus sylvatica,* and for the exotic species *Pseudotsuga menziesii*.

Hungary has quite large *ex situ* field collections for 23 species, the majority of which are native. The largest collections are for *Populus nigra* and *Pices abies*, with over 1,000 accessions each, then *Castanea sativa*, followed by species such as *Ulmus laevis*, *U. minor* and *U. pumila* each with over 300 accessions.

Ireland has 11 species conserved *ex situ* primarily in field collections with only one species being native, *Pinus sylvestris*. The collections for this species are extensive with 52 stands and 619 accessions and three clone banks with 562 clones. Additionally there are 100 *in vitro* and 75 seed accessions.

The majority of the Netherlands' *ex situ* collections are in clone banks with 59 native species represented. The largest collections are for *Crataegus monogyna* and *Juniperus communis* with 333 and 284 clones, respectively.

Norway has approximately 37 species in *ex situ* collections with the majority of species being native. Most of the collections are field stands and there are three species with clone banks, (*Prunus avium*, *Quercus* spp. and *Tilia cordata*). Norway has a large number of field collections for *Picea abies*, with 114 stands and 6,000 accessions. In Poland *ex situ* conservation efforts are for 33 species, with the majority of species being native. Seed storage is the main form of *ex situ* conservation, with the largest collection of 4,764 accessions for *Pinus sylvestris*, followed by 836 accessions for *Picea abies*. Additionally, there are smaller *in vitro* collections for 6 species.

Spain has *ex situ* collections primarily in the form of clone banks for approximately 27 species, the majority of which are native species. The largest of these collections is for four native species (*Populus tremula*, *P. nigra*, *Ulmus minor* and *U. glabra*). Spain also has *ex situ* seed collections for five native species (*Arbutus canariensis*, *Pinus pinaster*, *P. pinea*, *P. uncinata* and *Populus alba*).

Sweden's reported *ex situ* conservation collections are primarily field collections for such species as *Quercus robur*, *Betula pendula*, *Fagus sylvatica* and *Alnus glutinosa* and also include seed collections for few species and a few clone banks.

In the Ukraine, *ex situ* collections are comprised of field collections, including a few clone banks for native and exotic species. The largest collection is for *Pinus sylvestris* with 95 stands representing 1,148 accessions and 38 clone banks with 1,092 accessions. The next largest collection is for *Quercus robus* with 30 stands representing 539 accessions and 16 clone banks with 540 accessions.

Ex situ data was not reported by Russia.

<u>Africa</u>

In Africa, two countries Ethiopia and Burkina Faso out of 19 reported data pertaining to *ex situ* conservation. There are trends in their conservation activities for a few species. For native species, both countries have *ex situ* conservation collections for various *Acacia* spp. and *Tamarindus indica.* Additionally, these countries also conserve the exotic species *Eucalyptus spp. (Eucalyptus globulus* in Ethiopia and *Eucalyptus camaldulensis* in Burkina Faso). In Ethiopia, 92 native and 1 exotic species is conserved in multiple field and seed bank collections. The accessions from all native species include one or more field stand and *ex situ* seed bank collections. *Phytolaca dodecandra* is the native species with the largest number of collections with 59 accessions over 19 field stands and 59 accessions represented in three seed banks. Five native species had more than 20 accessions over multiple field stands including *Acacia etbaica, Cordia africana, Morinaga stenopetala, Oxytenanthera abyssinica* and *Phytolaca dodecandra.* For the only exotic species conserved *ex situ*, *Eucalyptus globulus,* there were ten accessions available from one stand and these ten accessions were also conserved in one seed bank. In Burkina Faso, six native (*Acacia nilotica* var. *adansonii*, *Acacia senegal*, *Faidherbia albida*, *Khaya senegalensis*, *Parkia biglobosa*, *Tamarindus indica*) and 4 exotic (*Eucalyptus camaldulensis*, *Leucaena leucocephala*, *Prosopis chilensis*, *Prosopis juliflora*) species are conserved in field collections, including clone banks and through seed collections. *Parkia biglobosa* and *Faidherbia albida* are the two native species with the largest number of field stands and accessions. Only one species, *Eucalyptus camaldulensis* has clone banks with 101 clones in two clone banks.

Latin America

Costa Rica and Ecuador were the only countries in the Latin America Region to report data on *ex situ* collections. Only one species *Swietenia macrophylla* is conserved *ex situ* in both countries. This species, a commercially important mahogany, is native to both countries and is identified by the IUCN as vulnerable (IUCN 1998). In Costa Rica, four native species and one of uncertain origin are conserved *ex situ* in field collections, Four species, three of which are native (*Dipteryx panamensis*, *Sacloglottis* sp., *Schlerolobium* sp.) and one of uncertain origin (*Himenolobium parahybum*) are represented in 26 accessions in field stands. *Sacloglotis* sp. and *Himenolobium parahybum* had the largest number of accessions with 12 and 9, respectively. *Swietenia macrophylla*, a native species, is the only species identified in clone banks with 600 clones established. Ecuador has 114 species conserved *ex situ,* in field collections, and 64 of these species are native, 49 are exotic and one species has uncertain origin. There are approximately 166 accessions in multiple field stands for all species. Three genera had multiple species listed including *Eucalyptus* with 17 species, *Acacia* with 13 species, and *Erythrina* with six species.

Near East

Iran was the only country in the Near East Region to report data on *ex situ* collections. The only species listed was *Populus spp.* with 18 species conserved *ex situ* in clone bank. A total of 258 clones are established. *Populus x euramericana,* with an uncertain origin and *Populus nigra,* a native species to Iran*,* had the greatest number of clones established with 59 and 91, respectively.

North America

In North America there are extensive *ex situ* conservation collections for *Pinus* spp. in the United States and Mexico. In Canada, 28 native and five exotic species have been established in over 510 field stands. Fourteen native and one exotic species are represented in 37 clone banks. Key conifer species with 550−770 accessions in clone banks are *Picea glauca*, *P. glauca* x *engelmannii* and *Pinus contorta* var. *latifolia*. Five hardwood species (*Fraxinus pennsylvanica*, *Prunus virginiana* var. *virginiana*, *Quercus macrocarpa*, *Sherpherdia argentea* and *Symphoricarpus occidentalis*) have 1,900−6,600 accessions in clone banks. Over 15,000 accessions from 74 native and one exotic species are stored in five seed banks. *Picea glauca*, *P. glauca* x *engelmannii* and *Pinus contorta* var. *latifolia* have over 1000 accessions each.

The United States of America has multiple *ex situ* conservation field and seed collections, predominately for native species. Over 200 tree and shrub species are conserved *ex situ* in seed collections of the US Department of Agriculture (Forest Service and Agricultural Research Service). Conifers are best conserved since they have large reforestation programs. The USDA Forest Service maintains family seedlots for 44 reforestation species, totalling over 80,000 families. The three species with the best representation are *Pinus lambertiana* with over 26,000 family collections, *Pseudotsuga meneziesii* with over 20,000 family collections, and *Pinus ponderosa* with over 13,000 family collections. The breeding cooperatives in the US maintain large breeding population sizes (population sizes in the 100s) for each of their breeding zones and their hundreds of progeny trials represent hundreds of field sites providing gene conservation as a secondary objective.

Mexico's *ex situ* conservation activities are conducted for 55 native and 12 exotic species, and include field collections, clone and seed banks. At the genus level, there has been extensive effort directed to 26 *Pinus* species and seven varieties with over 320 accessions of *Pinus greggii* var. *greggii* and *P. patula* in 28 field stands while just over 1,000 accessions of *Pinus greggii* and *P. patula* are represented in 16 clone banks. Considerable effort has been expended in establishing field stands of other species such as *Calophyllum brasiliensis*, *Cedrela odorata*, *Cupressus guadalupensis*, *Eucalyptus grandis*, *E. urophylla*, *Guaciacum coulteri* and *Platymiscum lasiocarpum* with almost 3,500 accessions represented in 39 stands. Of these species, *Eucalyptus grandis* and *E. urophylla* have 1,300 accessions in five clone banks. There are over 6,900 accessions from 36 species in seed banks. The number of accessions per species varies from 1 to 3,665 with *Pinus patula* and *Toona ciliata* having the most, 700 and 3,665, respectively.

<u>Southwest Pacific</u>

Ex situ conservation data was reported for Australia and Papua New Guinea. Australia has more than 1000 species conserved *ex situ* in seed banks and field plantings (clonal archives, seed orchards, arboreta). Well represented genera and species include 900 species of eucalypts (including *Angophora*, *Corymbia* and *Eucalyptus*) in seed banks and arboreta, *Acacia auriculiformis* (780 accessions in seed banks), *Araucaria cunninghamii* (800 clones and 400 families planted in field), Khaya senegalensis (150 clones and 80 provenances in seed banks), and *Pinus radiata* (916 clones and 772 seed accessions). PNG has 200 field stands containing 107 accessions have been established for five native species (*Acacia crassicarpa*, *A. mangium*, *Araucaria cunninghamii*, *A. hunsteinii* and *Eucalyptus deglupta*) and one exotic species (*Tectona grandis*). Seven clone banks contain 114 clones of these species.

2.4.4 Genetic improvement and breeding programmes

Introduction

Tree breeding programmes have the potential to sustainably improve the production of planted forests and trees and are necessary to meet growing global demands in forest products and services, driven both by population increase and greater wealth. More extensive development of forestry plantation industries based on diverse, improved tree germplasm has the potential to produce a large proportion of the world's wood requirements and relieve utilization pressures on natural forests, e.g. timber plantations, growing at 10-20 m^3 per ha per annum, and covering an area equivalent to 2.5-5% of the world's forests are capable of producing the entire projected global demand of 2 billion cubic meters of roundwood equivalent in 2030. At a national level on-going tree breeding is needed to support plantation development to help meet the export and local demands for forest products. This is especially the case in countries where logging in native forests is occurring at unsustainable rates, or where native forest logging is now highly restricted or banned and for those countries with limited areas and/or low yielding native production forests. Tree breeding is also essential to address new challenges associated with climate change and emerging pests and diseases.

Trees have been the subject of informal selection, breeding and movement for many hundreds if not thousands of years, with traditional domestication efforts mainly focussed on edible fruit and nut trees. Informally improved and aboriginally introduced trees make a significant contribution to livelihoods in many countries, although the benefit attributable to improvement is difficult to quantify. Over the past two to three decades there has been a renewed interest and focus on domestication and less intensive improvement programs for a wider range of multipurpose and food tree species, often of native origin. This is exemplified in ICRAFs tree domestication programs with national partners in sub-Saharan Africa, south-east Asia and Latin America. These programs focus on improvement of agroforestry tree products (AFTPs) such as poles/posts, charcoal, fodder, fruit and nuts, oils and medicines.

For much of the second half of the 20th Century, tree breeding and genetic improvement focused on species for commercial production of timber and pulpwood. The high costs involved in such tree breeding programmes were more than compensated for through future productivity gains and increased commercial returns of plantations established with the improved germplasm. Characteristics commonly evaluated as the basis for selection to improve performance and utility of commercial forestry plantation and agroforestry tree species included growth rate, volume, form, processing and product qualities (wood and NWFPs). The improvement process typically involves seed collection of a large number of individuals from native stands, which may be range-wide collections for exotic tree species, or more geographically focussed based on climate/soil matching or if superior sources have already been identified. These are followed by provenance and progeny trials, from which phenotypically selections of plus trees are made and/or breeding values determined, followed breeding/crossing/selection programs based on different strategies depending on species, breeding objectives and resources available. Increasingly sophisticated approaches and technologies are being applied to tree breeding to generate faster rates of gain, for example more statistically powerful trial and mating designs, combined index based selection taking account the economic weight, heritabilities and co-variances of different traits; prediction of breeding values based on Best Linear Unbiased Prediction; improved management of breeding populations and maintaining sublines to reduce risks of inbreeding; and promoting earlier flowering and seed production.

Hybrid breeding, involving inter-specific hybrids and wide provenance crosses, is being used in many countries to produce trees with superior productive capabilities, through heterosis, and also to introduce genes for disease resistance. They include eucalypt hybrids, *Larix* and *Populus* hybrids, *Pinus* hybrids and increasingly for diverse tree genera such as *Acacia*, *Casuarina*, *Fraxinus*, *Liriodendron*, *Prosopis*, and *Santalum*. At a global level there has been relatively few attempts to develop genetically modified or transgenic trees, mainly due to community concerns and associated legal restrictions and impediments to their development and use in Europe, USA and elsewhere. In China transgenic poplars have been produced through incorporation of genes for insect resistance into hybrid poplars.

In recent decades a wider range of tree species have been subject to domestication and formal breeding programs by governments agencies and private sector, to produce myriad goods including timber, paper pulp, fuelwood, fruit, nuts, oils, traditional medicines, dyes, resins, thatch, and other NWFPs, and provide forest service functions. In addition tree breeding efforts are increasingly focussed on adaptability-related traits, including to predicted new climate regimes, as well as resistance to drought, fire, pests and disease, and for use in forest restoration programmes. These breeding programmes are primarily initiated by public sector agencies; the USA country report lists several forest tree breeding and restoration programmes. Prime examples of breeding for conservation purposes involves programs to re-introduce American chestnut *(Castanea dentata)* and American elm *(Ulmus americana)* into forests which they have been eliminated by chestnut blight and dutch elm disease, respectively. Wild individuals resistant to these diseases are identified and selected, and used in breeding programmes to introduce the genes conferring resistance. Within identified genecological zones, inclusion of the broadest available range of genetic variability in direct seeded or planting stock maximises the opportunity for the species to reoccupy their former ranges, perform vital ecological services and allow for future adaptation.

Breeding programmes have usually been geared towards improvement of traits that will maximize economic gains from future plantation developments. Accordingly in most countries conventional tree improvement has focussed on a small number of commercially important traits in the major plantation species. The focus on commercial plantation species is related to the high costs involved in undertaking a comprehensive breeding program, specialist expertise needed, and typically long periods before benefits are realised, of the order of several decades in cooler climates. The scope and role of tree selection and breeding programs is changing and diversifying in response to several factors. These factors include the scale and unpredictability of environmental change (including climate change, especially extreme climate events and interactions with pests and diseases), new demands and requirements for trees for food nutritional security, environmental rehabilitation and maximizing carbon sequestration for climate change mitigation. There is a growing recognition of the need to generate and deploy selected improved tree germplasm with multiple objectives in mind, including human food, biofuels, environmental and ecological purposes. Adaptation characteristics which will be more sought-after in particular breeding programs include improved drought resistance, resistance to and recovery from fire, and an ability to withstand hurricane-force winds at all stages during the development and life of a plantation. It is further anticipated that introduction of more diverse and *a priori* better adapted genetic material, both inter- and intra-specific, will increasingly be required in both native and planted forests: this is because the rapid rate of climate change may exceed the ability of indigenous tree species and populations to respond to such changes, through natural selection and/or migration.

As noted by Sweden the success of on-going and future breeding activities will in large part depend on the natural variability of FGR contained in wild populations, and in existing breeding programs and plantations, and this underscores the importance of FGR conservation. Breeding programmes can also contribute to *ex situ* conservation: 'breeding programs, by default, have *ex situ* conservation plantings in their seed orchards, progeny tests in addition to any seed stores' (USA). However these activities by themselves cannot be regarded as secure form of long-term *ex situ* conservation, given that the facilities may be abandoned once the testing or breeding program has been completed.

Requirements of breeding and improvement programmes

Successful and efficient tree breeding requires genetic characterisation. Growth and morphological characterisations, principally through field trials (provenance, family/progeny and clonal trials), are used by countries with less resources, while such field studies are complemented by information from molecular and DNA characterisation in larger, developed countries with more resources and advanced tree breeding programmes. Developing countries may also undertake molecular studies of tree species, but this is usually done with the assistance of external international partners, either in the form of donor assistance or on a commercial basis.

Some countries remarked on the need to identify adaptation-relevant genetic variation for provision of germplasm for propagation and the breeding of climate-change resistant improved materials. For example Germany (p94) states: 'It is essential that future international research projects also provide more information about the genetic variation to adaptation-relevant gene loci. This would provide important information on the adaptation potentials of tree populations.' Identification of genetic markers for traits conferring adaptive advantage or superior performance in a desired characteristic may circumvent the long time periods required to generate results in breeding programmes based on field trials. Brazil (p74) noted that '…knowledge of potentially useful genes and their incorporation into elite cultivars have been very important to promote the use of genetic resources and broaden the genetic base for breeding programs….research involving the exploration, conservation and characterization of germplasm has become strategically important for Brazil.'

As far back as 1999 and 2001 the FAO Panel of Experts on Forest Gene Resources (11 and 12th Sessions) noted with concern the widening gap between science and practice, and stressed that successful application was at risk if knowledge produced at scientific level was more advanced than what the operational level was able to absorb and implement. This is increasingly the case today, with entire genomes now being sequenced for trees, both angiosperms (including important forest plantation trees, viz. *Populus trichocarpa* and *Eucalyptus grandis*, as well as four fruit tree species, viz *Carica papaya*, *Citrus sinensis*, *Malus domestica* and *Prunus persica*, and the most primitive angiosperm, *Amborella trichopoda* from New Caledonia) and gymnosperms (*Larix sibirica*, *Picea abies*, *P. glauca*, *Pinus lambertiana*, *P. pinaster*, *P. sylvestris*, *P. taeda* and *Pseudotsuga menziesii*). The sequencing of the coniferous giga-genomes, typically with genomes an order of magnitude larger than other organisms, has only been made possible through the introduction of new sequencing technologies and dramatic reduction in costs[5] and facilitated by collaboration between different laboratories/research groups. These studies are complemented by gene mapping studies and elucidation of gene function and expression including for growth, wood properties, biotic and abiotic stresses in seven economically important tree genera, viz, *Castanea*, *Eucalyptus*, *Picea*, *Pinus*, *Populus*, *Pseudotsuga* and *Quercus* (Neale and Kremer 2011). Novel approaches have been developed to link markers to important traits, with genomic and marker assisted selection close to being realised in several tree species. However, there is a growing realisation among molecular geneticists that they will not be able to use the rapidly expanding gene-level information without whole organism information coming from the field. In many developing countries there is a lack of skilled tree breeders able to understand and utilise the information generated by forest geneticists and to ensure its application in practical, large-scale R&D, breeding and planting programmes.

Prioritising uses, traits and species for improvement

Demand for forest products influences the traits and the species selected for improvement. This should reflect goals set out in the national development and forestry strategies, and of course the national FGR strategy. Where countries lack these documents or the objectives are not explicit, these decisions may be made within government departments or research and tree improvement institutes. It is vital that these reflect the needs of the actual users of forest products, and the needs of a country's rural communities, as well as changes in demand for forest produce: instances of failure to address the needs of the community have been mentioned above. China has noted the importance of responding to market signals in another context. Nonetheless the extremely long time frame for breeding programmes to generate improved germplasm is problematic when it comes to responding to changes in demand for forest products and services. For example there has been a recent growth in demand for wood as a sustainable energy source to mitigate climate change, and breeding of trees for energy production has been the focus of intensive improvement programmes in Germany, particularly focusing on rapidly growing species harvested on short rotation.

In different countries tree improvement may be undertaken by different organizations notably government research agencies, universities and private sector companies. With shrinking public funding for breeding programmes, increasingly private sector companies are pursuing their own research priorities, including through breeding co-operatives, rather than through coordinated national programmes (e.g. USA with 150 cooperative breeding programs, representing over 70 species). The private sector is guided by potential for commercial gain, and not bound by tests of public benefit in its selection of traits and species for improvement.

Many countries import improved genetic materials for evaluation and to undertake further breeding, including to adapt it to local conditions. These genetic materials are mainly of exotic species but may include species that are already indigenous to the country (especially for widely distributed species). A relatively small number of commercially important plantation species, e.g. acacias, eucalypts, pines, poplars and teak, are used widely around the globe, and are the focus of many breeding programmes internationally.

[5] Sequencing costs have reduced from more than $US 5000 per raw megabase of DNA sequence in 2001, to about 10 cents in 2012, the most dramatic decline being since 2007 (Source: National Human Genome Research Institute).

Environmental parameters changing in response to climate change will require planting stock adapted to the new conditions. Several countries observed that breeding programmes will increasingly need to focus on survivability, drought and fire resistance, and resistance to pests and diseases that may become more prevalent under climate change, and breeding for climate change is increasingly considered a high priority.

Many developing countries are yet to properly explore their indigenous tree flora for domestication and improvement. The example of Tanzania has been referred to above: its lesser-known, indigenous species have been neglected in favour of prioritised, tried and tested exotic species, or 'charismatic' local utility trees, and states '…the [indigenous] gene pool has more to offer' in terms of species for improvement. Likewise, the Seychelles have an extremely rich endemic tree flora, with many excellent timber species that have not been investigated for their forestry potential; it instead has focused on importing exotic species. Developing countries often contain large areas of native forests providing extensive reservoirs of tree genetic diversity with potential for development for human use, and increasingly national forest agencies are keen to explore such diversity, though domestication and improvement of local or indigenous tree species. Such approaches are being increasingly supported by international donors and research partners keen to promote indigenous species that already adapted and well known by the local communities, as well as contributing to biodiversity conservation objectives and avoiding risks associated with possible weediness from exotics.

Smaller countries often lack the resources or capacities to conduct their own domestication and improvement programs even for important local tree species. In some cases countries may have limited or no local forest industries and rely instead on imports or minor local harvest to meet their needs. Cyprus does not have a forest industry because of low growth rates and conserve its forests for environmental protection. Countries lacking improvement programs include almost all of the 52 Small Island Developing States (SIDS) in the Caribbean, Indian and Pacific[6] Oceans. For example, the Seychelles, with its small population and limited resources, does not conduct a breeding programme for trees, instead importing improved and proven varieties for its agricultural programme and conducting 'adaptive screening' of imported materials (e.g. mango and avocado) with 'no scientific plant breeding is done locally through lack of expertise, infrastructure and financial support'. Several other countries without domestication and breeding programmes choose instead to import improved material for use in the country; these are generally high-performing, high-value industrial forestry exotic species for which germplasm is readily available. Nonetheless, domestication and improvement programmes can deliver longer-term economic and other benefits and when appropriately designed can help to ensure conservation of the genetic diversity and preserve options of the included tree species.

Coordination of breeding and improvement programmes

The need for better coordination and documentation of tree breeding efforts at national level is indicated in the Brazil report "Eucalyptus and pine forest plantations have benefited for a long time,

[6] Some SIDS in the Pacific Islands have collaborative tree improvement/domestication programs such as New Caledonia (with CIRAD-Forêt), Papua New Guinea (with CSIRO/ACIAR), Fiji, Solomon Islands, Samoa, Vanuatu and Tonga (with assistance through the AusAID-funded South Pacific Regional Initiative on Forest Genetic Resources from 1996-2005).

since the 70´s, from pioneering cooperative network genetic research and improvement programs. Currently IPEF (Forestry Science and Research Institute), associated with the Forest Sciences Department of the University of São Paulo, is leading an effort to “rescue” most of the information scattered all over the country regarding genetic improvement programs for *Eucalyptus*, pine and other exotic tree species”.

Some countries with major/and or diversified forest sectors and market economies such as Finland and Norway have national tree breeding programs provided as a Government-funded public service while in other countries such as Germany breeding is undertaken by private sector forestry interests, and independent academic and other institutions. Collaborative tree breeding programmes are most well-developed in North America, viz. Canada and the USA including internationally through CAMCORE cooperative (established by North Carolina State University) with breeding cooperative increasingly finding favour in other countries, e.g. Australia. However in the majority of countries, for the benefits of tree improvement to be fully realized and on-going, there is a need for national information systems and better coordination between all actors, e.g. between and within government agencies and departments (especially between forestry and agriculture, and forestry and environment/ biodiversity conservation); research institutes and universities; and the private sector. The role of a national FGR strategy is paramount in coordinating these actors; furthermore, coordination of national FGR strategies with strategies in forestry, agriculture and development is also required.

It was evident from several country reports that there is a the tendency of governments to place more emphasis on allocation of resources to breeding of conventional agricultural crops, which maybe at the expense of forest trees. With few exceptions, tree breeding is normally administratively remote and separate from agricultural breeding, however, tree food crops and the forest food bank are extremely important for many people around the world, often providing vital nutritional components and sustenance when other crops fail due to drought, other environmental stress, or socio-political disruption. A number of countries in Central Asia, near East and south Caucasus contain progenitors or wild relatives of important food tree species, and these too are vital FGR for food security. There may an opportunity for closer cooperation between these two closely related areas, for breeding improved trees for a wide range of uses, particularly for use on farms, in rural communities, to alleviate rural poverty and hunger, and to increase food security.

In order to fully capture the benefits of tree improvement programs, which accrue over very long periods, national and local security is vital as is a favourable investment environment and stable global and national economies with assured demand for forest products. National Governments have essential roles in these areas, and in the case of publically-funded tree improvement programs there is a need for broad political support to ensure these programs reach fruition and preferably are continued and/or adopted by private sector. Private companies and others need to be able to protect the IP resulting from their breeding work, through plant variety rights, and/or have sufficient planting programs of their own to justify the required long-term investments. Legally binding and firm agreements for benefit sharing according to the relevant agreements are necessary.

A major scope for international collaboration in tree improvement is through sharing of genetic resources, especially for those species whose distributions cut across national boundaries. In certain situations there may also be scope to contract out tree improvement activities to other countries (breeding cooperatives and/or companies) but it would first need to be demonstrated that GxE interactions are limited. Furthermore high levels of confidence are required for a country to entrust the development of its unique genetic resources to another country, due to perceived o or real risks of losing control of the process and not receiving a fair share of the benefits flowing from improvement. This underscores the vital role of agreements that are firm, enforceable and fair, between parties engaging in such arrangements.

Domestication and tree improvement has been long practiced by individual tree farmers, notably for edible fruit and nut-bearing tree species, as indicated in several country reports. There is considerable scope for greater collaboration in these activities through better networking of so called ‘barefoot’ improvers, and provision of germplasm, sharing of information and technologies, and other resources.

A major scope for international collaboration in tree improvement is through sharing of genetic resources, especially for those species whose distributions cut across national boundaries. In certain situations there may also be scope to contract out tree improvement activities to other countries (breeding cooperatives and/or companies) but it would first need to be demonstrated that GxE interactions are limited. Furthermore high levels of confidence are required for a country to entrust the development of its unique genetic resources to another country, due to perceived o or real risks of losing control of the process and not receiving a fair share of the benefits flowing from improvement. This underscores the vital role of agreements that are firm, enforceable and fair, between parties engaging in such arrangements.

Gains from improvement

In China ‘Significant gains have been achieved due to the use of genetically improved plant materials in plantations, achieving an average growth gain of 10-30% for timber trees and an average yield gain of 15-68% for fruit trees.’ ‘The average growth gain of improved timber trees was more than 10%, and the average yield gain of improved economic trees was more than 15%.’

Genetic improvement programmes underpin Brazil’s 5 M ha eucalypt plantation industry, and the commercial benefits of this improved material are immense:

> *‘Brazil is also one of the main pulp and paper producers in the world, and a sector reference in terms of sustainable pulp wood production, which is 100% harvested from planted forests, mainly Eucalyptus and Pine. The productivity of these planted forests is the highest among all pulp producers in the market, with an annual average growth of 41 m3/ha/year for Eucalyptus and 35 m3/ha/year for pine plantations (BRACELPA, 2009). This is the result of 30 years of a successful research development and transfer process in a country where the climate is very favorable and private research institutes worked integrated with researchers in universities to generate genetically improved material and advanced silvicultural treatments.’*

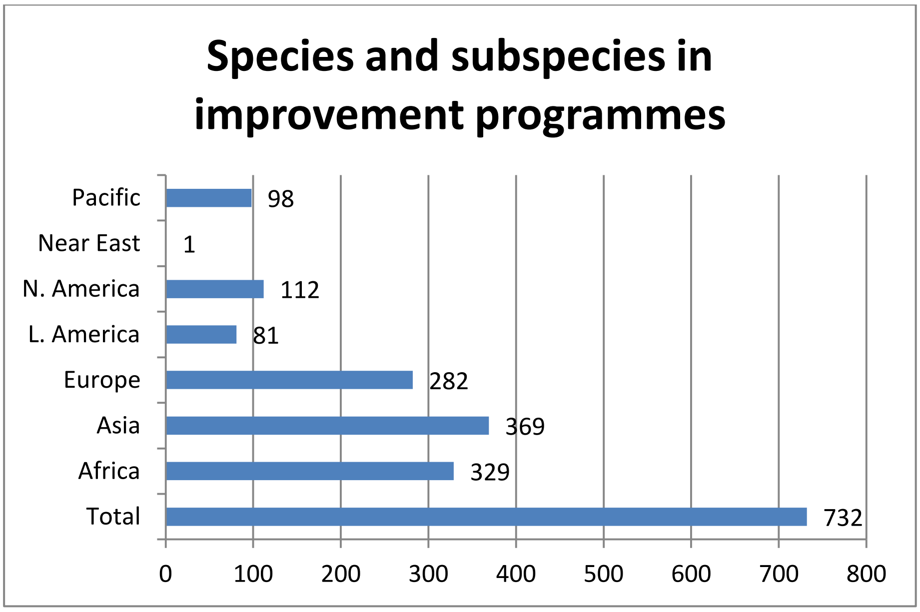
Benefit sharing arrangements

Where genetic material is contributed by a country to a collaborative improvement programme, fair and equitable benefit-sharing arrangements must be put in place through a legally binding mechanism. Several international agreements address this subject, such as the CBD, International

Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which mainly deals with non-tree agricultural crops) and more recently the 2010 Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity. However these agreements may not always adequately protect the rights of both parties in commercial arrangements, and further detailed arrangements and country-specific regulations may be necessary to protect the rights of countries and communities contributing the raw genetic resource. Patents and plant variety rights provide an opportunity for the benefits of genetic improvement to be returned to the parties undertaking the work. However it was reported that patents do not play a significant role in FGR at least for example in Germany.

The state of tree improvement and species priorities by region

Figure 6 below presents the number of species and subspecies in improvement programmes by region.



Africa

Tree improvement has a long history in Africa including in Kenya, Morocco, Republic of South Africa, and Zimbabwe. One of the earliest breeding programs for a broad-leaved tree in the world was for *Acacia mearnsii* in South Africa, initiated more than sixty years ago (Dunlop *et al*. 2003). Improvement objectives were initially to improve tannin yields, growth, and gummosis resistance, then for wood properties and most recently with the objective by 2015 to make material in future plantations sterile to reduce invasiveness risk. A number of the earliest tree improvement activities were undertaken with assistance of the UK (ODA and Oxford Forestry Research Institute) and France (CTFT) and mainly focussed on exotic timber species to be developed for industrial forestry plantations. These programs were dominated by *Eucalyptus* and *Pinus* species, and these genera still predominate today: eleven African countries have improvement programs for *Eucalyptus* species, notably *E. camaldulensis* (8 countries) and *E. grandis* (7), and *E. globulus* (3), *E. tereticornis* (3) and *E. urophylla* (3). *Pinus* improvement is reported in eight countries including for *P. caribaea* (3), *P. elliottii* (3), *P. oocarpa* (3), *P. brutia* (2) and *P. halepensis* (2).

Tree improvement typically requires sustained, and often considerable capital injections. This has meant that some improvement programs initiated in Africa many decades ago, often in collaboration with French (CTFT) and British (Oxford Forestry Institute) Research Institutes are no longer operational, while smaller countries such as Burundi and Seychelles do not have tree improvement programs. Zimbabwe's tree improvement programs for exotic industrial species, which have delivered impressive gains[7] are being reactivated due to improved economic circumstances.

Most tree improvement programs in Africa use traditional and modern breeding approaches involving provenance testing, plus tree selection, family/progeny trials, open-pollination and/or hand cross pollination, recurrent selection and multiple breeding populations and breeding indexes for multiple-trait improvement. Other exotic timber-producing genera/species undergoing improvement in several African countries include *Tectona grandis* (4), *Cupressus* spp. (3), *Acacia auriculiformis* (2), *Azadirachta indica* (2) and *Grevillea robusta* (2) with native timber trees including *Khaya* spp. (3), *Milicia excelsa* (2) and *Terminalia superba* (2). In sub-Saharan Africa over the past two decades there has been an increased focus on improvement of a large number and diverse local multipurpose, often traditional food trees: these programs often involve a collaboration between national agencies, ICRAF and may include involvement of local communities in a more participatory process of selection and breeding. Multipurpose food/NWFP and medicinal trees recorded as under improvement in several countries included *Acacia senegal* (3), *Adansonia digitata* (3), *Detarium* spp. (2), *Irvingia gabonensis* (2), *Parkia biglobosa* (2), *Sclerocarya birrea* (2), *Tamarindus indica* (3), *Vitellaria paradoxa* (3) and *Ziziphus mauritiana* (3).

Asia

The Asian region has a great diversity of tree improvement programs and species for improvement which vary depending on region, level of development and other factors. China, India, Japan and Thailand have well-developed and comprehensive improvement programs. China has a vast tree improvement program including more than 100 mainly native species, principally being improved for wood production. An example is the improvement of the native conifer *Cunninghamia lanceolata* which has involved trials of more than 200 provenances in nine regions and resulted in an average gain in wood production of 16%. India has on-going programs to improve more than 140 mainly native species, principally for wood production. Japan's tree breeding programs commenced more than sixty years ago, and aim to increase productivity and sawn timber quality for the major planted native conifers viz. *Abies sachalinensis, Chamaecyparis obtusa, Cryptomeria japonica*, *Larix kaempferi* and *Picea glehni*. The largest program is for *C. japonica* with breeding conducted in four regions, and based on 500-1000 selected individuals per region. The Republic of Korea's tree improvement activities has mainly focused on plus tree selection (2,724 trees of 28 species) and seed orchard development (59 species including 16 gymnosperms covering 734 ha) of native species. The main focus has been on the major planted species, *Pinus densiflora* (now into second generation of improvement) and two other native pines, viz. *Pinus koraiensis* and *P. thunbergia*. Thailand also has a long and successful history of tree breeding developed through collaboration with Denmark (DANIDA Forest Seed Centre) for improvement of teak and pines, and over the past three decades with Australia (CSIRO Australian Tree Seed Centre) for improvement of *Acacia, Casuarina, Chukrasia*

[7] e.g. Cumulative volume gain of up to 45% in 3rd generation selections of *Pinus patula* over the original wild material (Zimbabwe, p 24)

and *Eucalyptus*. Major improvement effort has been on the two main planted timber trees, viz teak (*Tectona grandis*) and *Eucalyptus camaldulensis.* Improvement of the latter species, and its hybrids, has involved improving form and growth rates, then disease resistance and most recently pulpwood traits, increasingly with involvement of private sector and clonal registration. *Eucalyptus* is an important genus for improvement in Asia with programs reported in eight countries involving many species including *E. camaldulensis*, *E. globulus*, *E. pellita*, *E. tereticornis* and *E. urophylla. Pinus* species are widely planted in Asia with more than ten different species are undergoing improvement in seven Asian countries. Teak (*Tectona grandis*) improvement is being undertaken in seven Asian countries, including three in which it is native (India, Myanmar and Thailand). *Pterocarpus* and *Dalbergia* include several high value timber species undergoing improvement in five and three Asian countries, respectively. *Gmelina arborea* and *Acacia* species (especially *A. auriculiformis*, *A. mangium* and their hybrid) are important industrial plantation timber species and each undergoing improvement in four countries. Important mainly Asian genera and species for timber and NWFPs undergoing improvement include *Albizia* spp. (3), *Casuarina* spp. (3), *Magnolia* spp. (3), *Santalum album* (3), *Azadirachta indica* (2) and *Phyllanthus emblica* (2). Improvement programs in central Asia are more often focussed on fruit and nut trees and their wild relatives, in the genera *Juglans, Malus*, *Pistacia*, *Prunus* and *Pyrus* spp. *Populus* species and hybrids are being improved in China, India and Kazakhstan both for wood and bioenergy, and *P. euphratica* has major climatic and ecological amplitude which is being increasingly exploited for restoration programs. Certain *Haloxylon* spp. are salt-tolerant and being improved in China and Uzbekistan for restoration plantings.

Europe

With the exception of Switzerland, all reporting European countries had tree improvement programs, although in some cases these were limited or only recently initiated. The most comprehensive improvement programs were detailed by northern European countries such as Finland, Germany and Sweden as well as France, mainly for timber and pulpwood species. In Finland breeding is managed by the Finnish Forestry Research Institute in six regions with activity is focussed on improving productivity, wood quality and improved climatic adaptation in the two main native timber species, *Pinus sylvestris* and *Picea abies* (which together comprise over 90% of the Finland's annual reforestation area). These two conifers are included in the programs of many northern and central European countries with programs reported by 11 or more countries for each species. Sweden's comprehensive breeding programs involve intensive plus tree selection in collaboration with forest owners, large-scale controlled crossings and evaluations, on 7 to 24 breeding populations for each major species. The massive impact of the tree improvement work in and deployment of improved germplasm is indicated by the projected annual increase in 10 million cubic metres of wood from planted improved germplasm of *Picea abies* and *Pinus sylvestris* in Sweden. Several other coniferous genera/species are included in breeding programs in Europe including *Larix* spp. (5 countries), *Abies* spp (2), *Cedrus* spp. (3), *Taxus baccata* (2) and the north American conifer *Pseudotsuga menziesii* is included in six improvement programs. Species in many broad-leaved genera are also being improved in several countries, mainly for increased timber production but also for bioenergy and environmental services. These include *Betula* spp. (6 countries, mainly *B. pendula*), *Fagus* spp. (6, mainly *F. sylvatica*), *Populus* (6; especially interspecific hybrids), *Quercus* (6, mainly *Q. petraea*), *Prunus avium* (5), *Ulmus* spp. (4), *Alnus glutinosa* (4), *Fraxinus excelsior* (4) and *Juglans regia* (4). A different suite of species is under improvement around the Mediterranean including more drought tolerant tree species such as *Pinus brutia*, *P. halepensis, P pinaster* and

Quercus suber. France's tree improvement programs include long distance inter-specific hybrids in three genera, viz. *Larix* or larch hybrids (between European and Japanese species), *Populus* or poplar hybrids between European and American species, and *Juglans* or walnut hybrids between European and USA species, highlighting the importance of past and ongoing germplasm exchange for tree improvement programs in the northern Hemisphere. The role of the DANIDA Forest Seed Centre in assisting development of tree improvement programs throughout the developing tropics over the past forty years is noteworthy, as are contributions from donors and tree breeders and geneticists in other European countries, including Finland, France, Germany and the United Kingdom.

Latin America and Caribbean

Well-developed tree improvement programs are found throughout Latin America, especially for species in the industrial plantation genera, *Eucalyptus* and *Pinus,* although several smaller countries such as Panama do not have improvement programs and may be reliant on importation of improved genetic materials such as for *Eucalyptus, Pinus* and *Tectona*. Brazil's improvement program for *Eucalyptus* is especially noteworthy based on considerable species/provenance selection work, family evaluation and hybrid development, resulting in some of the fastest growing plantation trees in the world with individual clones of *E. urophylla* x *E. grandis* growing at more than 100 m^3 per ha per year. In addition to *Eucalyptus grandis* and *E. urophylla*, there are improvement programs for *E. camaldulensis*, *E. globulus*, *E. nitens* and *E. tereticornis* and hybrid combinations in several Latin American countries as well as several other eucalypt species, such as *Corymbia maculata* in Peru (pp35-36) and *Eucalyptus dunnii* in Argentina. Major improvement programs are undertaken for *Pinus* species in several central and South American countries, with the largest program being for *Pinus radiata* in Chile, initiated over forty years ago and now into its third or fourth generation and involving more than 1,300 trials (including other *Pinus* species notably *P. ponderosa*). Argentina's pine breeding efforts are focussed on the two main planted species, viz. *P. elliottii* and *P. taeda,* their and hybrids. The germplasm of several *Pinus* spp. (*P. caribaea* var. *hondurensis, P. maximinoi*, *P. oocarpa* and *P. tecunumanii*) has been collected in Guatemala and subjected to breeding by CAMCORE members outside Guatemala, and more recently this material and information is being used for pine breeding in Guatemala. For species in other genera the main focus in tropical Latin America has been on often fast growing exotic timber trees such as *Acacia mangium, Gmelina arborea, Grevillea robusta, Tectona grandis* and *Terminalia* spp. Argentina and Chile have improvement programs for *Populus* species and hybrids. A more recent trend has been the development of improvement programs for diverse native species. In Brazil and Peru one focus has been on indigenous fruit trees, especially in the myrtle (*Acca*, *Campomanesia, Eugenia*, *Myrcianthes, Myrciaria dubia* and *Psidium*) and palm (e.g. *Bactris gasipaes* and *Butia*) families, but also legumes (e.g. *Caesalpinia spinosa, Inga*), custard apples (e.g. *Rollinia*) and stone fruits (*Prunus serotina*). A host of tropical American timber species such as *Alchorneoides hieronyma*, *Alnus acuminata*, *Cabralea canjerana, Calycophyllum spruceanum, Cedrelinga cateniformis, Cordia alliodora, Dipteryx panamensis, Guazuma crinita, Jacaranda copaia, Ochroma pyramidale, Parkia multijuga, Roseodendron donnell-smithii, Schyzolobium* spp., *Swietenia macrophylla*, *Terminalia* spp. (including *T. amazonica*), *Virola* spp. and *Vochysia* spp. (including *V. guatemalensis*) now feature in various of Costa Rica, Ecuador, Guatemala and Peru's improvement programs. In Chile four native timber species of *Nothofagus* and *Laurelia sempervirens* are undergoing improvement, while in Argentina the focus of improvement on native species is *Nothofagus* (*N. nervosa* and *N. obliqua*) for timber production, and *Prosopis* (*P. chilensis* and *P. flexuosa)* both for wood production and recovery of degraded lands.

Near East

There has been only limited tree breeding in near Eastern region, which is surprising given the need and potential to improve environmental adaptability to arid environments. Tree improvement in Iran is being conducted on *Fagus orientalis*, *Populus nigra* and *hybrids* and *Quercus castanifolia* for various product traits (for timber, pulpwood, NWFPs) and resistance to environmental stresses such as drought and salinity. Other species under improvement in the Near East include local acacias (*Acacia senegal, A. nilotica, Faidherbia albida*) and the exotics *Eucalyptus camaldulensis* for wood production and *Jatropha* curcas for biofuel.

North America

The USA has an exceptionally well developed tree improvement program with at least 150 public or cooperative breeding programs, representing over 70 species. There are 66 breeding programs involving 14 *Pinus* species, including *P. strobus* (11 programs), *P. taeda* (10), *P. ponderosa* (6), *P. elliottii* (5), *P. palustris* (4) and *P. rigida* (4 including two hybrid programs with *P. taeda*). Among other coniferous genera there are seven programs for four *Larix* species, six programs for three *Picea* species*,* six programs for *Pseudotsuga menziesii*, and four programs for three *Abies* species. Amongst broadleaves most breeding effort is focussed on *Quercus* with 18 programs for seven species including six programs on *Q. rubra*, and on *Juglans* with a total of 12 programs for *J. cinerea* and *J. nigra*. Many breeding programs are part of the USDA Forest Service or else based in universities which often lead the cooperative breeding programs. These tree improvement programs involve traditional techniques, often pioneered in the USA, and the whole array of modern breeding approaches and biotechnologies, including genetic engineering. Canada has major active tree improvement and breeding programs in seven of its eight provinces covering 30 species (22 native) in 13 genera and hybrids *Larix* and *Populus*. Key target species for improvement are native conifers for timber and pulp production including *Callitropis nootkatensis*, *Larix* spp., *Pinus* spp. (*P. banksiana, P.contorta, P. maritima*, *P. strobus*), *Picea glauca*, and *Thuja plicata*. First-generation programs are composed of more than 50,000 plus trees selected predominantly from the natural forest. Second-generation programs are in place for 14 species, and breeding populations contain more than 9,000 selections made from progeny tests and other tests. Third-generation selections have been made for *Pseudotsuga menziesii*. Mexico has a substantial tree improvement program, mainly in early stages and focussed on timber species of native origin. Native species under improvement include *Cedrela odorata, Cupressus lusitanica, Jatropha platyphylla, Pinus* spp*. (P. douglasiana, P. greggii, P. leiophylla, P. oocarpa, P. patula, P. pseudostrobus*)*, Swietenia macrophylla* and *Taxus globosa*, plus well-known exotics *Gmelina arborea, Hevea brasiliensis* and *Eucalyptus camaldulensis.*

South West Pacific

Tree improvement and propagation programs in Australia are highly developed and variously undertaken and managed by Government agencies (CSIRO and State Departments), individual industry members and/or cooperatively. These improvement programs mostly rely on traditional methods of selection, breeding, improvement and propagation. Molecular markers are being developed and applied to accelerate selection of preferred varieties through association of traits of interest with particular molecular markers. Species currently under improvement include native species, for timber, poles and pulpwood especially eucalypts (23 species of *Corymbia* and *Eucalyptus* and various hybrid combinations), native conifers (*Araucaria cunninghamii*), acacias (A*. crassicarpa* and *A. mangium*) and *Grevillea robusta*; essential oil species (*Backhousia citriodora*, *Eucalyptus polybractea* and other oil mallees*, Melaleuca alternifolia*, *Santalum album*) as well as exotic timber trees (*Khaya senegalensis, Pinus brutia, P. caribaea* var. *hondurensis, P. elliottii, P. pinaster, P. radiata* and *Tectona grandis*).

The larger Pacific Island nations and territories of Melanesia each have established tree improvement programs often with assistance from Australian institutions (CSIRO and Universities) and donors, and in the case of New Caledonia from French institutes (CTFT/CIRAD). The species under improvement vary but are mainly high valuable timbers such as the exotic *Swietenia macrophllya* in Fiji, native sandalwoods in Fiji, New Caledonia and Vanuatu, and multipurpose nut and timber trees such as *Canarium* spp. and *Terminalia catappa* (Solomon Islands and Vanuatu). Noteworthy is the spectacular improvement of teak (*Tectona grandis*) in Solomon Islands that has taken place in a short period through an intensive screening of teak stands in the early 1990s, grafting of 50 selected phenotypes and use of seed from this clonal archive for production purposes. This teak material is now being widely used globally including through selections supplied to Malaysia. Through the AusAID - SPRIG project, improvement activities have extended to promising indigenous timber species including *Cordia subcordata*, *Gmelina moluccana, Pterocarpus indicus*, *Terminalia catappa* and *Vitex cofassus* (Solomon Islands, p38-39). In PNG, collaboration with international and regional agencies and donor support have been vital for activities such as seed collections, provenance trials, seed orchards and tree improvement, and these need to be continued on longer term basis (e.g. expanded and large scale multipurpose provenance trials of promising native species p 38 building on an ACIAR funded collaborative project between PNGFRI and CSIRO). Fast growing industrial species under improvement include balsa or *Ochroma pyramidale* in PNG and *Pinus caribaea* var. *hondurensis* in Fiji and New Caledonia.

International collaboration and donor programmes (including Importance of international germplasm transfer)

International collaboration occurs through networks, commercial exchange, academic and research institutes, and donor assistance. Donor programmes may provide aid by assisting establishment of improvement programmes within a country. This may be especially beneficial where improvement is targeted at rural communities and others whom the private sector may not service adequately. The role for regional coordination and cooperation is especially vital where species, biogeographic and genecological zones are shared. The central role played by FAO and IUFRO-coordinated international species networks, such as for poplars, teak, neem and casuarina was often noted in country reports. Several countries acknowledged the vital role played by CAMCORE in the development of improved exotic plantation species, through the sharing of germplasm.

Improving the ease with which genetic materials are transferred internationally is essential for continued genetic improvement of a number of key commercial forestry species. Exchange of materials needs to be governed by legal agreements for fair and equitable sharing of benefits, in line with international agreements (Nagoya Protocol, CBD). Benefit sharing may involve profit sharing, access to any improved materials, technology exchange, contribution to *in situ* conservation projects, assistance with other programmes. Whilst under the CBD FGR are recognised as the property of sovereign nations, in Papua New Guinea they are considered under constitution to be the property of the traditional customary landowners whom own 97% of the land and are increasingly preventing access to FGR for research purposes. PNG has a history of exchanging and supplying seeds of indigenous and exotic tree species, both for research and commercial purposes, and mechanisms for securing additional benefits including development of a materials transfer agreement (MTA) with the Secretariat of the Pacific Community and others.

A cautionary note - Potential threats to FGR from breeding and improvement programmes

While the benefits of commercial genetic improvement programmes are extremely great, and vital for the meeting the ever-increasing global demand for forest products, there is also the potential for breeding programmes to have negative impacts on FGR if not managed well. The most significant issue is the loss of genetic variation in improved tree stock that is then widely distributed, potentially around the globe. Sweden notes: '… forest tree breeding may in the long run result in a decreased genetic variation in the production forest. Even though single stands may have a somewhat higher genetic variation, genetic diversity will likely on the landscape level be lower than in conspecific natural populations.' Clonal plantation forestry is regarded as the most genetically impoverished industrial forest option, especially where the entire plantation is derived from only one or a very small number of clones. Concentration on one or a few economically important trees in plantations is also risky and can contribute to loss of FGR: for example 90% of Ghana's plantations are comprised of only three species.

Summary

In summary tree improvement activities have mostly been limited to a small number of economically important, more widely planted tree species, due to financial constraints and because of their specific biological characteristics, viz. most trees are long-lived perennial species with long rotations (usually more than 10 years except for pulpwood and biofuels) and regeneration cycles, and late sexual maturity. Because of these characteristics, improvement and breeding research in tree species often requires many years and considerable resources (trained personnel, finances, land and laboratories). Accordingly there is a need to develop and promote the use of emerging technologies, such as genomics and micropropagation, which can accelerate the tree improvement process and help unlock the huge potential of planted forest trees.

2.4.5 Germplasm delivery and deployment (D&D)

The production, distribution and deployment of germplasm and planting materials is critical to the continued global supply of FGR-derived goods and services and the development of forest industries, as well as playing vital roles in programmes for the conservation of FGR, biodiversity and environmental restoration. It is estimated that forest plantations account for 7% of the world's forest area yet produce over 50% of the globe's industrial timber (FRA2010); further forest plantings, particularly using improved germplasm, will help satisfy burgeoning global demand while reducing harvest pressure on natural forests. As noted in the China report, 'the ultimate goal of FGR conservation is to utilize these resources, and to bring economic, ecological and social benefits'; the

USA similarly remarks 'if germplasm is not readily available for use, resources expended to preserve it will be wasted'.

Uses of germplasm and plant materials

Genetically appropriate germplasm is used as a base for propagating planting materials for the wide range of uses highlighted earlier in this report, including forest plantations for timber and pulp, agroforestry and fodder, food, fuel, farm and other *circa situm* plantings and the alleviation of poverty. The deployment of germplasm with appropriate levels of variability is an essential component of many FGR and biodiversity conservation programmes, as well as environmental restoration programmes, research and development.

Prioritising for delivery and deployment

As noted earlier, priorities for the delivery and deployment (D&D) of FGR and improved genetic materials are best established at a national level, in national strategies for forests and FGR conservation and management, coordinated with other relevant strategies. Priority objectives include addressing commercial/utility goals, conservation of FGR and biodiversity goals, and development, social and economic goals. Focal areas include development of plantation industries; developing local, small-scale industries and employment; assisting rural communities; contributing to the alleviation of poverty; reducing harvest pressure on natural forests; promoting environmental and restoration plantings; combating desertification, and preserving genetic variability and conserving threatened species. More specific aspects of delivery and deployment programmes include genetic traits, wood or other production characteristics, genotypes, populations, species, improved varieties, planting locations, and sectors of the economy and society identified for development or assistance. The private sector prioritises species, locations and management regimes for deployment on the basis of financial returns (in which government regulations, incentives and support may play a role), which are in turn determined by market conditions, structure and demand.

In developing countries it is important that delivery and deployment of plant materials is matched with areas of most need, particularly given the importance of trees in alleviating rural poverty. For example in countries where fuelwood is a major source of energy, then improvement, production, distribution and deployment of multipurpose and fuelwood species may be considered a priority. The need to more effectively match plant materials with their intended purpose was remarked in several country reports: China noted that market signals may help in the deployment of appropriate plant materials.

A number of countries, often in collaboration with ICRAF, facilitate alignment of selection, improvement, production, deployment of FGR with community needs through a participatory approach involving engagement of rural communities, farmers and villages. This approach is especially advantageous where markets are non-existent, poorly developed, or do not function effectively, for example due to poverty, lack of purchasing power, lack of market infrastructure, or lack of market signals and information.

Production of germplasm and planting materials

Countries varied greatly in the amount of germplasm and planting materials deployed, ranging from negligible (e.g. many SIDS) to extremely high for countries with major planting programs such as Brazil, China and Indonesia– for example Brazil has a huge demand for planting stock, developing 330,000 ha of plantation per year between 2005-2010. Some countries noted a paucity of information on demand for germplasm, although projected demand for wood products invariably indicated an increase in requirements with shortfalls in supply under current stocking and planting rates. National programmes requiring planting stock include for forestry plantation development, combating desertification, landscape-scale climate change adaptation and mitigation plantings, environmental rehabilitation and restoration following major infrastructure projects.

The approach to management of a country's production forests in large part determines the demand for germplasm and planting materials – for example, a forestry industry based on plantations or other artificial plantings will deploy more germplasm and plants than one reliant on harvesting naturally regenerated forests. Several countries, especially in Asia-Pacific region, refrain totally or in large degree from harvesting their natural forests (e.g. Samoa, Sri Lanka, Thailand), with local timber derived from planted sources; accordingly demand for well-adapted and improved germplasm and planting materials is proportionately high. Many countries, particularly in temperate and boreal regions, adopt hybrid management models, employing a mixture of artificial and natural regeneration of native forests and plantation development. For example Canada, the world's third largest exporter of wood products, is required by legislation to regenerate logged forests either naturally or artificially, such that 400,000 ha are planted annually, with 50% of the stock derived from genetically improved seed. In some countries availability of low-cost, high quality timber resources in natural forests has served as a disincentive to invest in development of improved germplasm and plantations, with reliance on utilising the natural capital contained in native forests reducing the demand for germplasm and planting materials.

Germplasm used by countries as base material for propagation is selected or improved to varying degrees, held in a variety of propagative resources and facilities, including: a) unimproved but selected forest seed stands, b) seed, cutting and clone orchards of phenotypically selected or genetically improved genetic materials ; and c) seed and vegetative materials from individual trees in *circa situm* situations. Seed stands 'are identified and delineated in natural stands or plantations with a high frequency of phenotypically good planting materials', while seed orchards are plantations of selected trees, clones or progenies 'which are isolated or managed to avoid or reduce pollination from genetically inferior sources outside the orchard, and intensively managed to produce frequent, abundant, and easily harvested crops of seeds…a seed orchard…can also be regarded as a breeding population as basis for further tree improvement' (Philippines p39). Vegetative materials for propagation from grafts, stem cuttings and micro-cuttings may be sourced from selected clones or seedlings. Cloned materials are favoured for plantations, due to the ability to produce true-to-type, genetically uniform plants from improved material, and are especially useful for utilizing heterosis in F1 interspecific hybrids. In many countries, small-scale or individual producers may select seed informally; both for use in their own enterprises or for sale and the implications of this are discussed below.

Country infrastructure for the production and distribution of tree germplasm and planting materials not only includes the above-mentioned propagative resources, but also the organisations, enterprises and facilities dedicated to germplasm collection, storage, propagation and distribution, such as government agencies, national tree seed centres (NTSCs), private corporations, public and private sector nurseries, community associations and villages, and individuals. This is discussed in more detail in the following section. Other crucial components include human and organisational resources – expertise, personnel, funding, and political support. Markets for forest products and germplasm, both formal and informal, also play a vital role in many countries.

Country reports described great variation in the extent of their germplasm and plant production capacities, reflecting the variables mentioned above and exemplified below.

Country examples

With its immense areas of plantings, China has a vast demand for planting materials of many types, and reports a remarkably extensive and decentralised network of 336,000 tree seedling nurseries covering 668,000 ha. Tree nurseries in China source their propagation materials from a) 19,600 ha of improved seed orchards comprised of progeny tested superior families, selected plus trees and introduced superior families yielding an average of 0.71 M kg/yr of seed; b) 18,100 ha of improved cutting orchards of bred and introduced superior clones of various species yielding an average of 1.8 billion seedlings annually; c) 146,000 ha of superior seed stands yielding 1.67 M kg/yr, and d) 630,000 ha of 'seed collection bases' of superior provenances of several species and genera yielding 9.3 M kg/yr. Major national forestry programmes in China need to increasingly make use of improved genetic materials; however most of the seed orchards and stands are first generation and quality was considered to be low. Other Asian countries reporting significant productive capacity and plant production included Indonesia, producing 29 million kg of seed annually from 104,000 ha, through the Department of Land Rehabilitation and Social Forestry, and India producing 3.8 million kg of seed of 27 species, and plants 102 million seedlings annually; India has 396 seed orchards covering 7090 ha (64% of which is teak).

In Europe, Germany has 425 forest tree nurseries producing 150-185 million plants annually, and 800 ha of seed orchards, including 215 for tree species. In Poland about 90 per cent of the currently established forest plantations come from planting or sowing; there is also a major import of tree seed, but export of tree seedlings. Several European countries, such as the Russian Federation rely heavily on natural regeneration of their forests.

The Republic of South Africa with its commercial plantation industries produces 200 million plants from 37 nurseries, almost all *Pinus, Eucalyptus* and *Acacia.* In Ethiopia the government through the Forest Research Centre is the sole supplier of tested seeds in the country, distributing 7.2 tonnes of seed capable of producing 570-880 million seedlings. In many other African countries seedling production was much lower; for example Madagascar's national tree seed centre nursery produces 250,000 plants per year. Most small developing, tropical countries would typically have less than 5 or 10 nurseries producing tree seedlings for production and environmental plantings.

The Ethiopian report describes its germplasm production and utilisation system, demonstrating elements that are common to many developing countries, particularly those with large informal sector involvement and a multiplicity of actors, including the public sector:

> *'Forest germplasm has considerable benefits to many small-scale farmers and other private seedling growers and forest owners. Small-holder farmers collect and plant seedlings or sow*

seeds of various trees for their own use or for sale. In central and south western part of the country, farmers grow germplasm of agroforestry trees in rows, in patches as woodlots, or scattered on farmlands, farm boundaries, and pasture lands. The most common tree/shrub species include Acacia albida, Arundinaria alpina, Acacia abyssinica, Acacia tortillis, Croton macrostachys, Albizia gumifera and Cordia africana….Local communities especially the youth are being benefited from production and sale of seedlings of certain forest species. In different regions of the country, many small holder farmers, youth, women and other private seed dealers/nursery operators are engaged in forest germplasm business. In Ethiopia, forest seeds/germplasm movement involves a range of stakeholders from governmental, non-governmental organizations, local people, private seed dealers, and nursery operators. There is no restriction regarding the movement of germplasm within the country. The sources of the germplasm/seeds supply are farmers, private seed dealers, and FRC [Forest Research Centre]. The seeds often obtained from the informal seed sources are of low quality and quantity. FRC is the only supplier of tested forest tree seeds in the country. It collects the forest germplasm from identified and established stands. The center sells the forest germplasm collected from the stands to governmental organizations mainly bureaus of agriculture, NGOs and private seed growers.'

Meeting increased demand for germplasm and planting materials

The previous section noted the need for large amounts of germplasm and planting materials in many countries, with nearly all expecting increases in demand for planting materials and a projected shortfall in supply, given current production levels and capacity. There is therefore a need to boost production to fill the gap. Ethiopia identifies a need for '…strengthening the tree seed production-supply system for satisfying needs for quality seeds and collection and conservation of germplasm'. The Philippines report remarks that '…the fundamental problem to be addressed at this point is the lack of supply of improved planting materials for production purposes, and of planting materials for conservation of endangered indigenous and other forest genetic resource'. Madagascar similarly notes the need for large-scale, low cost production of planting materials for forestry and mining restoration projects. In the Zambian report a 38% reduction in area of plantations since 1982 is in part attributed to 'reduced national capacity to produce sufficient good quality *Pinus* seed for plantation establishment'; and 'due to a critical shortage of good quality pine seed, seed is at present being imported from Asia and other places, and used for plantation establishment without any screening in provenance or progeny trials…. The quantity and quality of exotic tree seeds of *Pinus* and *Eucalyptus* species collected annually by the Forestry Department has declined from 250 kg of seed in the 1970s to 25 kg in 2010.' The priorities for action implied by these needs are recognised by SP13 and SP14.

To meet these shortfalls in supply of planting materials, a number of countries expressed an interest in developing their capacity for undertaking advanced propagation techniques including cloning, offering the prospect of producing large numbers of genetically identical improved planting materials at a low cost. Advanced propagation techniques, such as *in vitro* micropropagation and somatic embryogenesis, may also assist a range of FGR conservation programmes, particularly where the species involved are difficult to propagate or for mass propagation of superior seedlots. A cost-effective, low technology approach to boosting the supply of plant materials, both from seed and vegetative means, involves encouraging production by small producers, communities, villages or farmers, using participatory methodologies.

The lag time for seed orchards to produce improved seed is a constraint on the delivery of improved germplasm for deployment, often necessitating the continued use of unimproved seed. Advanced techniques in breeding and propagation, including for example increasingly powerful selection based on QLTs and marker-aided selection, grafting, micropropagation improvements/bioreactors, somatic embryogenesis, application of hormones/chemicals to promote early flowering in seed orchards, may shorten the time between improvement and deployment.

Actors involved in distribution and deployment

As discussed below, in many countries vast amounts of tree seed and seedlings are produced from seed stands, seed orchards, nurseries and other facilities on public forest or land, with public sector agencies and seed centres central to the exchange, delivery and deployment of germplasm. In some contexts the private sector is preeminent, generating large amounts of germplasm and plant materials for use in the corporate plantation forestry sector. In most developing countries, and some developed countries, small-scale and individual seed collectors and producers also play key roles, producing tree germplasm and planting stock for their own use or for sale, down to the level of the community, village or individual landholder/farmer.

Public sector

Public sector departments, agencies and corporations with remits in forestry, conservation, natural resource and land management may play major roles in the production, distribution and deployment of FGR materials, especially in developing countries where markets are poorly developed or do not function effectively[8]. This is consistent with the view expressed in the PRChina report that the '…collection and conservation of FGR is a basic, long-term, public welfare and strategic work'. The materials produced may be used for the advancement of national development and other policy goals, such as the alleviation of poverty, climate change mitigation, biodiversity conservation, environmental protection and both small and large-scale industry development. Public sector involvement in germplasm delivery and deployment includes the ownership of forest resources and land used for collection of germplasm, the creation of seed orchards, and the establishment of plantations; the sector also plays a vital role in the development of policy governing germplasm development and deployment, for example setting standards, and mandating and overseeing certification schemes for the production, movement and exchange of forest germplasm and planting materials .

Foremost amongst the public agencies involved in germplasm delivery and deployment are the National Tree Seed Centres (NTSCs) or their equivalents, which in many countries serve as primary agents for the collection, storage and distribution of forest tree germplasm to government forest and conservation agencies, and the private sector including nurseries, forestry companies, NGOs, communities and farmers. NTSCs are also typically involved in transfer and exchange of germplasm regionally and internationally. NTSCs may also play central roles in *ex situ* conservation and

[8] Lack of markets may be due to the type of political and economic system, inability of commercial operators to generate income or capture rewards from an activity, lack of regulatory, legal and financial infrastructure, or lack of capital.

improvement of FGR. Public nursery facilities, either associated with NTSCs or attached to other public bodies, are significant producers of plant materials, as evidenced in a number of country reports. NTSCs and public nurseries may also generate funds through germplasm or plant sales, consultations and/or supply of contracted services to the private sector, locally, regionally or internationally. For example, Madagascar's National Tree Seed Centre sells, 60% of its production to the private sector and NGOs, with the remaining 40% purchased by government agencies. Examples of countries in which NTSCs currently play major roles in germplasm delivery and deployment include Australia, Burkina Faso, Ethiopia, Kenya, Madagascar, Nepal, PNG, Sri Lanka and Zimbabwe. There are exceptions such as Guatemala's NTSC which under existing legislation cannot produce germplasm for commercial purposes while facilities and resourcing of NTSCs are inadequate in many countries (including much of Africa and most SIDS). The need to increase the productive capacity of tree seed centres to meet existing and projected demand for germplasm was noted often in reports.

Many public agricultural agencies have long-standing involvement in the production and distribution of improved plant materials, reflecting the long-recognised value and practice of using such germplasm. In some countries these agencies also develop and propagate trees to be used in agricultural applications, and in some cases they may play a major role in the *ex situ* conservation, distribution and deployment of FGR itself. This is particularly so where a country's native FGR includes many progenitors of widely used fruit and nut trees, for example apple, pear, peach, almond, pistachio, chestnut and walnuts that are widely distributed and/or originated in the Caucasus, Central and West Asia, or where food- or crop-bearing trees are important cash crops or contribute to food security. In some countries with meagre resources, this may be an effective way to achieve at least some level of *ex situ* conservation, storage and distribution of forest germplasm. There may be opportunities for greater cooperation and harmonisation of effort between agricultural and forests-based agencies, and such cooperation may be especially beneficial in countries where resources for FGR C&M are highly limited.

In summary, country reports detailed major involvement of the public sector in collecting, storing, propagating and distributing germplasm for purposes of:

- Conservation of FGR, including genetic diversity in threatened or potentially threatened species
- Research and tree improvement by local, national and international organizations (both public and private)
- Supplying planting materials to government agencies, corporations, NGOs and individuals
- Undertaking forest plantation development on public land
- Environmental restoration programmes
- Distribution of trees to assist in the alleviation of poverty.

Higher order public sector activities in germplasm D&D included:

- Facilitating and regulating private sector involvement in FGR D&D, including facilitating and participating in organisations and associations concerned with germplasm D&D
- Developing policy and enacting laws and regulations governing germplasm collection, delivery and deployment
- Developing, implementing and enforcing standards, guidelines and protocols.

The private sector

The private sector undertakes germplasm improvement, collection, storage, propagation, distribution, delivery and deployment for use in its own commercial forestry activities, or in some instances for sale on the open market; this may include ornamental and rare plants, with implications (both positive and negative) for threatened species. Increasingly the private sector is the primary actor in germplasm D&D, with producers propagating and deploying vast amounts of germplasm and plant materials for their own use or to supply contracts. Actors in the private sector include local and multinational companies, small-scale enterprises, communities, villages, and farmers.

Private sector participation in germplasm D&D can complement public sector efforts where the role of the public sector is limited by funding, political will, institutional capacity, remit, and where it has difficulties engaging with market processes. Where markets operate effectively it can respond efficiently to market signals and demand for goods and services. Larger, particularly multinational, companies may have access to capital, technology and expertise that may be unavailable in developing countries, the deployment of which, if managed appropriately, can help advance national forestry, FGR and other development agendas.

The private sector exercises a major influence on germplasm D&D through land ownership. In many countries private corporations, small enterprises, communities, villages, families and individuals own or control significant proportions of the total land area. Private land may be used variously for establishment of private plantations or other forest plantings, in pursuit of commercial, environmental or biodiversity conservation outcomes. In other situations the private sector may access public land for collection of germplasm and establishment of plantations (e.g. Australia, Indonesia). Land ownership pattern will help determine the balance between public-private sector involvement in germplasm D&D and the manner in which these activities are conducted.

Small-scale producers, communities, farmers

In many countries production of germplasm and planting materials is undertaken by small enterprises, landholders or individuals; this expands the area of forest and farm plantings at the same time as providing rural employment and income which assists in alleviating poverty. For example, traditional home garden agroforestry practices in Ethiopia provide employment for many people, and propagation and exchange of plant materials are part of the fabric of rural life. Home gardens in Sri Lanka produce 42% of timber in the country, compared with only 11% generated by forest plantations, and 27% of the fuelwood compared to 4% for plantations; this highly decentralised informal system also produces much of its own plant materials. However resource-limited farmers on small holdings and other small scale producers in the informal sector often have little or no access to improved varieties. Furthermore, the decentralised nature and lack of resources of this informal plant-production and utilisation sector presents challenges to increasing the deployment of improved FGR.

Germplasm is collected by farmers, small scale seed producers or communities living nearby forests for propagation for use in farms, home-gardens, or for sale – in many cases consistent with centuries-old tradition and practice. Germplasm collection within these systems is generally nonselective, or with selection based solely on phenotype, for example harvested from a limited number of parent trees which may be related (half-siblings) and/or relatively isolated with high levels of inbreeding. Such germplasm is all too often of relatively poor genetic quality and contains low levels of variability. A Philippines study found that small-scale seed producers generally collected material from less than ten plants, inadequate for inclusion of sufficient variability, and Madagascar similarly notes that collection and production of seed by individuals is undertaken without attention to proper selection and collection from a minimum number of plants, and remarks that this may lead to loss of genetic variability. These practices present a challenge to the goal of increasing deployment of improved germplasm, and limit opportunities for genetic improvement and maintenance of variability of FGR. Where collection practices do not conform to national, regional, and international certification requirements (e.g. OECD), the ability of growers to sell into germplasm markets that demand this certification is limited.

As noted, access to appropriate germplasm and plant materials by the informal or community sectors in many countries is hampered by lack of appropriate germplasm and materials, lack of money to purchase materials, lack of information on the availability of germplasm and its benefits, poor promotion, logistical barriers to delivery, or failure of markets. Despite the difficulties of ensuring adequate variability is represented, ensuring quality and selecting appropriate material, there are major opportunities for the development, increased use, and production of improved germplasm within the informal sector. This is contingent on its participants gaining access to affordable appropriate materials, as well as information and assistance; government-run National Tree Seed Centres and extension services may have an important role in distribution of information, practice guidelines, and improved germplasm or plants, especially in developing countries where small-scale growers or individual farmers lack funds, and markets for improved FGR are non-existent or limited. This may be achieved through boosting community involvement in the production of seed materials: the Tanzanian report recommends 'strengthening farmer seed systems' and increasing their access to information to help consolidate their roles in conservation and promotion of diversity. Sri Lanka recommends incentives for increased plantings in home gardens, and development of a partnership approach to the production of high quality planting materials. Participatory models of selection, improvement and plant production may assist in increasing adoption of improved varieties.

The germplasm collection and propagation activities of the informal sector may also be improved through establishment and operation of grower cooperatives and associations. For example, in the Philippines the Agroforestry Tree Seed Association of Lantapan, a farmer association established in 1998 has been successful in educating many small seed producers in correct techniques producing to a standard that provides them with an assured market for their seeds. The assistance of community volunteers in propagating trees for conservation purposes is another avenue for production, distribution and deployment, in both developed and developing countries alike. In the USA, community volunteers have been sought to assist in the 'Seeds of Success' programme, while in the Seychelles the Division of Environment intends to mobilize people to participate in conservation of endemic tree species, firstly through growing indigenous trees.

Aspects and issues of private sector involvement in the germplasm D&D gleaned from examination of country reports include:

- It is responsive to market demand, although where demand is internationally driven private sector activities may not always be consistent with national strategies or programmes in the areas of forests, FGR conservation and management, and national development
- Requires adequate protection of intellectual property and reward (e.g. through sales) to encourage sharing of improved germplasm
- Requires stable investment environment
- There may be limited ability to deliver public goods and benefits for which markets are poorly developed or non-existent
- Tends to address ecological and social objectives only as required by regulation
- Improved materials deemed proprietary in nature may not be shared in interests of maintaining commercial advantage; sharing may occur through sales but this may be limited where markets do not exist or are limited for example through lack of capital
- It may be difficult to collect information on private sector germplasm D&D activities, due to commercial-in-confidence considerations and lack of a process for collecting and collating data on deployment and delivery

Joint public and private involvement in germplasm delivery and deployment

With the complex interplay of different, complementary, overlapping and competing roles of the public and private sectors, coordination and adopting a partnership approach to germplasm collection, storage, propagation, delivery and deployment is essential. Several joint approaches to delivery and deployment were mentioned by countries. Firstly, governments may offer incentives to the private sector for the production of quality germplasm and planting materials, particularly for activities consistent with national FGR, forests, conservation and other goals. Payments may be made to private suppliers directly: in Germany the owners of private forest stands or seed orchards from which seed is produced receive 'tenancy revenues'.

Secondly, associations and organisations with joint public and private sector membership may be created, to assist in data collecting, standardisation, preparation of guidelines and policy relating to FGR, including matters relating to exchange and deployment. This can greatly assist in coordinating the two sectors and advancing the FGR C&M agenda. Associations with joint memberships include the Canadian Forest Genetics Association, which promotes information exchange and sound practice and policy. Other examples are the USA's National Plant Germplasm System, which has both government and industry involvement and includes accessions of 87% of US tree genera; Chile's Cooperativa de Mejoramiento Genético, a joint enterprise that regulates, certifies and documents seed produced by its members, has been mentioned above, and Costa Rica has a co-operative tree improvement organisation (GENFORES), led by the Technological Institute of Costa Rica, involving 11 reforestation companies and local NGOs. Thirdly, specific initiatives may be devised and implemented jointly, such as the development in Germany of private seed certification schemes with input from private organisations, state and federal governments.

Finally,in some cases different aspects of the delivery and deployment system may be shared and/or divided between the public and private sectors: in Germany seed harvest and storage is undertaken by both private and public organisations, but the collection and long-term gene bank storage is undertaken by the state governments. In Iran government agencies may directly import and distribute seed or provide oversight of the private sector: '…all the seed imports and distribution is done either directly by the ministry of agriculture or by private companies after receiving permission from the Ministry'.

Form of germplasm and methods of producing planting materials for distribution and transfer

The form in which planting materials are delivered to end-users depends on the purpose of the planting programme, the characteristics of the germplasm, the nature of the planting situation, the method of propagation most suited to the species, the capacity for production of plant materials, and the capacities of the people or organisation undertaking the planting.

Germplasm is transferred for use in propagation, research and improvement, both internally and also internationally, and countries reported that material available for transfer was overwhelmingly in the form of seed, at 66% compared to the next highest category, scions at 12%. While seeds are generally the most convenient and safest method of germplasm transfer, they are not suitable for the collection, storage, propagation and distribution of germplasm for all species; reasons include inaccessibility of collecting materials, intermittent seed production, lag time between improvement and seed production, difficulties in ensuring progeny are true to type, limited storage ability (recalcitrant seeds), and lack of knowledge on propagation methods. Macro-vegetative propagation (cuttings and micro-cuttings) methods for producing clones are commonly used, and micropropagation (tissue culture) techniques are increasingly applied, although the cost and technical requirements of micropropagation make this prohibitive for some countries. Nonetheless industrial-scale production by micropropagation of some species of commercial interest or for large restoration purposes is being undertaken despite the high costs.

The predominance of seed as the most available form of germplasm for transfer within and between countries, suggests that distribution, deployment, and perhaps even research and improvement, may be skewed towards species producing orthodox seed that is most convenient to reliably transfer. This may be at the expense of other potentially useful species, or species requiring conservation, and underscores the need for further research and development of storage, propagation and transfer techniques for recalitrant and short-lived orthodox seeded species.

Use of improved and unimproved germplasm

The germplasm and plant materials produced for deployment may be either genetically improved or unimproved. For productive purposes use of improved material from genetic improvement and selection programmes enables the delivery of larger amounts of desired benefits with fewer inputs, or better growth under less favourable environmental conditions. For example, in Chile about 95% of planted forests of exotic species are derived from improved material, while less than 2% of natural forests have some degree of genetic improvement. FGR and biodiversity conservation and environmental rehabilitation programmes may also benefit from intervention and breeding to enrich genetically impoverished remnants, or to introduce characteristics vital to the survival of threatened species (e.g. introducing resistance to chestnut blight into North American chestnuts). By contrast, many programmes aimed at conservation of FGR require the inclusion of materials representing the fullest range of local genetic variability (whilst excluding importing germplasm from more distant provenances or other seed transfer/genecological zones).

Plant materials used for commercial and utility plantings and plantations are largely derived from high-quality, improved, source-identifed seed and plant materials. For the private sector, this is driven by the need to obtain an adequate return on investment, through obtaining the highest yield for the lowest cost. Public sector plantation programmes are driven by the need to maximise public benefit for the amount of public resources invested.

Movement and transfer of genetic material

Identifying regions of provenance, gene-ecological and seed transfer zones

The identification of regions of provenance and seed/germplasm transfer or 'gene-ecological' zones within a country, that is, areas possessing consistent bio-geographical characteristics to which local populations have adapted, facilitates the selection and deployment of appropriately adapted plant materials best suited to the local conditions. The deployment of germplasm from different, non-conforming gene-ecological zones may lead to the loss of adaptive advantage (including through potential genetic impacts on existing populations), as well as poor performance or at worst complete failure of the introduced material. Knowing the biogeographical origins of germplasm is also essential when transferring internationally for purposes of research and genetic improvement.

Two major schemes governing the transfer and movement of germplasm address of matching tree germplasm to planting sites. Firstly, the OECD Forest Seed and Plant Scheme 2012 requires the delineation of provenance regions (OECD 2012a p11). Secondly, the European Union Directive 1999/105/EC paragraph 5 which governs germplasm movement between EU members states that research shows 'it is necessary to use reproductive material that is genetically and phenotypically suited to the site', and that 'demarcations of regions of provenance are fundamental to selection' (paragraph 14) while paragraph 12 states 'native species and local provenances that are well adapted to site conditions should be preferred'. Article 9 requires the identification and demarcation of regions of provenance in order to facilitate exchange of germplasm between EU countries.

Several countries have identified their seed transfer or gene-ecological zones, partially or fully, and have focused their selection and tree improvement programmes on materials adapted to these zones as well as using them as the basis for determining the movement and transfer of germplasm. On the other hand many developing countries have not yet defined their gene-ecological zones, and neither identified nor developed appropriately adapted species and improved materials for planting in these zones (e.g. refs). Ethiopia identified the need for '…establishing and strengthening a system for the provision of indigenous and exotic tree species and seed inputs that are suitable for the different agro-ecological zones'.

As noted, a number of countries such as Germany adopt strict controls on the movement across gene-ecological boundaries/seed transfer zones; for other countries the focus is on identifying, selecting and developing FGR that will perform well in particular zones. India is developing a 'Seed Zoning' system, with the intention of obtaining legislative support to facilitate its implementation. 147 seed zones in 1978 were identified, although the initiative suffered from lack of regulatory support at the time. The implementation of seed transfer zones supports the development of appropriately adapted materials by tree breeders, through ensuring a market for their improved materials. However China notes that too narrow a geographic focus for development of improved materials may restrict their application and deployment. Some countries that apply the seed zone concept have yet to develop national guidelines for transfer within their borders. For example Canada, notes provinces develop their own propagation materials based on seed zones, often developed on the basis of provenance trial information, but that there is no national legislation or guidelines regarding transfer within the country. Poland has strict rules for the movement of forest reproductive materials within its borders for example through its FRM Act of 2001; these rules cover not just movement between regions but also the movement between altitudinal zones.

The need to select and breed trees better adapted to climate change, and to facilitate adaptation of local FGR through protecting and enriching the variability of local FGR, and perhaps undertake assisted migration for certain species to ensure their survival may require increased transfer of gemplasm as noted in Tanzania report. This may run counter to the strict enforcement of gene-ecological zoning approaches. Germany and other countries (e.g. Sweden, USA) propose that climate change will require the identification and use of species and germplasm adapted to new and rapidly changing conditions, which may differ from the materials identified to date as appropriate for existing gene-ecological zones. Germany is currently increasing its use of climate-change adapted species such as the introduced *Pseudotsuga menziesii*. Flexibility in the gene-ecological zone approach would be required to accommodate these changes, particularly while appropriately adapted species and genetic materials are being identified and developed.

The exchange and transfer of germplasm

While exchange and transfer of germplasm within and between countries occurs for purposes of planting or establishing a base for propagation of planting materials, it is also done for purposes of research, genetic improvement, breeding, and conservation of FGR - internationally, regionally, or within a country.

Internationally, the contribution of genetic materials to global research and breeding efforts to develop improved trees contributes to global economic progress, through facilitating the production of better adapted trees with superior performance characteristics and utility traits, able to produce goods and services more efficiently and cheaply. The exchange of germplasm allows countries lacking the capacity to undertake their own improvement programmes (e.g. Seychelles p42) to partner with or outsource to countries or external organisations with the relevant expertise and resources. International trade in germplasm and plant materials also allows countries to purchase improved planting materials to supply their forestry planting and development programmes. Furthermore, international trade in germplasm and plant materials is an important commercial activity in its own right: China, for example, exports over 300,000 kg of seed and several hundred thousand seedlings annually of over 400 species, and Australia also has a major international export seed trade mainly in *Acacia* and *Eucalyptus* species.

Phytosanitary, pest and invasive species risks accompany the transfer and exchange of germplasm and plant materials, and it is essential that these risks are minimised, including through development and implementation of guidelines for safe movement of tree germplasm (such as those as developed by FAO, IPGRI/Bioversity and DANIDA Forest Tree Seed Centre). Various mechanisms and regulations exist at international, regional and national levels to manage risks associated with germplasm transfer, although these may be limited in their application. Movement of germplasm and tree planting materials between jurisdictions at any scale (intra-country, regionally, internationally) may become problematic where the regulations and standards differ. Indeed, lack of harmonisation of regulations, standards and transfer protocols create barriers to the efficient exchange of genetic materials, and delays in the supply system may cause loss of viability in orthodox seed and complete mortality of desiccation sensitive, short-lived recalcitrant seeds.

Strict and legally binding materials transfer agreements (MTA) should be governing such exchanges to ensure the rights of suppliers are protected, for transfers both between and within countries. Suppliers may include countries, provinces, companies and traditional communities and germplasm owners. Canada's British Colombia Province has an MTA governing transfer of seed and breeding material ensuring ownership/custodianship is recognised and conferring limited rights for use for example for seed production.

Papua New Guinea illustrates some of these issues in transfer and exchange. The country has a history of exchanging and supplying seeds of indigenous and exotic tree species, both for research and commercial purposes, and has mechanisms for securing additional benefits including development of a materials transfer agreement with the Secretariat of the Pacific Community and others. Whilst under the CBD, FGR are recognised as the property of sovereign nations, under PNG's constitution they are the property of the traditional customary landowners who own 97% of the land, and landowners are increasingly preventing access to FGR for research purposes. A further example is provided by Brazil, which has a number of control mechanisms relating to the transfer and use of FGR: 'Any intended utilization of genetic material, native and exotic alike, must comply with specific laws and regulations. The import, export, research and improvement of plant genetic resources are regulated by phytosanitary, environmental, access, benefit-sharing and intellectual property legislation.'

Transfers of germplasm –patterns observed in country reports

Of germplasm reported in country reports as available for transfer nationally and internationally for either research or commercial purposes, national transfers were overwhelmingly for commercial purposes (87% of availabilities reported); this was reduced to 39% for international transfers. Conversely, transfers for research were low nationally at 13%, but comprised 61% of international transfers. These data reflect the importance of movement of germplasm within countries for commercial and utilisation purposes, and the major importance of international exchange and transfers for research purposes.

Countries in Europe recorded by far the greatest amount of availability for transfer nationally for commercial purposes, at 87% of all national commercial availability reports by region. This suggests well-developed internal markets in European countries for germplasm for commercial use, and/or an effective system of documentation of germplasm exchange incorporating the private sector.

Globally, countries reported a total of 412 different species available for national and international transfer, [Judith v3 tab 16a] although this is likely to be an underestimate as much exchange of tree germplasm, especially ornamentals such as palms, occurs through the private sector and not necessarily recorded in official figures. Latin America had the largest number of species available at 28 species per country, followed by Asia at 20 species per country and North America at 16. This is consistent with the focus on a small number of priority species of high commercial value noted earlier in this report.

Ensuring the quality of germplasm and planting materials

To give surety to purchasers of germplasm and allow vendors access to markets that require guarantees of quality, seed and plant materials may be quality-assured through international, regional and national certification schemes, involving adherence to procedural guidelines and protocols. Quality parameters may include source (e.g. geographic location or biogeographic, gene-ecological zone), whether the material is improved stock, the breeding generation, the level of natural variability represented, improvement in performance of desired characteristics, the collection protocols followed, phytosanitary criteria, and the quality and health of the seed lot or plant material batch including germination rates. Quality may be assured, increased and monitored through mechanisms including regulation, voluntary codes of practice, the use of guidelines, and producer education.

There are several regional and international mechanisms for quality control and certification, including, for example, those already mentioned above, the OECD Forest Seed and Plant Scheme 2012 and the EU Directive 1999/105/EC. The OECD Scheme governs international exchange of certified material, and ‘….has a major role in helping world forests adapt to changing climatic conditions’; it states that ‘…emphasis should be made on preserving species diversity, and ensuring high genetic diversity within species and seed lots thereby enhancing the adaptive potential of forest reproductive material for future reforestation and afforestation’ (OECDa 2012 p7). It specifies three categories of ‘basic material’ from which reproductive material can be selected, i.e. seed source, stand and seed orchard; reproductive material may be certified as a) *source-identified*, the minimum standard whereby location and altitude of collection is specified, with little or no phenotypic selection; b) *selected*, whereby material is phenotypically selected at the population level, and c) *qualified*, whereby material the components of the basic material have been selected at the individual level; however, evaluation may not have been undertaken or completed. There are three types of basic material recognised in the Scheme from which reproductive material can be collected, namely: seed source, stand and seed orchards.

Within the EU, germplasm exchange operates freely within and between members, consistent with the EU Directive 1999/105/EC; this directive relates to particular species and also provides a standard classificatory system for reproductive material. EU regulations allow members to import forest reproductive materials of ‘source identified’ and ‘selected’ categories from external third parties as long as the exporting country is approved under EU Directive 2008/971/EC; for example, if conforming to the OECD Forest Seed and Plant Scheme 2012 (EU Directive 1999/105/EC article 19; Germany p68). Suppliers of germplasm under the EU directive must be registered (article 6.4).

Various member countries of the EU have enacted laws to implement the EU directives on germplasm production and transfer. EU members may impose regulations if these exceed the quality requirements of EU Directive 1999/105/EC. Germany’s Act on Forest Reproductive Material (FoVG) governs activities relevant to production and exchange of germplasm of tree species, for example through encouraging the improvement of seed quality through certification. The Act specifies categories to describe forest reproductive material for exchange, and regulates the commercial production, marketing as well as imports and exports of forest reproductive material: production and sale of these materials is restricted to registered seed and plant material producers, and all materials must be approved.

International forest certification schemes such as the Forest Stewardship Council and Programme for the Endorsement of Forest Certification Schemes, which a number of countries have adopted, have elements relating to the quality, nature and genetics of germplasm and forestry planting materials. China has its own system for certification, having certified 2776 varieties, and has implemented a set of rules for use of improved forest trees, requiring their deployment in major forestry programmes, although take-up for was not as high as hoped due to lack of incentives for seed producers and users, and limited geographic applicability. In Denmark the promotion of improved genetic material by law requires approval, which is granted if the material is deemed above average. Madagascar categorises the sources it uses to produce seed consistent with OECD guidelines, i.e. assessed sources, selected stands and seed orchards; seed is tested to International Seed Testing Association standards. In other countries use of improved or preferred germplasm is encouraged rather than regulated, particularly where use by small landholders predominates; for example in Iran, '…although the use of recommended varieties by the farmers have been encouraged by the government, there is not any legal prohibition preventing them from using a farmer's variety.'

A number of countries reported having grower organisations or private-public collaborations involved in the preparation of guidelines, quality control and the certification and documentation of seed, consisting variously of public sector, academic institutions, large private companies as well as smaller seed producers. For example, in Chile the Cooperativa de Mejoramiento Genético, a joint enterprise established in 1975 involving public agencies, the private sector and a university, regulates, certifies and documents seed produced by its members. The example of the Lantapan cooperative in the Philippines shows how this may be achieved through the establishment and operation of a small holder, farmer-operated association.

Information management in transfer, distribution and deployment

The production and transfer of germplasm for research, breeding and propagation purposes requires excellent documentation, including quality control and source-identification. An efficient, comprehensive and integrated information system is essential for promoting, managing and monitoring the transfer, deployment and delivery of germplasm and planting materials. Indeed, some country reoports noted that a lack of knowledge of the availability and performance of both non-improved and improved germplasm held by NTSCs and similar institutions was a significant barrier to wider deployment of germplasm held in collections. Detailed, accurate information is for example required for certification of forest reproductive material under the OECD Forest Seed and Plant Scheme 2012 (OECD 2012), and the EU Directive 1999/105/EC. Poland, for example, has an extensive information management system documenting forest reproductive materials around the country. Information requirements of different schemes vary, and may include seed source and origin, provenance, region, provenance region/gene-ecological/seed transfer zone, performance with respect to desirable traits, number of parents, amount of variability represented, germination percentage, adherence to standards and certification schemes. Adequate documentation allows purchasers and users to verify that the material is true to type, fit for purpose, and whether it is putatively well adapted for the conditions into which it will be planted. Proper documentation also permits genetic material to be tracked; this allows a) data on performance of improved varieties to be collated for evaluation and research purposes; b) the plants to be used as a source of reproductive material of known origin at a later date – particularly important in the case of conservation plantings; and c) assists in assessing any impacts on native vegetation at the host site.

Adequacy of documentation may vary between countries and regions. For example, Germany's Act on Forest Reproductive Material requires the German states to maintain databases of seed stands, orchards, and clones registered under the Act, thereby providing both a degree of oversight as well as ease of access to site-appropriate, approved sources of germplasm. Iran notes that documentation, management and safe storage of data is a vital aspect of maintaining and sharing germplasm, and has a dedicated unit for data management and for dealing with germplasm requests. On the other hand documentation was identified as inadequate by a number of countries, who recognised the need to improve their information management systems in this area. In developing countries where resources are scarce and there are proportionately higher levels of informal germplasm production and exchange, documentation of forest germplasm is largely non-existent.

Some countries reported that they had information on breeding, delivery and deployment activities occurring within the purview of the public sector, but lacked information on what was occurring in the private sector. For these countries there is a need to integrate and harmonise documentation and data gathering activities between the sectors; industry organisations with comprehensive joint public and private sector membership, such as exist in Canada, may assist in promoting this practice. European countries developed a regional system to document the origins and track the movement of FGR; Brazil initiated its National System of Forest Information to amongst other things record the origins of improved material. This provides an example of a harmonised, integrated system that facilitates the international and regional transfer of germplasm. There is a need for thorough and effective, centralised information systems that document the origins and movement of germplasm and plant materials used in commercial, utility and conservation plantings, harmonised across jurisdictions and countries.

Management and adequacy of germplasm production, storage progagation and distribution facilities

Germplasm production and storage facilities require committed, ongoing management to maintain and operate effectively. Dry/cold seed storage facilities are subject to humidity, temperature fluctuations, floods, fires, insect attack and potentially catastrophic power failures (in absence of back-up generators). The need for replacement or repair of failing equipment was a significant impediment to the success and expansion of *ex situ* programmes and the operation of many NTSCs. Zambia mentioned that its seed is stored in deep freezers, '…as all the cold rooms need rehabilitation. A standby generator may need to be installed to minimize effects of power disruptions.' Zimbabwe noted intermittent power supply to cold storage rooms as a major challenge to their NTSC. Newer freezers with defrosting cycling produce fluctuating temperatures which considerably shorten seed life span, but this information may not be known on parts of the international tree seed community.

Seed and clone orchards require ongoing maintenance and management and are subject to threats including neglect, poaching, illegal harvesting and encroachment of agricultural and other activities. Political, social and economic stability are required for ongoing maintenance and operation of these facilities with several countries, including Cameroon and Zimbabwe, noting they had experienced decline or disruption due to these factors. The effective management of these facilities requires ongoing commitment of government funds or industry support, and/or adequate income from the sale of germplasm and planting materials. This highlights the potential risks of a single focal point for the production and distribution of germplasm – strategies to encourage safety duplication with widespread production by multiple organisations, companies or individuals reduces these risks.

International assistance

Many developing countries have received assistance from international partners, especially ICRAF, in building up their production, delivery and deployment systems. Establishment of the Mindanao Tree Seed Centre was facilitated with the assistance of the Australian Overseas Aid Programme; Thailand has received assistance in breeding programmes feeding into delivery and deployment programmes from Danida (Danish International Development Agency), Australia's CSIRO and ACIAR, and the ITTO, with some programmes dating back to the 1960's. CAMCORE has provided technical assistance to Guatelmala's Forest Guild and Guate Group in establishing seed orchards for several *Pinus* species (Guatemala p128). The importance of promoting international and regional assistance is recognised in SP 24. Tanzania has received assistance from the Gatsby Charitable Foundation in improving germplasm for plantations through cloning, with CAMCORE as a partner.

Increasing adoption of improved germplasm

In many countries the public bodies undertaking breeding and improvement such as the National Tree Seed Centres, research institutions, forests and agriculture departments and others may also undertake promotion, distribution, education and extension to ensure the deployment of their improved materials. The private sector similarly undertakes extensive improvement and breeding, for both its own plantings as well as for sale; in the latter case there is significant financial incentive to promote the uptake of their products. Indeed, countries with well developed genetic improvement programmes generally have relatively well developed methods of distributing and deploying their improved materials, whether in the private of public sectors.

Benefit sharing

Firm, adequate and enforceable benefit sharing arrangements are essential to ensure that the interests of the owners of any materials exchanged are duly recognised and receive an appropriate share of benefits. This is required to ensure that a) traditional and other owners of germplasm (or information contributing to the improvement of that germplasm) are treated equitably, and b) to allow developers of improved varieties and other suppliers of services to capture income generated from their investments and activities, providing incentive to.

Benefit sharing is conducted under provisions of treaties and agreements including the CBD, the Nagoya Protocol, and patent regulations where applicable. Most countries reported they were signatories to these agreements and the majority had patent laws in place, although these were not commonly applied to FGR.

Benefit sharing arrangements require a legislative and regulatory framework, and an effective bureaucracy and administrative infrastructure to implement and enforce any arrangements that are developed. China believes that to improve the development and uptake of improved varieties through more effective delivery and deployment '…a benefit-sharing mechanism needs to be established and improved. The lack of policies and regulations for protection of intellectual properties related to genetic resources, and the lack of effective mechanisms of sharing responsibilities, rights and interests between suppliers and users of the genetic resources, have led to [a situation where] the suppliers cannot benefit from the exploitation and utilization of the genetic resources whereas the users cannot get use right of the genetic resources.'

Country activities in transfer D&D

Countries reported transferring seed and vegetative material internationally (import and export) of a total of 534 different species. The African region reported the most transfer activity with 398 species, followed by Europe with 338. Nearly 19 times more species were transferred for commercial purposes than for research. In Latin America, Brazil describes a successful programme in which wild races of peach-palm were bred and distributed to over 80% of Latin-American farms now growing this high-value product. The USA undertakes restoration works for conservation purposes; its distribution and deployment approach includes arrangements with native plant nurseries, working with 'friends' groups that obtain native plant donations for restoration projects, and participating in large-scale cooperative multi-agency, state and private restoration collaborations. Opportunities for utilizing volunteers have been explored, through the national Seeds of Success program. In the South Pacific Islands, national priorities for improving the production, distribution and deployment of improved trees include strategies developed through the SPRIG project and SPC, to upgrade seed storage facilities and develop seed orchards; forest extension programs are also a focus.

<u>Priorities</u>

Priority matters from country reports for germplasm D&D, and including identified strategic priorities (SPs), included:

- Coordination of public and private sector activities
- Consider centralized organization to coordinate exchange of germplasm and data collection]
- Identify opportunities for coordinating germplasm collection, storage for deployment with ex situ conservation activities e.g. through tree seed centres
- Establishment of clear benefit sharing arrangements and use rights to promote production and deployment of improved trees
- Incentives for adoption and use of improved varieties
- Increase access to improved varieties by farmers, rural communities for use in informal sector
- Increase capacity for producing adequate numbers improved planting materials to meet demand

- Closer alignment of delivery and deployment with the needs of communities and market demand through better consultation, coordination, effective priority setting including participation of communities, development where appropriate of markets, and more effective response to market signals.
- Development and expanded use of consistent standards for collection, storage, of germplasm for exchange, distribution and deployment; promotion and advancement of or harmonization with programmes that already exist (e.g. OECD Forest Seed and Plant Scheme, EU Directive 1999/105/EC), at national, regional, and international levels; include promotion of common language and terminology
- Promote and reward production and exchange under preferred schemes and guidelines, while retaining the vigour of exchange in informal germplasm production and exchange systems in developing countries
- Development and promotion of appropriate certification systems and use of improved materials in informal germplasm exchange and production systems
- More effective integration of data bases including access to information about deployment in the private sector
- Promote improved fuelwood plantations to promote carbon-neutral energy sources and reduce degradation of natural forests and FGR, particularly for countries where wood is currently a major energy source
- Maintain genetic variability in the distribution and deployment process.

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