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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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DRAFT REPORT ON *THE STATE OF THE WORLD'S FOREST GENETIC RESOURCES*

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HIGHLIGHTS OF THE REPORT

This section provides the highlights of the report. It should be noted that the different draft chapters of the report have been prepared at different points of time. They will therefore have to be updated prior to the publication of the final report. However, the "Highlights of the Report" present key facts and findings as identfied as of 1 March 2013. Information and data provided in the different chapters may therefore in some case be different from the facts and key findings contained in this section.

OVERVIEW OF FOREST GENETIC RESOURCES

Chapter 1 covers characteristics of forest genetic resources (FGR), differences and similarities between trees and other organisms, the context of FGR management, main forest management systems (including agroforestry systems) - Economic, environmental, social and cultural values of FGR – Threats and risk status – causes of genetic erosion.

Key features of forest genetic resources

- Close to 1.6 billion people – more than 25% of the world's population – rely on forest resources for their livelihoods. The forest products industry alone is a major source of economic growth and employment, with global forest products traded internationally in the order of USD 186 billion, of which developing countries account for 20 percent in which forest based employment provides 32 million jobs
- Multiplicity of uses and management systems:
  - Commodities from forest trees and plants include a wide range of products (timber, fire wood, food fodder etc), which contribute to the economic development of countries and welfare of people.
  - Forests are important providers of environmental and ecosystem services
  - Forests and trees are subject to many different management systems, including agroforestry systems, with multiple objectives, production, protection, conservation, which are often combined
- Planted forests represent only 7 percent of the total forest area of the world (but produce 50 percent of the industrial round wood).
- The some 80,000 forest tree species are mostly wild, and managed in natural ecosystems. Biological characteristics and natural mechanisms maintaining high levels of genetic variation within species, combined with variable native environment make them the most genetically diverse organisms (between populations within a species and between individuals within populations).
- Dynamic *in situ* conservation of genetic diversity and processes is the preferred approach for conservation of genetic resources of many forest species (Conservation and sustainable use often combined).
- Internationally coordinated exploration and assessment of intraspecific diversity of economically important, broad range species started as early as 1907 (IUFRO *Pinus sylvestris* provenance trials) and were extended to many other species : temperate, sub-tropical and tropical pines, *Eucalyptus*

spp., tropical timber species (including *Tectona grandis* and *Gmelina arborea)*,multi-purpose tree species, etc.

- A relatively small number of species are widely-planted as exotic, and are economically important 'global' forestry species.

- Data from the Global Forest Resource Assessment (FRA) show that there are large differences in the proportion of planted forest consisting of exotic species in the regions of the world, from a very high proportion of exotics in Eastern and Southern Africa (100%), South America (97%), Central America (81%), Oceania (77%), Western and Central Africa (70%) through to very low proportion of exotics in North America (2%) and arid regions, such as Western and Central Asia (4%) and North Africa (7%). This data underscores the need for continued and increased international collaboration in the conservation, exchange and benefit sharing of tree germplasm and FGR.

<u>Key findings</u>

- Over 7950 species were mentioned in the country reports, among which 2207 species were identified as priority species (Figure 1). These figures are a confirmation of the extent of the forest genetic resources which are used and considered as important around the world. They also reflect the diversity of uses and management systems. Country reports included a broad array of species, frequently multipurpose, providing timber, non-wood forest products and services. Figure 2 illustrates regional differences in importance of species managed for non-wood forest products.

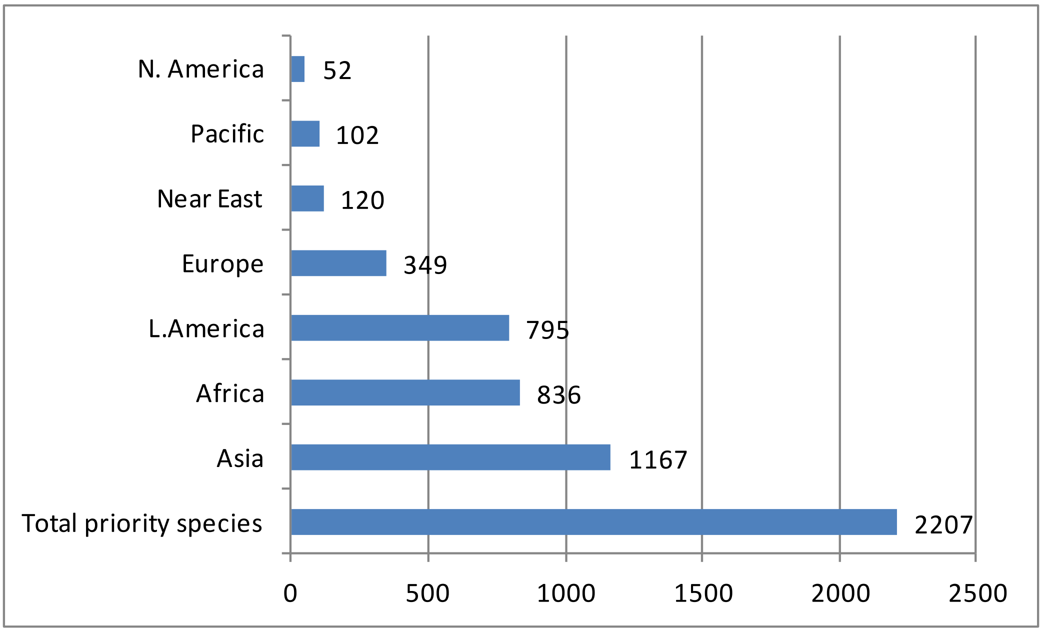

Figure 1: Number of priority species mentioned in the country reports, by region

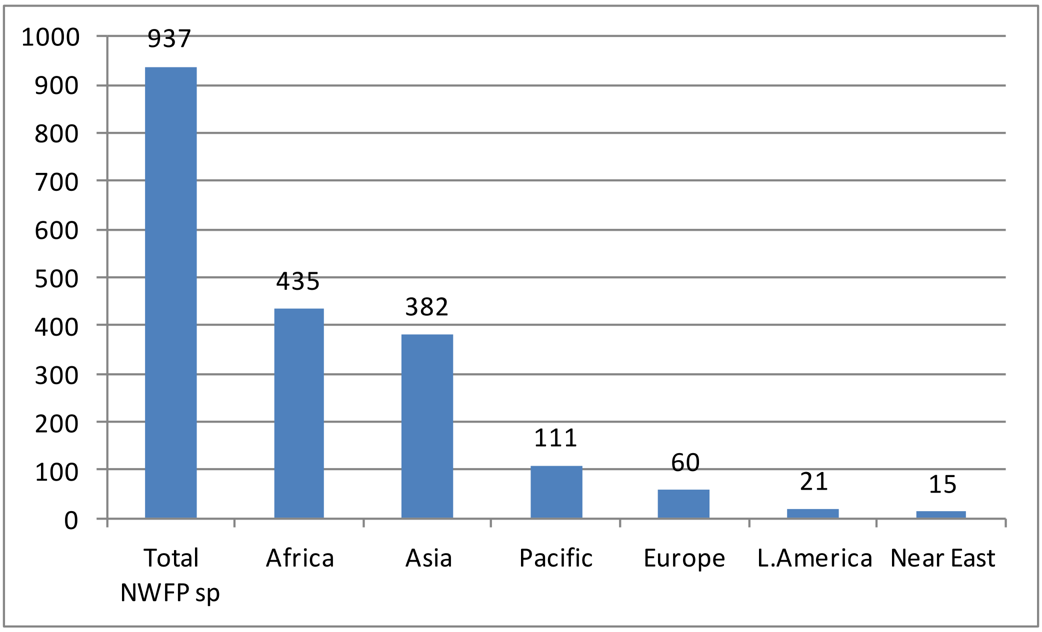

Figure 2: Species used and managed for Non-Wood Forest Products across regions

- Only 25 species are mentioned as priority species by at least 10 countries. Most priority species are not of global or regional interest, but are important at local level for their contribution to the livelihood of people, ecosystem services they provide and/or opportunities they represent for the economy.
- Among the 1451 cases of species used in plantations reported globally, 1240 or 85% were used as exotic and only 211 or 15% were used as native.
- Over 2280 species have been mentioned in country reports as actively managed for various objectives, in different management systems. Figure 3 below gives the number of species used for main types of objectives. A particular species can be managed for multiple objectives, and included in different types of management systems.

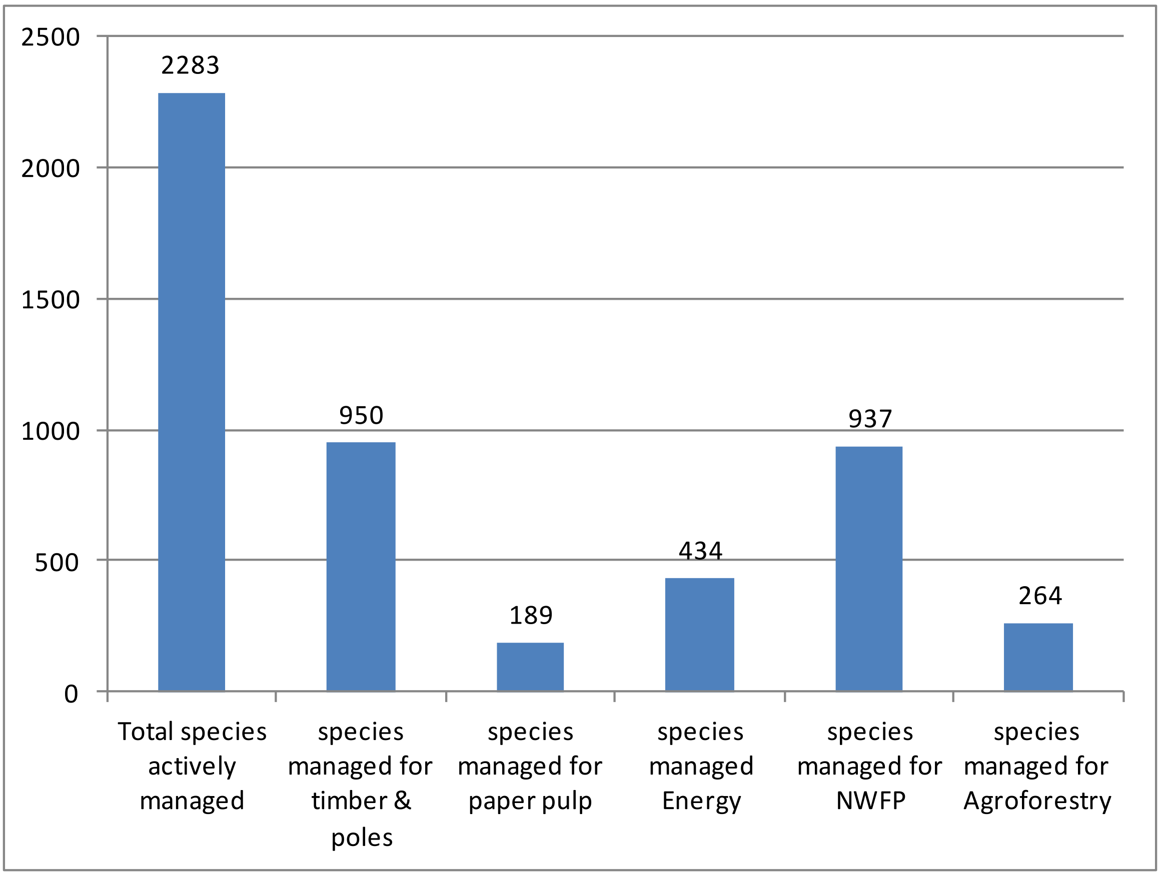

Figure 3: Number of species and management objectives

- **More than 3,800 species threatened** at different levels (Africa 881, Asia 1641, Europe 240, Near East 56, L. America 284, N. America 284, Pacific 32)

- Most threats to forest genetic resources are related to man induced processes of forest degradation and deforestation, including land use change.

THE STATE OF FOREST GENETIC RESOURCES MANAGEMENT

Chapter 2 aims to capture all relevant information available in the country reports with regard to the status of management of Forest Genetic Resources. Information is organized according to the following:

Keys findings

- A total of 620 species have been mentioned as genetically characterized with varying intensity across regions (Figure 4).

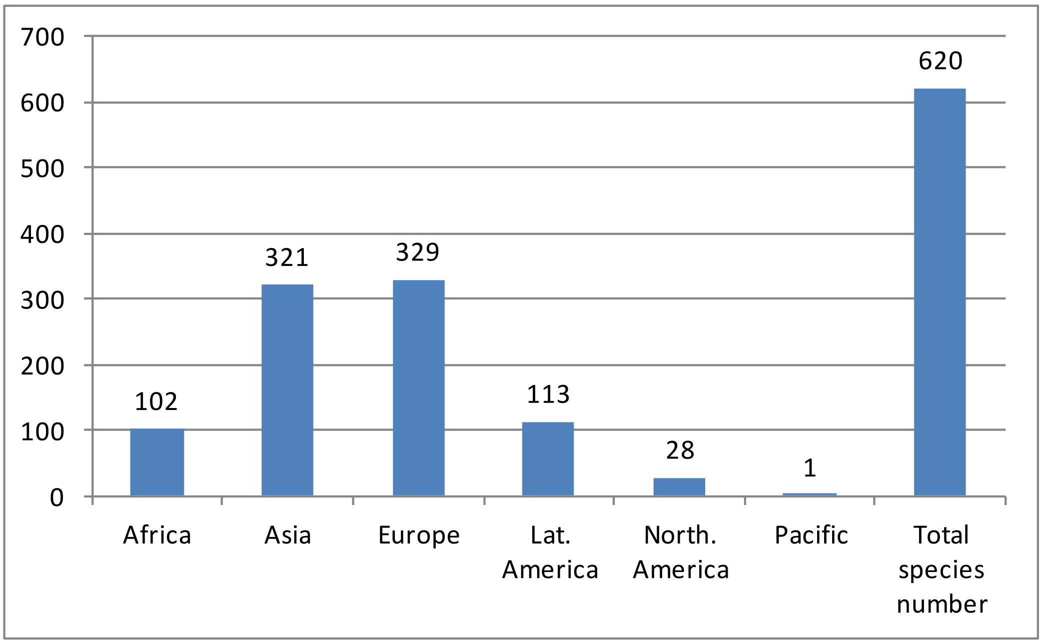

Figure 4: Number of species genetically characterized

- About 570 **species** are included in tree improvement programme or undergoing domestication or various exploratory research activities (Figure 5).

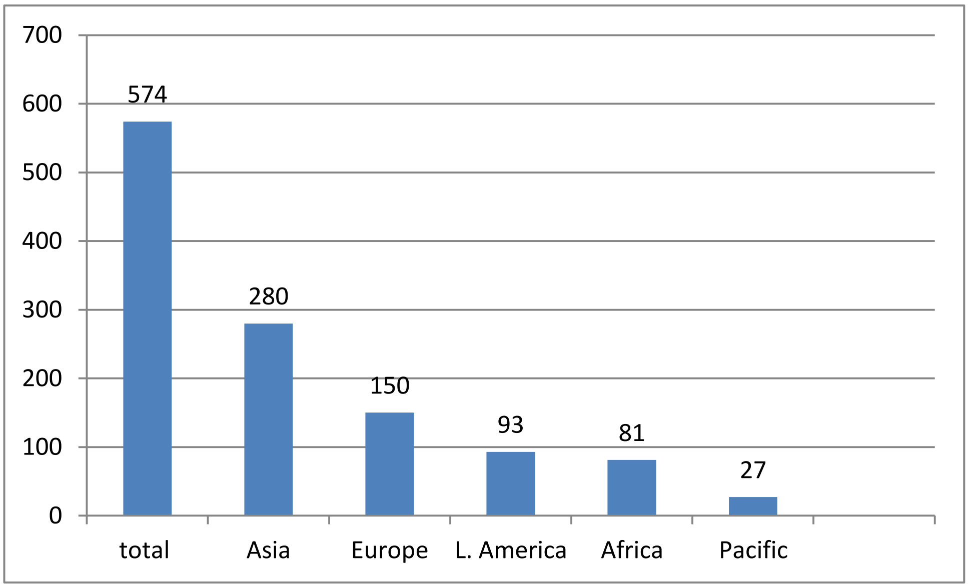

Figure 5: Number species under tree improvement programmes by region

- Most Genetic improvement programmes under implementation in the countries target species respectively for timber production, NWFP, energy, paper pulp and agroforestry .
- **Tree improvement programmes resulted in some cases to substantial production gain of** 10-30% for timber trees and an average yield gain of 15-68% for fruit trees
- Forest genetic resources conservation is commonly implemented by countries through broad ecosystem management and conservation practices. Important and/or threatened species are often targeted for conservation in various forest management regimes. **Many countries included protected areas** as part of their conservation strategy for targeted forest species. It

is interesting to notice that tree improvement programmes are mentioned as contributing to the conservation of genetic resources of many species by countries (Figure 6).

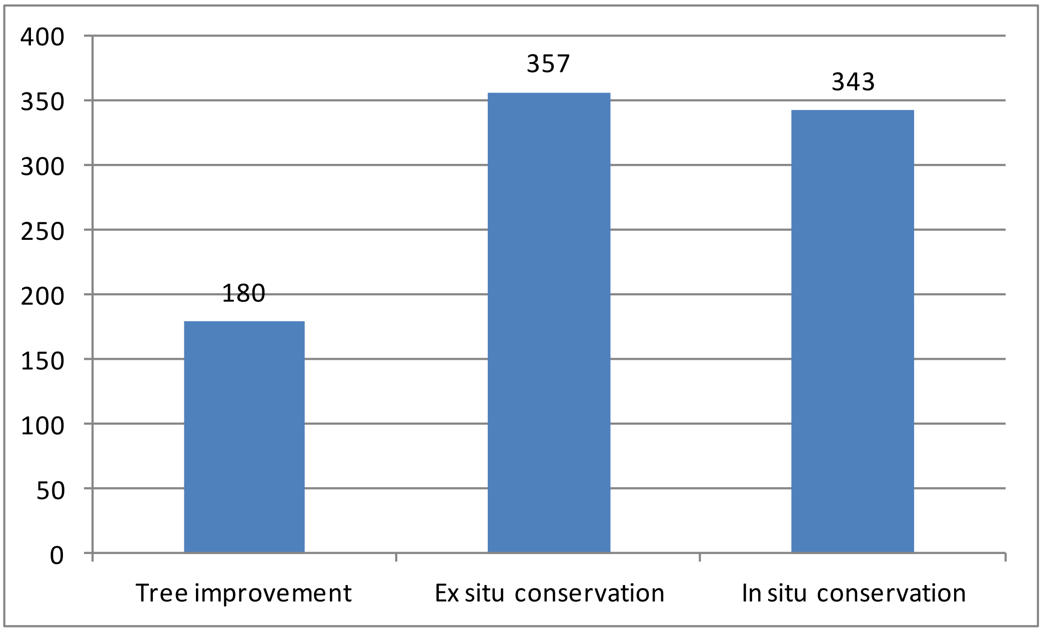

Figure 6: Conservation of threaten species through different management systems

- The total number of **1690 species are conserved *ex situ*** is and, Africa reported 1062 species in *ex situ* reserves, 420 species reported as conserved in Latin America, 408 species in Asia, 402 in Europe, 101 in North America, 63 in the Southwest Pacific and 60 in the Near East**.**

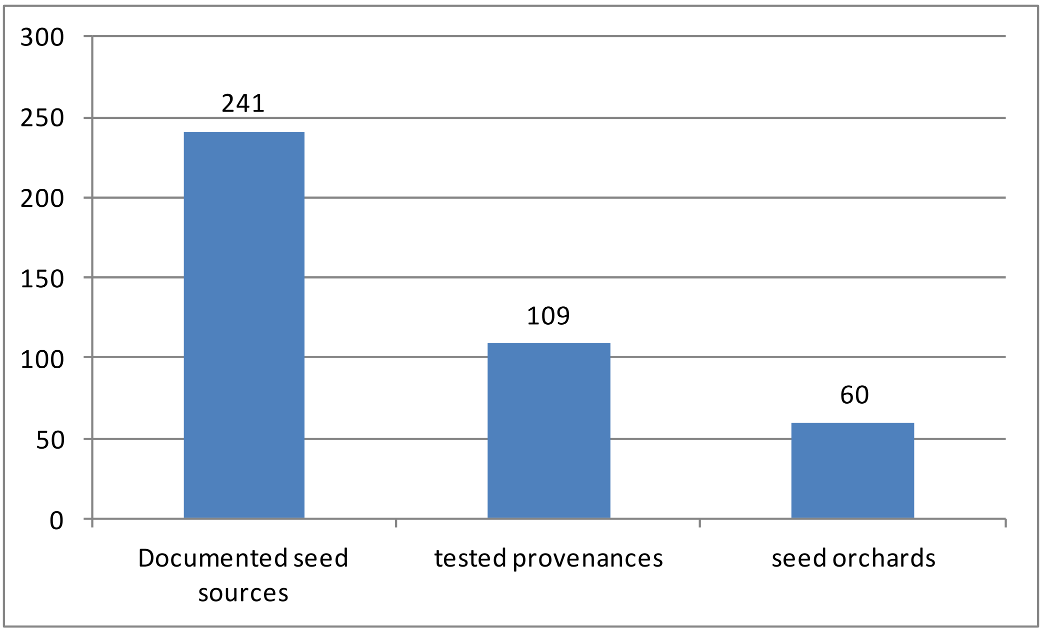

Figure 7: Number of species and available quality seed sources (3 categories)

- 32 countries reported on quality of forest reproductive material used, indicating that documented seeds sources covers 241 tree species, tested provenances 109 species and seed orchards 60 species (Figure 7).
- Number of species with available reproductive material is presented by region in Figure 8 below. However many country does not have access to quality reproductive material.

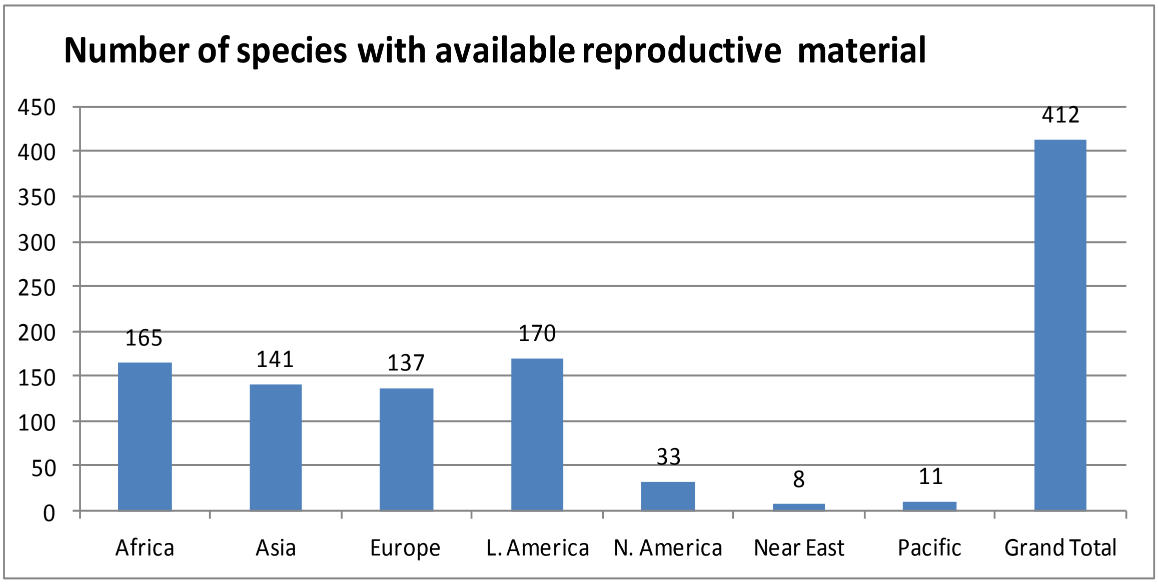

Figure 8: Regional overview of number of species with available reproductive material.

<u>Constraints and knowledge gaps</u>

- Information and knowledge on genetic diversity of most species are weak or inexistent in many c*ountries.*
- Insufficient information on production of Non Wood forest products and development of subsequent required management options on sustainable forest genetic resources management.
- Lack of knowledge on genetic resources processes in their natural habitat, and gene-ecological zones of species.
- Low effectiveness of in situ conservation measures due to forest degradation
- Lack of adequate knowledge on the actual status of genetic diversity and resources of most species and their ability to adapt to climate change effects.
- Lack of sufficient and long-term investments to ensure availability of qualified human resources as well as adequate technologies.
- A huge potential of FGR that could contribute to poverty alleviation, food security and environment sustainability remains un explored
- Threat of FGR by invasive alien species
- Adequate forest seed supply system is lacking in many countries

<u>Needs</u>

- Establish and strengthen national FGR assessment, characterization and monitoring
- Develop national and sub-national systems for the assessment and management of traditional knowledge on FGR
- Strengthen contribution of protected areas to in situ conservation
- Support and develop sustainable management and conservation of FGR on farm land

- Promote development of efficient and sustainable ex situ conservation systems
- Develop and reinforce national seed supply programmes
- Promote use of new technologies to support development and conservation of FGR
- Promote use of appropriate genetic material in restoration and rehabilitation of ecosystems
- Need to focus on priority species for more efficiency

TRENDS AFFECTING THE FOREST SECTOR AND THEIR IMPLICATIONS ON FOREST GENETIC RESOURCES

Chapter 3 is not yet finalized, however the key findings, constraints and needs for efficient assessment of the effect of the various trends on FGR management and conservation are identified and presented hereafter

Key findings

The main drivers affecting forest genetic resources are identified by the countries as follow:

- Forest and forest ecosystems loss and degradation
- Increased threat on species
- Ecosystems restoration
- Decentralized and/or local management and development
- Climate change and need to promote adaptation ability
- Valuing non wood forest products

Constraints and knowledge gaps

- Lack of widely accepted indicators for monitoring genetic diversity
- Large programmes on ecosystems restoration and reclamation of degraded land lack sufficient and appropriate quantity and quality of forest reproductive material.
- Strategies and technologies adapted to local management of FGR is inadequate
- Lack of adequate statistics on the contribution of NWFP to countries economy and food security and their implications for sustainable FGR management.

Needs and priorities

- Development of indicators for sustainable FGR management
- Select and develop plant material and methods, and build capacity for restoration of ecosystems
- Develop strategies and methods, build capacity for conservation and sustainable use at local level
- Review/update conservation strategies in the context of climate change
- Integrate climate change into policy, programs and regulations

CAPACITIES, INSTITUTIONAL AND POLICY FRAMEWORK FOR CONSERVATION AND MANAGEMENT OF FOREST GENETIC RESOURCES

Chapter 4 is not yet finalized; however the key findings, constraints and needs in capacities, institutional and policy framework for FGR conservation and management and conservation are identified and presented hereafter.

Key findings

- Numerous and diverse institutions involved in FGR at national level - Capacity often inadequate
- Active regional cooperation: networks, strategies, programs
- Forest reproductive material regulations/schemes in place at national, regional and international levels
- Few Information systems on FGR

Constraints

- Many Countries have no specific low on forest genetic resources
- Indicators for monitoring genetic diversity
- Reproductive material and technology adapted to ecosystem restoration - Capacity
- Strategies and technologies adapted to local management – Capacity
- Strategies for adaptation

Needs and priorities

- Coordinate FGR activities and integrate them in broader national strategies ad programs (forestry, biodiversity, food security, poverty reduction, etc)
- Development and implementation of regional strategies and programs for conservation of FGR
- Develop and improve information systems on FGR for conservation and sustainable use at national, regional and global levels
- Strengthen research and training programs to produce knowledge and capacity necessary for conservation and sustainable use of FGR
- Improve germplasm movement for research and development

STATUS OF KNOWLEDGE ON CURRENT AND EMERGING TECHNOLOGIES

Draft Chapter 5 describes the status of knowledge on FGR with a particular emphasis on emerging technologies currently used in research. Information is mostly drawn from country report, thematic studies committed by FAO and various publications. In addition to describing the important findings from the reports, the chapter presents the constraints to knowledge generation and research development on FGR.

Keys findings

All countries reported an inadequate public awareness of FGR – thus an impediment to generating new knowledge to alleviate the woeful information gaps, is lack of general understanding of its importance.

- Knowledge of FGR is reported to be inadequate for well-informed policy or management, in most countries.
- Among the 80 – 100,000 tree species, a small proportion has been studied to describe genetic parameters (less than 1%) although both the number of studies and the number of species studied has increased significantly in the last decade.
- Most studies conducted during the past two decades are at the molecular level, either using DNA markers or genomic technologies to characterize genetic resources; the quantity of information at the molecular level is accumulating much faster than whole-organism information, with the consequence that little of the accumulating knowledge has direct application in management, improvement or conservation.

- A few species are very well studied and genetically characterized, based on both molecular and quantitative studies. These are mainly temperate conifers, Eucalyptus, several Acacias, teak, and a few other broadly adapted, widely planted and rapidly growing species.
- Quantitative genetic knowledge has led to significant productivity gains in a small number of tree species that have high value as plantation timber.
- Genomic knowledge of forest trees lags behind that of model herbaceous species, including the important agricultural crops, but the entire genome of several tree species has been or is in the process of being sequenced and novel approaches have been developed to link markers to important traits. Genomic or marker assisted selection is close to being realized but phenotyping and data management are the biggest bottlenecks.
- Progeny and provenance trials established for many species in many countries were abandoned as funding and interest switched to molecular approaches. Existing but dispersed data should be assembled, maintained and evaluated for potential to inform seed zone delineation, plans for assisting gene flow in response to climate change, identification of propagation material for restoration and conservation efforts for high-value populations.
- Many of the species identified as priorities, especially for local use, have received little or no research attention, indicating a need for associating funding to priority setting exercises. This should be a starting point for expanding knowledge, particularly about genetic control of and variation in valuable traits.

Constraints and knowledge gaps

- Weak Research and tree improvement capacity
- Information on FGR is inadequate, Scattered, not shared and lack compatible formats
- Insufficient number of professionals working on FGR themes
- Forest companies are reticent to share information on technological advances
- The national inventories do not include indicators or parameters to evaluate FGR.
- The understanding of FGR of native species is generally insufficient.
- Inadequate knowledge on species distribution, biology, FGR
- Inadequate capacity (training) to undertake genetic level research
- Insufficient infrastructure to carry out research and studies
- Difficulty to access information
- Research is still localized and not extensive enough within countries and between countries.
- Lack of government investment in knowledge of FGR program development
- No structure for FGR by country to share information, knowledge and ideas
- No list of priority species for gene conservation.

Needs

- Develop research to get knowledge and information on genetic diversity of priority species used in different management systems
- Assess and develop use of emerging technologies to support the conservation and sustainable use of FGR
- Promote *exi situ* strategy which includes development of knowledge on post harvest seed
- Training: university courses, modern methods in FGR conservation including development of post-harvest technologies for proper seed conservation and handling, and assessment of seed storage behavior and tolerance to desiccation.
- Develop joint regional data base on FGR conservation.
- Seed zoning development.
- Include FGR in forest policy and improve legislation.
- Carry out baseline studies and create species information database for distribution, habitat, biology, genetic variation

- Establish nodal action points for species to collate information and coordinate action
- Increase awareness of policy makers on the importance of FGR
- Strengthen technical capacity of scientists by organizing research workshops on recent technologies and advancements and exposure visits
- International organizations to support research coordination and integration of FGR into development framework
- Strengthen national coordination of activities in FGR, e.g. information, researches, uses, etc
- Assessment/monitoring of genetic diversity of identified species with important and potential economic values;
- Allocation of budget funds.

NEEDS, CHALLENGES AND REQUIRED RESPONSES FOR THE FUTURE

Introduction

- Most forest tree species are wild, managed in natural ecosystems, or are at a very primitive stage of selection or domestication as compared to agricultural crops
- Forest tree species are typically long-lived, highly heterozygous organisms, which have developed natural mechanisms to maintain high level of intraspecific variation, such as a high rate of out crossing, and dispersal of pollen and seeds over a wide areas. These mechanisms, combined with native environments that are often variable in both time and space, have contributed to the evolution of forest tree species into some of the most genetically variable organism on earth1. In situ conservation allowing dynamic maintenance of the genetic diversity and processes is the preferred approach for forest species, while ex situ conservation most commonly used for domesticated plant species.
- Trees have multiple functions by providing numerous products and services about 80 percent of people in the developing world make use of non-timber forest products for health, nutrition and income purposes.
- Quantifying the value of the benefit derived from FGR is difficult for several reasons. Apart from timber, most forest products are harvested for local consumption or commercialized without proper national monitoring and documentation. This is particularly the case in developing countries.
- In term of their present or potential contribution to food security and environmental sustainability, FGR are underutilized and undervalued.
- Knowledge of FGR is usually scattered and detained by different institutions in unpublished reports, with limited access in most countries. Baseline information, such as country species checklists, species distribution maps and forest reproductive material catalogues, are lacking.
- The number of known forest tree species exceeds 80 000, but current efforts in member countries to test and improve forest species focus on approximately 450 species.

Priority areas

The chapter is structured around the following four priority areas:

- Improving the availability of, and access to, information on FGR
- In situ and ex situ conservation of FGR
- Sustainable use, development and management of FGR
- Policies, institutions and capacity building

Priority area 1 - Improving the availability of, and access to, information on FGR

Needs and challenges:

- lack of an updated species check list;
- lack of an accurate global picture of the status and trends of FGR;
- lack of a comprehensive assessment of national and international capacities to manage FGR;
- lack of an accepted methodology for directly linking general information on changes in forests to their impacts on biological diversity, species, (provenances), populations and genetic variation.
- lack of knowledge on reproductive and development characteristics of forests species, allowing for ex situ conservation, effective production of seedlings, planting and development of such species outside their original habitats.
- loss of traditional knowledge and beliefs leading to decrease in valuing genetic resources of indigenous species.

Required responses

- Establish and strengthen national FGR assessment, characterisation and monitoring system
- Develop national and subnational systems for the assessment and management of traditional knowledge on FGR
- Develop international technical standards and protocols for FGR inventories, characterisation and monitoring of trends and risks
- Promote the establishement and the reinforcement of FGR information systems (databases)

Priority area 2 - In situ and ex situ conservation of FGR

Needs and challenges:

- 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 and market demand for timber
- Lack of or insufficient integration of FGR issues into current wider national policies and laws, impacting on FGR.
- Climate change reducing regeneration of conserved species; causing range shifts of species and vegetation communities due to shift in climatic zones.
- Lack of knowledge on genetic resource and processes, and gene-ecological zones, including of those assets already in conserved *in situ*
- Concentration on charismatic, priority species at expense of conservation of other indigenous and traditional species
- Lack of knowledge of relevant policies, laws and regulations on the part of stakeholders, including those charged with law enforcement

Required responses:

- Develop national strategies for in situ and ex situ conservation of FGR and their sustainable use

- Strengthen the contribution of primary forests and protected areas to *in situ* conservation of FGR
- Promote the establishment and development of efficient and sustainable ex situ conservation systems, including *in vivo* collections and genebanks
- Support assessment, management and conservation of Marginal and/or range limits Forest Species Populations
- Support and develop sustainable management and conservation of FGR on farmland
- Support and strengthen the role of forests managed by indigenous and local communities in sustainable management and conservation of FGR
- Identify priority species for action
- Develop and implement regional *in situ* conservation strategies and promote eco-regional networking and collaboration

Priority area 3 - Sustainable use, development and management of FGR

Needs and challenges:

- There are no common standard methods for measuring changes in the status of FGR in relation to sustainable forest management as undertaken in most countries.
- Knowledge of the effect of climate change on forest genetic resources is sufficiently understood to allow identidication of appropriate respons to the challenge.
- Many countries lack adequate forest seed supply systems
- Tree improvement activities remain limited to a few economically important tree species
- A huge potential of forest and tree products and services remains unsufficiently explored and valued, although widely used by local and indegenous people.
- Too manay species with limited resources for research activities in the countries

Required responses:

- Develop and reinforce national seed programmes to ensure the availability of genetically appropriate tree seeds in the quantities and of the (certified) quality needed for national plantation programmes
- Promote restoration and rehabilitation of ecosystems using genetically appropriate material
- Support climate change adaptation and mitigation through proper management and use of FGR
- Promote appropriate use of emerging technology to support the conservation development and sustainable use of FGR
- Develop and reinforce research programmes on tree breeding, domestication and bioprospection in order to unlock the full potential of FGR
- Develop and promote networking and collaboration among concerned countries to combat invasive species (animals, plants and microorganisms) affecting FGR.

Priority area 4 - Policies, institutions and capacity building

Needs and challenges:

- In many cases, national policies and regulatory frameworks for FGR are partial, ineffective or inexistent
- Lack of appropriate advocacy tools on FGR at countries, regional and international levels

- Technical and scientific capacities on FGR were reported by many countries as weak
- Difficult access to quality (including genetic quality) forest reproductive material
- Lack of adequate technical resources on FGR to ensure that FGR are properly dealt with in decentralised administrations.
- Lack of adequate collaboration and partnership between stakeholders at national level.
- Lack of adequate resources (financial and human) to support sustainable use and management of FGR

Required responses:

- Update and Integration of FGR conservation and management needs into wider national policies and programmes frameworks of action at national, regional and global levels
- Develop collaboration and promote coordination of national institutions and programmes related to FGR
- Establish and strengthen educational and research capacities on FGR to ensure adequate technical support to related development programmes
- Promote participation of indigenous and local communities in FGR management in the context of decentralization.
- Promote and apply mechanisms for germplasm exchange at regional level to support research and development activities, in agreement with international conventions
- Reinforce regional and international cooperation to support education, knowledge dissemination, research, conservation and sustainable management of FGR
- Encourage the establishment of networks activities and support development and reinforcement of international networking and information sharing on FGR research, management and conservation
- Promote public and international awareness of the roles and values of FGR
- Strengthen efforts to mobilize the necessary resources, including financing for the conservation and sustainable use and development of FGR

Chapter 1. OVERVIEW OF FOREST GENETIC RESOURCES

Genetic diversity provides the fundamental basis for the evolution of forest tree species and for their adaptation to change. Conserving forest genetic resources (FGR) is therefore vital, as they constitute a unique and irreplaceable resource for the future, including for sustainable economic growth and progress, and environmental adaption. The sustainable management of forests and trees in agroforestry systems requires a better understanding of the specific features of forest trees and their genetic diversity and how this can be best conserved, managed and utilized. Forest tree species are generally long lived and extremely diverse. One species can naturally occur in a broad range of ecological conditions. In addition, many forest species have evolved under several periods of major climatic change, and their genetic variability is the basis for adaptation to climatic regimes different to those in which they are have evolved. FGR have provided the potential for adaptation in the past, and will continue to provide this vital role as we address the challenge of mitigating or adapting to further climate changes.

Forestry practices that maintain genetic diversity over the longer term will be required as an integral component of sustainable forest management. In future more proactive management of FGR may be needed to accelerate adaptation of forest trees to climate change including through breeding and deliberate movement and relocation of germplasm. Much remains to be discovered concerning how genes function and are regulated in different tree species and further research will likely yield findings of immense economic, social and environmental importance. As a precautionary principle, until there is an improved understanding of tree genetics, there is a need to conserve as much FGR as possible, viz. the heritable materials of important, including locally important, tree and woody plant species. There is also a need to ensure the survival of the vast majority, and preferably all, of tree and woody shrub species likely to have values hitherto unknown and/or novel products and services which may be required by future generations. Especially critical are those tree species in monotypic families or genera which are genetically more distinctive and irreplaceable.

The State of World's Forest Genetic Resources has a broad scope covering genetic resources of species used for different purposes and managed or contained in the broad range of management systems (see Table 1- Main types of forest and tree resources management), and addresses the conservation, management and sustainable use of forest tree and shrub genetic resources of actual and potential value for human wellbeing. Whilst the main focus of the report, as reflected in national reports, is on tree and larger woody species present in forests, both natural and planted, this reports also deals with tree and woody shrub species outside forests which are arboreal components in more open situations, including agroforestry systems, woodlands and home gardens.

Table 1: Main types of forest and tree resources management

Naturally regenerated forests			Planted forests			Trees outside forests, and agroforestry systems
Primary	**Modified natural**	**Semi-natural**		**Plantations**		
		Assisted natural regeneration	**Planted component**	**Productive**	**Protective**	
Forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not directly disturbed by humans	Forests of naturally regenerated native species where there are clearly visible indications of significant human activities	Silvicultural practices in natural forest by intensive management: • Weeding • Fertilizing • thinning • selective logging	Forests of native species, established through planting or seeding intensively managed	Forests of introduced and/or native species established through planting or seeding mainly for production of wood or non wood goods	Forests of introduced and/or native species, established through planting or seeding mainly for provision of services	Stands smaller than 0.5 ha; tree cover in agricultural land (agroforestry systems, home gardens, orchards); trees in urban environments; and scattered along roads and in landscapes

1.1. ATTRIBUTES OF FGR

1.1.1. Definitions of FGR, FGR conservation and related terms

Forest Genetic Resources (FGR) refers to the economic, environmental, scientific and societal value of the heritable materials maintained within and among tree and other woody plant species. In the country reports, which provided the scope of *The State of World's Forest Genetic Resources*, 2440 different species were identified globally as priority FGR species. The country reports used several categories of values in nominating species for priority, with economic uses the most frequent (46%), conservation including threatened status values second (24%), and social and cultural values third (15%). Among the 1451 cases of species used in plantations whose origin was identified, 1240 or 85% were used as exotic and only 211 or 15% were used as native. A relatively small number of species are widely-planted as exotic, and are economically important 'global' forestry species. Some country reports included species which may be regarded as marginally FGR because they are woody shrubs which may often be of low stature when grown in difficult and arid environments. Country reports included fruit and nut trees and their wild ancestors, and these have been included in reporting as they are frequently multipurpose, providing timber, medicine and services and often being handled by Forestry agencies. The term FGR is also sometimes used incorrectly to more generally to cover the tree and forest resources and products themselves.

Forest biodiversity has a broader connotation than FGR and denotes the variability among forest dwelling organisms and the ecological processes of which they are a part, and includes variation at forest ecosystem, species and molecular levels.

FGR comprise one subset of ***plant genetic resources for food and agriculture*** (PGRFA). PGFRA are defined as any genetic material of plant origin of actual or potential value for food and agriculture (which in the UN system is broadly circumscribed to include forestry). FGR are also included as a subset of ***agrobiodiversity*** which is defined as the variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. Agrobiodiversity includes the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems (FAO, 1999). Increasingly traditional knowledge of biodiversity or ethnobiodiversity is being understood to be an integral component of agrobiodiversity (Thaman 2008) and its loss may proceed and threatens loss of diversity at different levels – agrobiodiversity systems, species and intraspecific diversity.

Intraspecific diversity, or the genetic variation within species, may be considered from several perspectives, ranging from formally recognised taxonomic categories of subspecies and varieties through to genetic differences between and within populations. ***Subspecies*** are usually morphologically or otherwise distinctive entities within a species which have evolved in geographic and reproductive isolation: if they continue to be separated for many generations, subspecies may become distinctive enough from each other, or have developed reproductive barriers, to develop into separate species. ***Ecotypes*** are an intraspecific group having distinctive characters which result from the selective pressures of the local environment. ***Genotypes*** can be considered as the sum of the total genetic information in an individual or the genetic constitution of an individual with respect to genetic loci under consideration. Individual long-lived trees of different species may develop into chimeras of many genotypes due to the accumulation of spontaneous mutations of neutral selective fitness in nuclear genes in bud meristems, but this topic has been little researched.

An organism's ***genome*** represents its total genetic material, and in plants is comprised of three separate genomes, viz. nuclear (c. 50-100,000 genes), chloroplast (c. 100-120 genes) and mitochondrial (c 40-50 genes) (Murray *et al*., 2000). Understanding of genetics and the nature of ***heritable materials*** in trees is rapidly evolving; informed by genomic studies in economically important forestry trees such as *Eucalyptus* and *Populus* (both angiosperms), woody fruit trees such as apple (*Malus domestica*) and sweet orange (*Citrus sinensis*), an ancestral flowering plant (*Amborella trichopoda*), in coniferous families through transcriptome (RNA) sequencing (e.g. Walter Lorenz *et al.* 2012) and by genetic research on other plants and other organisms. Advances in gene sequencing technologies, have made possible the sequencing of conifer giga-genomes and several such studies are now in progress or planned (see e.g. Mackay *et al.* 2012, Ch 2 and Ch6).

Genes, are a nuclear DNA sequence to which a specific function can be assigned, while ***allele*** are alternative forms of a gene located on the corresponding loci of homologous chromosomes. In plants, as well as other higher organisms, a variable proportion of the nuclear genome is composed of non-protein coding, repeat DNA sequences, which has several origins, and some of which has specific regulatory functions and/or may donate segments of DNA which can become incorporated into genes. Angiosperms possess genomes with considerable gene redundancy much of which is the result of ancient polyploidization events (Soltis *et al.* 2008).

DNA present in cellular organelles, notably chloroplasts and mitochondria, comprise vital components of a tree's heritable materials. While nuclear DNA is always inherited biparentally from the male and female parent, organellar DNA may have different modes of inheritance. Chloroplast DNA in usually maternally inherited in angiosperms (e.g. in poplars, Rajora and Dancik 1992; and in eucalypts Byrne *et al.* 1993), but may also be inherited from both parents (Birky 1995), or rarely paternally (Chat *et al.*, 1999). In gymnosperms, chloroplast DNA is mainly inherited paternally or infrequently from both parents (e.g. Neale *et al*. 1989, Neale and Sederoff 1989, White 1990; Wagner 1992). The mitochondrial genome is most often maternally inherited in angiosperms (e.g. Reboud and Zeyl 1994, Vaillancourt *et al*., 2004), but may be maternally, paternally or biparentally inherited in gymnosperms (e.g. Neale *et al.* 1989, Neale and Sederoff 1989, Wagner 1992, Birky 1995). Chloroplast DNA is strongly conserved, and therefore useful for evolutionary studies (e.g. in

Eucalyptus Freeman *et al*. 2001, and in *Juglans* Bai *et al.* 2010), while mitochondrial DNA is commonly used as a source of genetic markers in studies of gene flow and phylogeography. Heritable changes in gene expression or cellular phenotype may be caused by several mechanisms which do not involve any change in the underlying DNA sequence and these are the realm of the poorly understood science of epigenetics.

A ***population*** of a particular tree species comprises all of the individuals of that species in the same geographical area, and genetically isolated to some degree from other populations of the same species. In sexually reproducing species the population comprises a continuous group of interbreeding individuals. A ***metapopulation*** of a forest tree species comprises a set of spatially separated local or sub- populations, co-existing in time, and which interact infrequently via pollen and seed dispersal between them. The term ***provenance*** is particularly important in relation to forest tree germplasm and refers to the geographic origin of a particular germplasm source, although sometimes used synonymously and interchangeably with population. The field performance of a particular representatively sampled provenance seed source, if from a rather narrow geographic area (including same soil type and without much altitudinal variation) will generally be more consistent than for a population which may differ considerably due to clinal variation arising from gradients in selective pressures.

FGR conservation approaches

Practical approaches and best practices for conservation and management of forest and plant genetic resources have been extensively discussed in various practical guides and texts (Young *et al*. 2000; FAO, DFSC, IPGRI, 2001; FAO, FLD, IPGRI 2004, 2004a; Heywood and Dulloo 2005). ***In situ conservation*** refers to the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings, and in the case of domesticated or cultivated in the surroundings in which they have developed their distinctive properties (CBD 1992). ***Circa situm conservation*** emphasises the role of regenerating saplings and linking vegetation remnants in heavily modified or fragmented landscapes such as those of traditional agroforestry and farming systems (Barrance 1999). The related term ***matrix management*** has been coined to refer to approaches to conserve and manage biodiversity in forests outside of protected areas (Lindenmayer and Franklin, 2002): dynamic conservation of FGR will mainly occur in the matrix and will involve management of trees on farms, in forest fragments and especially in sustainably managed production forests. ***Ex situ conservation*** refers to the conservation of components of biodiversity outside of their natural habitats, including FGR in plantations, tree breeding programs, ex situ gene conservation stands/field genebanks, seed and pollen banks, *in vitro* storage and through DNA storage (FAO, FLD, IPGRI 2004a).

Evolutionary or ***dynamic conservation of FGR*** essentially involves a natural system in which the evolutionary forces, and natural selective processes, which gave rise to diversity are allowed to operate and which over time modify allelic frequencies. The recent past few decades, and the next century, represent an era of unprecedented change in selective pressures on almost all trees species. These altered selective forces include more extreme climatic events, gradual increases in temperature and altered rainfall regimes, changed fire regimes, increased air pollution and elevated atmospheric CO_2 levels, habitat fragmentation, increases in and new pests and diseases, competition with invasive exotic plant species including transformer species capable of changing the ecology of entire ecosystems, and the loss of or changes in pollinators and dispersal agents. Dynamic *in situ* conservation allows species adaptation through continuous ‘selection of the fittest’ and co-adaptation of host-pathogen systems and other complex biological interactions (Kjær *et al*. 2001; Byrne 2000).

In situ conservation of the FGR associated with identified, superior provenances of economically important tree species is vital even when they may be relatively well conserved *ex situ*, e.g. through planting and breeding programs. This is because tree breeders may need to re-sample and infuse later breeding populations, and/ or identify new desired traits in already well-known and adapted populations. Selective forces may differ in the native and exotic/planted environments, and this is the basis of the, often remarkably swift evolution of ***land races*** which are much better adapted than the original introduction after just one or two generations of selection. Increasingly rapid climate change and associated extreme climatic events is altering the selective forces in both the native and exotic/planted environments and throwing up new challenges for FGR conservation.

Static conservation of FGR involves conserving individual genotypes, e.g. in the field as clonal archives and *in vitro* in tissue culture and cryo-preserved embryo culture, and groups of genotypes in long term seed storage for tree species with orthodox seed storage behaviour (Kjær *et al.* 2004). This approach has generally been viewed as a complementary approach to dynamic *in situ* conservation and more often as a short-term conservation strategy and for safety duplication in the case of cryopreservation. Given the unprecedented scale of threats to FGR and likely losses of diversity and changes in selective forces which will drive rapid changes in the genetic makeup of natural (and artificial) populations of tree species , it might be timely to reconsider the potential value and cost effectiveness of static conservation activities.

1.1.2. Characteristics of FGR

Forest tree species are generally long-lived and have developed natural mechanisms to maintain high levels of genetic variation within species. They include high rates of outcrossing and often long-distance dispersal of pollen and seed. These mechanisms, combined with native environments that are often variable have enabled forest tree species to evolve into some of the most genetically diverse organisms in existence. Forest community ecosystem processes, including evolution of biodiversity, have been found to be closely related to the genetic diversity in structurally dominant and keystone tree species (e.g. Whitham *et al.* 2006 and references contained therein).

Differences between trees and other organisms

Chromosomes and DNA

There are large and seemingly inexplicable differences and variations in chromosome number, ploidy level and genome size both within trees, and between trees and other organisms. The two major groups of trees, viz. gymnosperms (including conifers) and angiosperms, appear to have been separated by more than 290 million years of independent evolution. Conifers typically have very large genomes, or giga-genomes, with numerous highly repetitive, non-coding sequences (Ahuja and Neale 2005; Mackay et al. 2012). DNA sequencing studies of selected model plants species in these two groups are providing different perspectives and insights into plant genome biology and evolution. Whilst there are large overlapping sets of DNA sequences between conifers and angiosperms (e.g. Pozo et al.), about 30% of conifer genes have little or no sequence similarity to angiosperm plant genes of known function (Pavy et al. 2007; Parchma et al. 2010). Whilst polyploidization or whole genome duplication is rare in animals and conifers2, it is now considered ubiquitous in angiosperms and has occurred frequently through the evolution of angiosperms. Polyploidization is a mechanism of sympatric speciation because polyploids are usually unable to interbreed and produce fertile offspring with their diploid ancestors. Polyploidization may be involve autopolyploidy (spontaneous multiplication involving the chromosomes of a single species) or allopolyploidy (involving more than one genome or species). Whole genome duplication is considered likely have led to a dramatic increase in species richness in several angiosperm lineages including families with important FGR such as the legumes (Fabaceae) and provided a major diversifying force in angiosperms (Soltis et al.,

[2] Polyploids in conifers include *Sequioa sempervirens* (hexaploid) and *Fiztroya cupressoides* (tetraploid) – see for a review of polyploidy in gymnosperms see Ahuja (2005)

2008). In animals, aneuploidy is usually lethal and so is rarely encountered, whereas in angiosperms the addition or elimination of a small number of individual chromosomes appears to be better tolerated; new research has indicated that aneuploidization may be a leading cause of genome duplication (Considine et al. 2012). These authors have found that auto-triploidization is important for speciation in apples (Malus spp.), and that the features of such polyploidization confer both genetic stability and diversity, and present heterozygosity, heterosis and adaptability for evolutionary selection. The monotypic small tree Strasburgeria robusta from New Caledonia has an extremely high ploidy level (20 n with n=25) and may have enabled it to adapt to an extreme edaphic environment, viz. ultramafic soil (Oginuma et al. 2006).

Longevity and Size

Trees, including woody shrubs, differ from other organisms in several key respects. They are perennial, often long-lived, organisms which need to be able to either endure environmental extremes and changes and/or persist in the soil seed bank or regrow from root suckers and coppice in order to survive long-term at a particular site. Angiosperms trees have high levels of genetic diversity, both a high number of genes, e.g. more than 40,000 for poplar[3], with high allelic variation; while gymnosperms have giga-genomes with an order of magnitude more DNA than other organisms, but with likely a similar number of genes to angiosperm trees distributed more sparsely in a large pool of non-coding DNA (Rigault *et al.* 2011, Mackay *et al.* 2012). The high genetic diversity that characterizes tree populations and individuals, and associated stress tolerance and disease resistance mechanisms, help explain their capacity to persist and thrive for long periods. The life span of tree species typically ranges from about 10-15 years (short lived pioneer species) to 200-300 years (many larger trees species and those found in arid zones). Root suckering clones provide the oldest known trees and woody shrubs, examples include aspen (*Populus tremuloides*) with one clone in central Utah (USA) estimated to be 80,000 years old (DeWoody *et al.* 2008) and with 5-10,000 year-old clones reputedly common. A sterile triploid clone of the woody angiosperm shrub king lomatia (*Lomatia tasmanica*) has been determined to be at least 46,300 years old (Lynch *et al.* 1998). A colony of Huon pine (*Lagarostrobus franklinii*) trees covering one hectare on Mount Read, Tasmania (Australia) is estimated to be around 10,000 years old, with individual tree stems in this group more than 2,500 years old, as determined by tree ring samples (The Gymnosperm Database – http://www.conifers.org/po/Lagarostrobos.php). A specimen of Norway spruce (*Picea abies*) in Dalarna Province (Sweden) has been found to be at least 9,550 years old, surviving by resprouting from layered stems, rather than underground root suckering (Anon. 2008). Three species of bristlecone pines in USA may live for several thousand years with one specimen of Great Basin bristlecone pine (*Pinus longaeva*) in California determined to be c. 4,850 years old. Interestingly almost all of the world's oldest recorded trees are conifers (Rocky Mountain Tree Ring Research http://www.rmtrr.org/oldlist.htm. Accessed 18/10/2012). It is likely that different xylem structure and associated ability to survive lower conductivities and drought (Choat *et al.* 2012) contributes to the great longevity of gymnosperms and especially conifers, compared with angiosperms. Ancient trees occur in all three orders of conifers, viz. Pinales, Araucariales, and Cupressales: > 4000 years – *Pinus longaeva*, *Picea abies*; > 3000 years – alerce (*Fitzroya cupressoides*), giant sequoia (*Sequoiadendron giganteum*)*;* > 2000 years – western juniper (*Juniperus occidentalis*), Huon pine (*Lagarostrobus franklinii*), Rocky Mountain bristlecone pine (*Pinus aristata*), foxtail pine (*P. balfouriana*), coast redwood (*Sequoia sempervirens*)*; and* > 1000 years – Nootka cypress (*Chamaecyparis nootkatensis*),

[3] *Populus trichocarpa* has been determined to have 41,335 loci containing protein-coding transcripts (http://www.phytozome.net/poplar; accessed 9 March 2013).

sugi (*Cryptomeria japonica*), Rocky Mountain juniper (*Juniperus scopulorum*), alpine larch (*Larix lyalli*), whitebark pine (*Pinus albicaulis*), pinyon pine (*P. edulis*), limber pine (*P. flexilis*), douglas fir (*Pseudotsuga menziesii*) and bald cypress (*Taxodium distichum*). The capacity of gymnosperms to persist, often almost unchanged in form, over millions of years, is evidenced by ginkgo (*Ginkgo biloba*) recently re-discovered in the wild in south-west China where glaciation was relatively weak (Tang *et al.* 2012), whereas it was previously only known from cultivation in Japanese and Chinese temple gardens and in fossils. Likewise, the discovery in 1994 of the Wollemi pine (*Wollemia nobilis*), in a valley near Sydney, eastern Australia and presumed to be the last remnant[4] of a genus which evolved about 61 million years ago (Liu *et al.* 2009). There are less than 100 stems of this tree, all genetically identical; and likely a single clonal root suckering clump. The only comparable long-lived organisms to the oldest trees are corals, fungal mats and other clonal suckering plants such as creosote bush (*Larrea tridentata*).

Trees also provide the biggest and tallest organisms on the planet. Coast redwood (*Sequoia sempervirens*) has been recorded up to 115 m tall and weighing up to 3,300 MT. The world's tallest and biggest angiosperms are eucalypts in south-eastern Australia, viz. mountain ash (*Eucalyptus regnans*) from Victoria and Tasmania with trees measuring over 100 m, but historically to at least 114 m tall, and trunk volumes to 360 cubic metres. By contrast the largest animals to have evolved are blue whales which can weigh up to 180 MT. Populations of large old trees are rapidly declining in many parts of the world, with detrimental implications for ecosystem integrity and biodiversity (Lindenmayer *et al.* 2012). Throughout the tropics the biggest forest trees are disappearing partly due to selective targeting by loggers, but more recently as a result of forest fragmentation, climate change and exposure to drought.

Trees are the dominant structural element in forests and several other terrestrial ecosystems (agroforests, woodlands, and gardens), intercepting much of the radiant sunlight, dominating photosynthetic processes and carbon flows, comprising the greater proportion of the biomass, and central to the cycling of water and mineral nutrients (especially absorbing and returning nutrients from deeper root zones, mobilizing mineral elements through associations with mycorrhizal fungi and fixing atmospheric nitrogen through symbiosis with bacteria). Increasingly the diversity within and between tree species is being found to be critical to promoting and maintaining almost all other life forms present in forest ecosystems.

Breeding systems – diverse

Trees are also notable for their diverse breeding and reproductive systems, which are in turn major determinants on spatial patterns of the tree species genetic diversity. Most tree species reproduce sexually, although many have a combination or sexual and asexual reproductive means, while a few have lost the ability to reproduce sexually and are maintained as sterile, root-suckering clones in certain parts of their range, e.g. Chittering grass wattle (*Acacia anomala*) in south-western Australia (Coates, 1988), swamp sheoak (*Casuarina obesa*) in western Victoria (Australia), and Eastern Polynesian sandalwood (*Santalum insularis*) on Mangaia (Cook Islands). It is possible that a long distance pollen or seed dispersal event to such plants might lead to their regaining a sexual mode of reproduction. Trees species reproducing by sexual means have diverse reproductive biologies including monoecious (separate male and female flowers on the same tree), dioecious (individual trees may bear either male or female flowers), hermaphroditic (functional bisexual flowers) and

[4] The species may die out in the wild due to the recent introduction of the virulent root rot pathogen *Phytophthora cinnamomi*, but is well conserved globally *ex situ* by a successful campaign to promote its use as an ornamental.

polygamous (with male, female and bisexual flowers on the same tree). Almost all flower sex combinations are possible including trees with male and bisexual flowers; female and bisexual flowers and with both bisexual flowers and small number of either male or female flowers. At a global level, populations of flowering plant species are mainly hermaphrodite (72%), with a variable proportion as monoecious (4%), dioecious (7%), gynodioecious or androdioecious (7%) and trioecious (10%) (Yampolsky and Yampolsky 1922; Dellaporta and Calderon-Urrea 1993), but these rates will vary regionally and between trees and other flowering plants, e.g. dioecy, an obligate outcrossing pollination arrangement, was found to be higher (>20%) in tree species (Bawa *et al*. 1985). The majority of angiosperm species with hermaphroditic flowers have preferential out-crossing systems such that fertilized, viable seeds are generally derived from outcrossing. Reported outcrossing rates [5] in tropical angiosperm tree species in different families, and including those occurring at low density, found outcrossing rates typically were in the range 60 to 100%, but with considerable variation. Outcrossing rates vary within species, populations and between different flowering events. For example tropical acacias from humid zones in Papua New Guinea and northern Australia typically have rates of 93-100% outcrossing, but lower rates (30-80%) have been found in more southerly populations of mangium (*Acacia mangium*), while polyploid dry-zone African acacias had low outcrossing rates of between 35-38%. Plasticity in mating systems has also been observed in response to changes in pollinators, e.g. kapok tree (*Ceiba pentanda*) had predominantly self-incompatible system in regions with high bat pollinator visitation, but changed to a mixed mating system with high levels of self-pollination in situations with low pollinator visitation rates (Lobo *et al*. 2005).

Conifers are wind pollinated and either monoecious or dioecious (obligate outcrossing): species in the families Araucariaceae, Podocarpaceae and Taxaceae may be either monoecious or dioecious; Pinaceae and Cupressaceae are monoecious (with the exception of *Juniperus* which are usually dioecious); and Cephalotaxaceae are dioecious or occasionally monoecious (The Gymnosperm database; http://www.conifers.org accessed November 2012). Mating systems in conifers vary in space time, mainly due to variation in self-pollen availability (Mitton, 1992). Mechanisms to promote outcrossing have been identified in monoecious conifers, e.g. loblolly pine (*Pinus taeda;* Williams *et al*., 2001), and the outcrossing rate for most conifer species is above 80% (for the 52 species reviewed in O'Connell, 2003). Through their long evolution plasticity in the reproductive systems of conifers may have helped them to survive, e.g. Saharan cypress (*Cupressus dupreziana*) has evolved a unique reproductive system of male apomixis whereby the seeds develop entirely from the genetic content of the pollen (Pichot *et al.*, 2000). Coast redwood (*Sequoia sempervirens*) reproduces by both asexual (basal suckering) and sexual means but with low seed set (1-10%) due to irregular meiosis and associated with its hexaploid condition; dual reproductive systems have enabled redwoods to maintain heterozygosity and adaptability for survival (Ahuja 2005).

1.1.3. Types and complementarities of FGR conservation

Conservation of forest genetic resources can be defined as the policies and management action taken to assure their continued availability and existence. The strategy of conservation and the exact methodologies applied depends on the nature of the material, the timescale of concern, and the specific objectives and scope of the programme. There are two basic strategies for genetic conservation: these are *in situ* (on site) and *ex situ* (off site, e.g. in designated conservation

[5] Byrne 2008; Butcher *et al.* 1999; Gandara 1996; Hamrick and Murawski 1990; Kitamura *et al.* 1994; Lepsch-Cunha *et al*. 2001ab; Mandal *et al.* 1994, Moran *et al*. 1989. Muluvi *et al.* 2004; Murawski and Hamrick, 1991; Murawski and Bawa 1994; Murawski *et al*. 1994ab; Murawski, 1995; Nason and Hamrick, 1997; O'Malley and Bawa 1987; Olng'otie 1991; Sebbenn 2000; Stacey *et al.* 1996; Ward *et al*.2005.

stands/field gene banks, genebanks, arboreta and botanic gardens). These two strategies are generally viewed as being complementary and best carried out in parallel in the case of conservation of species and intra-specific genetic variation. However this presents major organizational, institutional, regulatory and technical challenges due to the different types, ownerships and dynamics of repositories of FGR (Sigaud *et al.* 2004). A highly coordinated approach is required between the various concerned agencies and organizations, viz. Forestry Departments for managing reserved forests and *in situ* gene conservation stands; Environment Departments managing protected areas; Government Agencies and Private forestry companies and cooperatives for tree improvement programs; Government Research Agencies, Botanical Gardens and Universities maintaining gene banks of seed and tissue cultures; private landholders and communities managing privately owned managed forests, plantations, agroforests and farmlands. Both the general and particular strategies and programs to be pursued will be dependent on factors such the available financial, human and land resources; human population and resource use pressures on land, forests and trees; technological options for particular species and the nature and dimensions of the conservation challenges, e.g. whether the aim is to conserve a large number of forest species, a smaller number of rare and endangered species or to conserve the genetic diversity and evolutionary potentials of a smaller number of high priority species for planting programs. Additional challenges and opportunities arise in situations where there is an international dimension, e.g. for species with natural ranges which cross national borders (or even state/provincial borders); in cases where a species may be much more economically important as a planted exotic than in its own country and native habitats; and opportunities for *ex situ* conservation in well-resourced facilities (tree seed banks, tissue culture facilities etc).

The management of forest genetic resources to simultaneously ensure their conservation, improvement and sustainable use is a complex technological and managerial challenge. Fortunately, when simple basic principles are applied, the production of goods and services from managed forests forming part of a legislated permanent forest estate is generally compatible with the genetic conservation and development of particular forest tree species, as discussed in section 1.1.5.

There are four quite different, but complementary, approaches and actions which are making important contributions to conservation of forest genetic resources. These are:

1-Targeted species based approaches, typically highly resource intensive, and which aim to conserve as much intraspecific diversity as reasonably possible for high priority forest tree species. The main reason for high priority rating is that the particular species is of major national and/or international economic importance. A species based approach may also utilized for endangered tree species, but in these cases the intensity of genetic conservation effort is less and directed towards maintaining enough diversity, in preferably more than one population, to ensure the species survival. In the ideal species-based conservation plan the distribution of the species intraspecific diversity and associated relevant factors will be well known. Populations for conservation are selected on the basis of most efficiently and securely conserving as much genetic diversity as possible including rare alleles and co-adapted gene complexes of identified high value populations/ seed sources, in a network of managed *in situ* FGR reserves. For species exhibiting clinal variation, connectivity and gene flow between populations would be maintained through vegetation corridors and/or linked by *circa situm* plantings. In many instances implementation will involve a diverse group of land managers and interested parties, and in some cases international collaboration. Ideally safety duplication of the material conserved *in situ* would also be undertaken through *ex situ* methods, such as long term seed storage banks for species with orthodox seed storage behaviour, and through tissue culture banks and field gene banks for species with recalcitrant seed storage behaviour. Despite this approach having major benefits and having been widely promoted by FAO and forest geneticists over the past thirty or more years, there are few examples where it has been implemented, and these are mainly restricted to developed countries in Europe and North America e.g. Norway spruce (*Picea abies*) in Finland (Koski 1996), but with only a few documented cases in tropical countries, e.g. Sumatran pine (*Pinus merkusii*) in Thailand (Theilade *et al.* 2000). Since 2007, considerable preparatory work for conservation of priority European tree species in 36 European countries has been undertaken through Bioversity's European Information System on Forest Genetic Resources (EUFGIS; http://www.eufgis.org), implemented in collaboration with the European Forest Genetic Resources Programme (EUFORGEN)). This involved creation of an on-line information system network of FGR inventories and development of minimum requirements for dynamic conservation units of forest trees. EUFGIS involved the creation of an online information system and a documentation platform for forest genetic resources (FGR) inventories in Europe. While EUFGIS is not itself a programme for *in situ* conservation of forest genetic resources it will support participating countries in their efforts to implement forest tree gene conservation as part of sustainable forest management. Since 2120 EUFGIS is being further developed as part of EUFORGEN.

2-Large scale, long term ex-situ conservation in seed banks for tree species with orthodox seed storage behaviour . Many countries have national tree seed banks but these are usually active collections, with rapid turnover and use of collected seedlots and in which conservation is a supplementary or incidental benefit, e.g. CSIRO's Australian Tree Seed Centre. A major international example of this conservation strategy for trees and woody species is the Kew Millennium Seed Bank Partnership, based in Wakehurst, UK (http://www.kew.org/science-conservation/save-seed-prosper/millennium-seed-bank/about-the-msb/index.htm and see section 1.1.6). This partnership covers about 50 countries, and has already successfully banked 10% of the world's wild plant species, including many woody species, and has an objective of conserving 25% of the world's wild plant species by 2020. An example of this partnership in action is in Burkina Faso where the National Forest Seed Centre (CNSF) has 160 tree species in long-term cold storage (Burkina Faso p 2 and 22).

3-Ecosystem- and landscape-based conservation approaches and management regimes which either aim to, or sometimes incidentally, conserve in situ a wide array of forest tree species and their diversity (SP6). These approaches are devoid of a particular tree species focus unless the tree species has been identified as a keystone species whose continued existence and diversity are vital for maintaining the ecosystem's health. These management regimes are well-suited to areas with high tree species diversity, such as lowland tropical rainforests. In locations where local human populations are reliant on a vast number of tree and woody species to provide diverse products, then managed multiple-use production forest systems. This approach can ensure the continued survival and availability of large numbers useful tree species which may have localised and/or potential importance. Fully protected areas systems will only likely succeed in the longer term in areas of low population pressure.

4-Conservation through planting and use (SP9). Increasingly many socio-economically important tree species are being conserved through use, often planted for productive and other purposes in plantation forests, agroforests, orchards and urban landscapes (home gardens, parks and street trees). The conservation of FGR in these cases is often incidental, unplanned, and suboptimal; an exception is breeding programs and seed orchards which are often designed with maintaining a balance of diversity and improvement. There are opportunities to conserve substantial tree species diversity (including within species diversity), in for example urban landscapes, farms, hotel resorts, golf courses etc if managers of these areas could be made aware of the importance of such activities and linked into national FGR programs.

1.1.4. Forest Cover

The Global Forest Resources Assessment 2010 (FAO, 2010) provides a comprehensive assessment of the world's forests. Some of the major findings of FRA 2010, with notations on impacts and considerations for FGR[6], are as follows:

The world's total forest area is just over four billion hectares, with the five most forest-rich countries (the Russian Federation, Brazil, Canada, the USA and China) accounting for more than half of the total forest area. The rate of deforestation – mainly from the conversion of tropical forest to agricultural land shows signs of decreasing, but is still alarmingly high. Around 13 million hectares of forest were converted to other uses or lost through natural causes each year in the last decade compared with 16 million hectares per year in the 1990s. Two countries with biodiverse and FGR-rich forests, viz. Brazil and Indonesia, which had the highest net loss of forest in the 1990s, have significantly reduced their rate of loss and this will also entail a slowing in rate of loss of tree species and populations.

At a regional level, South America suffered the largest net loss of forests between 2000 and 2010 – about 4.0 million hectares per year – followed by Africa, which lost 3.4 million hectares annually. Both regions are rich in tree species and FGR, and such forest loss would be accompanied by an irreplaceable, but poorly documented loss, of valuable FGR. Oceania also reported a net loss of forest (about 700,000 ha per year over the period 2000–2010), mainly due to large losses of forests in Australia, where severe drought and forest fires have exacerbated the loss of forest since 2000. The area of forest in North and Central America was estimated as almost the same in 2010 as in 2000. The forest area in Europe continued to expand, although at a slower rate (700,000 ha per year) than in the 1990s (900,000 ha per year). Asia, which had a net loss of forest of some 600,000 ha annually in the 1990s, reported a net gain of forest of more than 2.2 million hectares per year in the period 2000–2010, primarily due to the large-scale afforestation reported by China. Whilst the forested area has been increasing in Asia, this is masking a loss of valuable FGR (both species and especially populations of useful tree species) from shrinking native forests in many countries in south and south-east Asia. Primary forests, which include some of the most FGR-rich forests, account for 36 percent of the global forested area, but have decreased by more than 40 million hectares since 2000 with, in most cases, a permanent loss of associated forest genetic resources. It some cases the forest cover estimates have varied from FRA 2005 due to changes in the criteria used for assessment, e.g. Ethiopia's forest cover jumped to 11% (from 3.5%) in the 2010 FRA assessment on inclusion of high woodland areas into forested area (Institute of Biodiversity Conservation, 2012), but during this period there has been increased human pressures and severe drought impacts on Ethiopia's tree resources.

Around the globe the area of planted forest is increasing and now accounts for seven percent of total forest area, with the highest proportion in Asia (almost 20%). These figures underscore the need to carefully consider the genetic materials being used to establish planted forests, and for forests regenerated artificially or with human management. There is a need to ensure such forests are utilizing appropriate, diverse, adapted (including for predicted new climates) and useful genetic materials and that information on the genetic makeup is being well-documented. There is also a need for safe movement of germplasm to ensure that pests and diseases are not inadvertently introduced,

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[6] Forest cover is a crude measure of FGR conservation as, at either extreme, forests may range from well-connected, highly biodiverse, well-managed tree-species rich communities, with limited immediate threats to their integrity, and which conserve substantial amounts of FGR through to clonal monocultures which have no meaningful FGR conservation role.

especially as forest tree species may be more vulnerable to pests and diseases due to climate change. Regionally and sub-regionally there are large differences in the proportion of planted forest consisting of exotic species, from a very high proportion of exotics in in Eastern and Southern Africa (100%), South America (97%), Central America (81%), Oceania (77%), Western and Central Africa (70%) through to very low proportion of exotics in North America (2%) and arid regions, such as Western and Central Asia (4%) and North Africa (7%). This data underscores the need for continued and increased international collaboration in the conservation, exchange and benefit sharing of tree germplasm and FGR.

FRA 2010 is a treasure-trove of useful data on forest distribution and their status, including on matters impacting on FGR conservation and management for example type of regeneration method, indicators of sustainable forest management, extent of permanent forest estate and protected area. This first SoW-FGR is complementary to the FRA process, and annual State of the World Forests reports, given that forest cover and related data cannot be used as a surrogate for assessment of the status of FGR, and will help to differentiate between the state of the world's forest resources and the genetic resources on which they depend for their utility, adaptability and health.

1.1.5. Management systems in the field (including in situ and circa situm conservation of FGR)

"Sustainable forest management of both natural and planted forests and for timber and non-timber products is essential to achieving sustainable development and is a critical means to eradicate poverty, significantly reduce deforestation, halt the loss of forest biodiversity and land and resource degradation, and improve food security and access to safe drinking water and affordable energy…The achievement of sustainable forest management, nationally and globally, including through partnerships among interested Governments and stakeholders, including the private sector, indigenous and local communities and non-governmental organizations, is an essential goal of sustainable development…" (Paragraph 45, Plan of Implementation, Report of the World Summit on Sustainable Development).

The sustainable utilization of timber and non-wood forest products (NWFP) from forests, without depletion of the supporting FGR, is becoming increasingly challenging, notably in the context of heavily-populated, developing countries many of which suffer poverty and chronic famine[7]. Limited options for economic development and an imperative to focus on immediate needs, promotes short-term perspectives in the use and management of natural resources, including forests and the FGR on which they depend. The global population continues to increase[8], especially in tropical developing regions and placing additional pressures on forests. There are estimated to be around 400 million people dependent or highly reliant on forests for their livelihoods[9]. Whilst there is a marked trend

[7] The UN's 2012 Millennium Development Goal report estimates that, despite progress in eradication of extreme poverty, almost 1 Billion people will be living on an income below USD 1.25 per day in 2015, while FAO estimated that 850 Million people (or 15.5% of the world's population) was living in hunger in the period 2006-8.

[8] The current global population of around 7 billion is projected to reach 9.3 billion by 2050, according to the medium variant of the 2010 Revision of World Population Prospects

[9] According to the World Bank's 2002 strategy on Sustaining Forests, there are about 60 million people (mainly indigenous and tribal groups) are almost wholly dependent on forests, and some 350 million people who live within or adjacent to dense forests depend on them to a high degree for subsistence and income.

towards increasing urbanization of human populations[10] the movement of people into cities does not much diminish their needs for wood and fibre for building, fuel, paper; NWFPs and agroforestry tree products (AFTPs) such as herbal medicines and foods. Forest genetic resources conservation and management in the field, should ideally, be considered and integrated into all land uses and management systems containing trees, the most important of which are sustainable managed multiple-use production forests, protected forests, and agro-forests[11].

FGR in sustainably managed multiple-use production forests

Sustainable forest management involves the management of forests in a manner that ensures that their overall capacity to provide environmental and socio-economic benefits is not diminished over time. Central to the sustainable development of forests is the challenge of balancing resource use and conservation. Sustainable forest management and the maintenance of FGR are best considered as interdependent: the essential underpinning role of FGR in forest and natural resources management practice needs to be better understood and appreciated by forest owners, custodians and managers in order that they will implement effective interventions for their conservation and use. In many cases, the management measures for maintaining diversity in forest ecosystems and for simultaneously promoting the sustainable use of this diversity have been developed and are known (see for example, FAO 1993; Thomson 2004). What is lacking is their constant application and monitoring. Furthermore, harmonizing conservation objectives and utilization practices in production-oriented, multiple-use native forests will be essential for conservation of the diversity of the majority of tree species, given that they are not well represented in protected areas, plantations and *ex situ* collections (Thomson 2004).

Technologies for sustainably managing and utilizing native forests without diminishing, and preferably enriching, their FGR have been traditionally practiced through diverse indigenous forest management systems and practices. FGR management practices are able to be readily integrated into modern silvicultural systems by forest agencies and/or private forestry companies. However in many parts of the world, tree species diversity and intraspecific diversity, is declining because best practice forest management systems are not being implemented or are breaking down for various reasons.

Traditional forest and woodland management systems are coming under increased pressures, viz. more people per unit of available forest, resulting in tree resources being harvested and used unsustainably, including overharvesting of timber, fuelwood and NWFPs; reduction in seed sources of pioneer and early secondary trees and not enough time for deep-rooted perennial vegetation to replenish soil fertility in-between shortened fallow periods. Selective overharvesting, much of it illegal, and leading to extinction of the highest value species in the forests is a major and increasing problem intertwined with rural poverty. Tree being harvested include both high value timbers such as Thai rosewood (*Dalbergia cochinchinensis*) species in Thailand and Indochina, African blackwood (*Dalbergia melanoxylon*) in sub-Saharan Africa and red sandalwood (*Pterocarpus santalinus*) in India, and those producing valuable NWFPs, such as massoia (*Cryptocarya massoia*) in New Guinea (bark for massoia lactones for food industry), African cherry (*Prunus africana*) in Afromontane forests (bark for treatment of benign prostrate hypertrophy), sandalwoods (heartwood of certain

[10] The United Nations Population Fund has described how the movement of people from rural to urban areas has contributed to the explosive growth of cities around the globe, whereby in 2008, for the first time in history, more than half of the world's population was living in towns and cities

[11] Trees outside of forests in non-agricultural land use systems, such as urban landscapes, also may comprise important FGR but are considered to be outside of the scope of this first swr-FGR.

Santalum and *Osyris* spp. for essential oils) in India, Indonesia, Timor Leste and the Pacific Islands and Himalayan yew tree (*Taxus contorta* for production of taxol, a chemotherapy drug to treat cancer) in Afghanistan, India and Nepal.

Harvesting of wood resources for fuelwood and charcoal is often less discriminatory but can lead to permanent loss of tree species and locally adapted populations, reducing options for future recovery either by natural or human-mediated means from the associated environmental degradation. For example, severe deforestation is taking place in Somalia to provide income for the militant group al-Shabaab: this includes elimination of ecologically important tree species such as *Acacia* for charcoal, along with selective harvesting and loss of the highly valuable frankincense (*Boswellia* spp.) trees. In north-east Thailand, high rates of drug addiction in some villages have resulted in increased charcoal production and unsustainable resin harvesting from dipterocarps and pines in adjacent forests to pay for the illicit drugs, threatening Thai Forestry Department efforts to conserve unique lowland populations of Sumatran pine (*Pinus merkusii*).

FRA 2010 reported on broad progress towards sustainable forest management since 1990 and found that at the global level the situation has remained relatively stable. The 2010 assessment did not include species or population-level indicators suitable for a global comparison of trends over time and therefore does not directly report on FGR. The biological diversity theme was covered through reference to: the area of primary forest, areas designated for conservation of biological diversity and area of forest in protected areas. The results for forest biodiversity conservation were mixed, with the area of primary forest recording one of the largest negative rates (in percentage terms) of all measures, and declining by between 4.7 million hectares per year during the 1990's and 4.2 million hectares per year between 2000-2010. The area of forest designated for conservation of biological diversity increased by about 6.3 million hectares per year during the last decade with a similar increase in the area of forest in protected areas. The area under production forests, and considered equally vital for conservation of FGR, has continued to decline at an increasing rate, by about two million hectares per year during the 1990s and three million hectares per year between 2000 and 2010.

FRA 2005 reported that globally 80% of world's forests are under public ownership and that 80% of publicly-owned forests are under public administration. This data would suggest that National Governments are in a strong position to directly influence and control forest management practices. However, in the developing tropics, many production forests are under private logging concessions, and Governments frequently lack resources to develop and enforce sustainable best practices by private operators, such as codes of logging practice and reduced impact logging guidelines. The problem is compounded where concessions are issued for a short term or once-off, as the logging concessionaire will harvest in a manner that will maximise profits from the logging operation, with less or little consideration for regeneration and subsequent harvests.

In future sustainable production of goods from native forests will be increasingly challenged by predicted more extreme climatic events, the most severe of which for forest products will include more intense tropical cyclones, droughts and associated bushfire, intense rainfall events with landslips and flood, and melting of permafrost. There will also be interactions of climate change with existing and new pests, diseases and invasive weeds, and on pollinators and dispersers, which will impact on production, selective forces and the future forest composition. The genetic diversity contained within and among tree species will provide an essential buffering for these impacts on many forest productive and service functions, but may require a much greater level of management intervention and manipulation, including movement of tree germplasm to respond to new climates, changed pest and diseases and new selective pressures.

Sustainable forest management cannot by itself ensure conservation of all FGR. There are tree species and populations that require special and immediate attention, as well as many species of no or little current utilitarian value that the forest manager probably will not be able to attend to. Some of these lesser-known or less economically important species may depend on complicated ecological interaction and may suffer from what at present is believed to be gentle utilization of the forest resources. Therefore, an integrated approach encompassing management of natural stands and establishment of specific conservation populations is advocated.

FGR in protected areas

The existing national protected area systems are often a valuable starting point for a network of conservation stands of a particular species. Indeed there are likely to be several thousand tree species which only occur within the existing protected area network. However, the security of forest protected areas remains a major concern, especially in developing nations. It has been argued that only a minor percentage of protected areas can be truly regarded as secure and more than half face threats to their integrity and existence in the medium term. On a positive note, FRA 2010 found that the area of forest designated for conservation of biological diversity increased by about 6.3 million hectares per year during the last decade and a similar increase occurred in the area of forest in protected areas. In both cases the increase is equivalent to nearly two percent per year over the last decade. The role of protected areas in conserving FGR has been reviewed in Thomson and Theilade (2004). These authors also discuss ways to enhance the FGR conservation role of existing protected areas, and emphasized the imperative of involving local people in protected area conservation measures.

FGR in agroforestry systems, including trees on farms

The work of ICRAF and national partners in the development of context-specific agroforestry systems, integrating traditional knowledge and scientific advances, and based on diverse, adapted tree germplasm, offers one of the most promising solutions to addressing problems of over-population and limited land base. FAO estimates that 1.2 billion people use trees on farms to generate food and cash (http://www.fao.org/forestry/livelihoods accessed November 2012), with almost half of the agricultural land in the world, or more than 1 billion hectares, having a tree cover of more than 10 percent (Zomer *et al*., 2009). there has been an increasing appreciation of the importance of using appropriate, matching, diverse and improved germplasm in agroforestry systems over the past two decades, including appropriate seed and seedling production and dissemination systems. This has included the domestication of many different indigenous fruit and nut tree species to provide a source of nutrition and income for rural households through meeting identified, different market opportunities. Simmons and Leakey (2004) have coined the term of agroforestry tree products (AFTP) for these new products. The R&D and extension efforts into agroforestry led by ICRAF, and many national, donor and NGO organization partners have borne and will continue to bear fruit as long as the genetic diversity on which they rely is both conserved and accessible. There has also been an important spill over of knowledge on the importance of, selection and improvement of germplasm in conventional plantation forestry to agroforestry R&D. An example of the evolution of use of tree germplasm in modern agroforestry is provided from Fiji and the South Pacific Island nations. Through the mid-1970s and early 1980s, the official promotion of village forestry mainly consisted of distributing seedlings of Caribbean pine (*Pinus caribaea*), including those leftover from *P. caribaea* planting programs. During the 1980s the emphasis moved to alley cropping systems with fast-growing nitrogen fixing exotic trees, through the Fiji-German Forestry Project: red calliandra (*Calliandra calothyrsus*) was shown to be well-suited but the systems were not adopted by farmers. During the mid-1990s and 2000s the AusAID-funded SPRIG (South Pacific Regional Initiative on Forest Genetic Resources) project worked with national partners to develop and domesticate a much broader selection of native tree species and a few key exotics, such as big-leaf mahogany (*Swietenia macrophylla*) and teak (*Tectona grandis*), which are now being incorporated into a diverse range of agroforestry systems, including modified traditional polycultural systems, in Fiji and other South Pacific Nations. Species such as the extremely cyclone tolerant, multipurpose timber tree malili (*Terminalia richii*) which had been reduced to scattered trees by mid-1980, is now being widely planted by smallholder farmers and tree growers in Samoa.

1.1.6. Role of ex situ conservation

Role of genebanks:

The primary aim of *ex situ* conservation has always been to ensure the survival of genetic resources which otherwise would have disappeared. For forest genetic resources, *ex situ* conservation has generally been referred to storage as seed, when practical, usually under conditions of low moisture content, and where species are intolerant of these conditions, it has been necessary to rely on field or glasshouse collections. However, such collections are costly to maintain, are at risk from pest and disease outbreaks and climate variability and extremes, and therefore are not as safe a long-term option as seed storage. For these reasons *in vitro* technology has been proposed as an alternative strategy. Conventional seed storage is believed to be a safe, effective and inexpensive method of conservation for seed-propagated species. Successful long-term conservation through seed storage relies on determining the factors that regulate seed viability and vigour, as well as continuous monitoring of viability with re-collection or regeneration whenever the viability drops below an acceptable level. Seeds can be categorized according to their storage behaviour, which is a reflection of the seed moisture content. The final moisture content in the seeds depends on the species and the external environment. Orthodox seeds dry out to 5-10% during maturation; these seeds are shed in a highly hydrated condition, endure a chilling period during maturation and are therefore adapted to the low temperatures used for orthodox seed storage. They can be stored for long periods of time at seed moisture contents of 3-7% on a fresh weight basis at -18^{o}C or cooler (Theilade and Petri 2003).

In contrast relatively high moisture content, generally greater than 40-50%, is maintained in recalcitrant seeds. A distinction has been made between those seeds that are temperate-recalcitrant and tropical-recalcitrant. Species which fall into the former group can be stored at near freezing temperatures for several years but are intolerant of drying. For example, *Quercus* species can be stored for 3- 5 years as long as a high (35-40%) seed moisture content is maintained. Seeds from tropical-recalcitrant species require the same gas and moisture levels but are very sensitive to low temperatures. For example, species from the genus *Shorea*, *Hopea* and several tropical fruit trees will lose viability at 10-15^{o}C (Phartyal *et al*. 2002). Many forest tree species from temperate and especially tropical regions produce recalcitrant seeds. An intermediate category has been identified where seeds are partly tolerant to dehydration and cold. Longevity of intermediate seeds is quite short, a significant constraint for conservation in a number of species, which include a large proportion of tropical forest trees (Joët *et al*. 2009). Generally seed behaviour is probably best considered as a progression from orthodox to recalcitrant, and the number of species identified with non-orthodox behaviour is increasing, and its basis more complex than initially envisaged (Berjak and Pammenter 2008).

Before the seed from any species can be considered for storage the behaviour of that seed to desiccation and chilling must be determined. Variable success has been achieved globally with seed drying such that some species considered as recalcitrant have later been identified as orthodox. For example, European beech (*Fagus sylvatica*) and two tropical species, lemon (*Citrus limon*) and African oil palm (*Elaeis guineensis*) fall into this category (Phartyal *et al*. 2002) A further complexity occurs when species within a genera show both orthodox and recalcitrant behaviour, for example, *Acer* spp. (Phartyal *et al*. 2002) and *Shorea* spp. (Theilade and Petri, 2003). Infrequently apparent seed storage behaviour may vary geographically within the same species as in yang-na (*Dipterocarpus alatus*; with populations from drier zones having more desiccation tolerant seeds) and New Caledonian sandalwood (*Santalum austrocaledonicum*; Thomson 2006) and even depending on the stage of maturation at collection, storage and rehydration regimes in neem (*Azadirachta indica*; Sacandé and Hoekstra 2003).

Short to medium term storage of recalcitrant seeds can be achieved by maintaining the seeds at the lowest temperature they will tolerate, under conditions that do not allow water loss. However, these conditions will encourage the growth of micro-organisms and therefore appropriate action, such as fungicide treatment has to be used (Berjak and Pammenter, 2008). Fungicide treatment was effective in extending the storage life of kongu (*Hopea parviflora*; Sunilkumar and Sudhakara 1998).

Problems with seed handling and storage affect the implementation of conservation programmes. The Millennium Seed Bank Project (MSBP) is the largest *ex situ* conservation project in the world; the project aims to conserve 25% of wild plant species by 2020. The number of tree species conserved by the MSBP at this stage is difficult to predict, however the research being conducted by the MSBP into the challenges of seed banking, such as post-harvest handling (including seed sensitivity to drying) will significantly expand existing possibilities for conservation of forest genetic resources. To date the seeds of more than 20 important palm species and around 100 dryland species have been tested for tolerance to drying (http://www.kew.org/science-conservation/save-seed-prosper/millennium-seed-bank/seed-research-problem-solving/index.htm).

Seed storage duration varies across different plant species, hence the MSBP is evaluating various factors such as structure of the seed embryo and climate conditions during seed development and ripening, which can impact on seed storage duration. Baseline data on the desiccation tolerance and longevity of tree seeds is very limited (Hong *et al*. 1998; Dickie and Pritchard 2002). Similarly, more information is needed on the control of tree seed germination, including the method by which dormancy can be alleviated. Species of the temperate and tropical highland zones possess a range of varying degrees of dormancy with dormancy conditions within a species differing according to factors such as time of collection and climatic conditions. Under the MSBP, a unique seed database has been established, which provides information on a wide range of functional traits or characters including seed desiccation tolerance, germination and dormancy etc. Seeds are classified according to the different storage categories, at the same time the lack of knowledge that exists for tropical species is acknowledged. The World Agroforestry Centre maintains an Agroforestree database, which provides storage information for a total of 670 agroforestry tree species.

***In vitro* conservation**

More than 70% of commercially valuable tropical tree species are estimated to have recalcitrant or intermediate seeds (Ouédraogo *et al*. 1999), as such long term conservation using conventional seed storage is not possible. For this reason significant effort has gone into establishing *in vitro* approaches for conserving forest genetic resources. However, woody species are often difficult to establish *in vitro*, with problems occurring at any one of the multiple stages of shoot culture establishment.

The first stage of establishing cultures derived from mature forest trees can be challenging because of high levels of contamination and/or high secretion of polyphenols and tannins. A review of the progress made in establishing tissue cultures of threatened plants (Sarasan *et al*. 2006) highlights a range of methods that have been developed to initiate cultures of often recalcitrant plants of limited number. The same review explores different approaches to managing tissue and medium browning.

Successful initiation of *in vitro* cultures is not the only challenge; of key importance is the establishment of stabilized shoot cultures to provide a stock of plants that are more reproducible and stable to those found in the field or greenhouse. Despite progress in this area, *in vitro* shoot growth stabilization, that is a culture with uniform and continuous shoot growth, is not well understood (McCown and McCown 1987). However, rejuvenation is undoubtedly a major contributing factor with explants derived from juvenile sources easier to establish *in vitro* than adult plants of the same genotype. The use of juvenile tissue has been successful with a number of species for example, mangium (*Acacia mangium*), ear-pod wattle (*A. auriculiformis*), teak (*Tectona grandis*), jelutong (*Dyera costulata*), sentang (*Azadirachta excela*), agarwood (*Aqualaria malaccense*) and rotan manau (*Calamus manan*) (Krishnapillay 2000).

Episodic species, such as many of the nut trees and conifers, are highly problematic in tissue culture compared to the sympodial species which show continuous seasonal shoot growth, such as many of the pioneer trees. Episodic trees tend to maintain their episodic growth pattern in culture, so that random flushes of growth are followed by periods of inactivity during which the cultures deteriorate. Success using *in vitro* approaches is generally found in non-episodic species, for example *Eucalyptus* and *Populus* (McCown, 2000). However, two approaches to culturing highly episodic species have been successful. One approach utilizes the generation of shoots *de novo*; the actual induction of adventitious meristems being a rejuvenation process in itself. This approach has been very successful with conifers (Ahuja, 1993). The second approach focuses on rejuvenation either of the stock source or of the tissue cultured tissues (Greenwood 1987; McComb and Bennett 1982).

Multiplication and rooting of shoot culture systems for tree species can be demanding with very specific requirements depending on the species and often the variety. For example, multiplication and rooting of the endangered tree ginkgo (*Ginkgo biloba*) was promoted by incorporating the endosperm from mature seeds of the same species in the culture medium (Tommasi and Scaramuzzi 2004). Sarasan (2003) reported the use of supporting materials such as Florialite and Sorbarods to improve rooting and the quality of roots produced from the critically endangered tree Saint Helena ebony (*Trochetiopsis ebenus*). A recent publication (Pijut 2012) reviewed *in vitro* culture of tropical hardwood tree species from 2001 to 2011. The publication provides outlines of methods used for a wide range of species of this commercially important group.

Only once an efficient and effective system for generating stabilized shoot cultures is established should there be any attempt to develop an *in vitro* storage protocol. *In vitro* conservation technology provides two options, that of restricted or minimal growth conditions or cryopreservation. Minimal growth storage can be achieved in a number of ways. The most popular are modification of the culture medium, reduction of the culture temperature or light intensity. Minimal growth storage has been reported for several species such as flooded gum (*Eucalyptus grandis;* Watt *et al*. 2000), lemon-scented gum (*E. citriodora*; Mascarenhas and Agrawal 1991) and *Populus* spp. (Hausman *et al.* 1994). *In vitro* conservation of kokum (*Garcinia indica*) with subculture duration of up to 11 months has been reported after the establishment of cultures from adventitious bud derived plantlets (Malik *et al*. 2005).

Minimal growth culture is generally only considered as a short-to-medium term conservation approach, because of problems in the management of collections even if the intervals between transfers are extended and also because of concerns of genetic instability caused by somaclonal variation. In addition, it is generally very difficult to apply one protocol to conserve genetically diverse material. A study conducted into *in vitro* storage of African coffee germplasm, which included 21 diversity groups showed large variability in the response: losses occurred in some groups whereas others were safely conserved (Dussert *et al.* 1997a). Technical guidelines are available on establishing and maintaining *in vitro* germplasm collections, although not specifically of forest genetic resources (Reed *et al.* 2004)

Cryopreservation offers an additional *in vitro* methodology for long-term conservation of forest genetic resources. Cryopreservation is the storage of biological material at ultra-low temperatures (usually that of liquid nitrogen, -196^{o}C). At this temperature all cellular divisions and metabolic processes are stopped, and therefore the material can be stored without alteration or modification for theoretically an unlimited period of time. In addition, cultures are stored in a small volume, are protected from contamination and require very little maintenance (Engelmann 2004).

One of the disadvantages of minimal growth storage is the possibility of somaclonal variation occurring. Cryopreservation reduces this possibility because the metabolism of the plant cells is suspended and subculturing is not part of the process. However it has to be acknowledged that the cryoprotocol exposes plant tissues to physical, chemical and physiological stresses which can all cause cryoinjury. However, although the number of studies conducted to determine the risk of genetic and epigenetic alterations is limited, there is no clear evidence that morphological, cytological or genetic alterations take place due to cryopreservation (Harding, 2004). For example, the genetic fidelity of white cedar (*Melia azedarach*) after cryopreservation was confirmed using isoenzyme analysis and RAPD markers (Scocchi *et al.* 2004). Cryopreservation is particularly useful for conserving embryogenic cultures of conifers where regular subculturing with conventional *in vitro* storage could affect the growth and embryogenic potential of the cultures.

Cryopreservation is also a cost-effective conservation protocol compared to minimal growth storage. To date studies have only been conducted on crop plants but the annual maintenance of the cassava collection (about 5,000 accessions) at the International Centre for Tropical Agriculture (CIAT) is USD 30,000 for slow growth storage and USD 5,000 for cryopreservation (Engelmann 2010).

Cryopreservation of biological tissue is only successful when the formation of intra-cellular ice crystals is avoided, since the crystals can cause irreparable damage to cell membranes, destroying their semi-permeability. In cryopreservation, crystal formation can be avoided through vitrification which significantly reduces cellular water through the formation of an amorphous or glassy state (non-crystalline) from an aqueous state. For cells to vitrify, a concentrated cellular solution and rapid freezing rates are required. Three categories of explants can be cryopreserved for woody species, shoot-tips for species that are vegetatively propagated, seeds or isolated embryos axes for those species which reproduce using seeds, and finally embryogenic callus.

Cryopreservation of hardwood trees has become increasingly successful since the introduction of PVS2 (plant vitrification solution), a solution containing penetrating and non-penetrating cryoprotectant solutions. Species where the vitrification/one-step freezing protocol (using PVS2) has been successful include *Malus, Pyrus, Prunus* and *Populus* spp. With these species survival rates higher than 50% have been achieved (Lambardi and De Carlo 2003). Over 90% survival rates have been reported for flowering cherry (*Cerasus jamasakura*; Niino *et al.* 1997) and white poplar (*Populus alba*; Lambardi *et al*. 2000). Vitrification has proved successful (71% recovery rate) with silver birch and morphology and RAPD analysis of regenerated plants in the greenhouse suggests that the genetic fidelity remains unchanged (Ryynanen and Aronen 2005a). Compared to shoot tips, cryopreservation of embryogenic callus and somatic embryos from hardwood trees however is limited. Success using the vitrification/one-step freezing protocol has been achieved with European chestnut (*Castanea sativa*; Correidoira *et al.* 2004), and cork oak (*Quercus suber*; Valladares *et al*. 2004).

Cryopreservation of embryogenic cultures of conifers is well advanced with successful application to a range of species including *Abies*, *Larix*, *Picea*, *Pinus*, and *Pseudotsuga*. Over 5,000 genotypes of 14 conifer species are cryostored in a facility in British Columbia (Cyr 2000). The technique used is mainly based on slow cooling technology where slow cooling to -40^{o}C concentrates the intra-cellular solution sufficiently to vitrify upon plunging into liquid nitrogen. Other cryobank collections of tree species exist (Panis and Lambardi 2005):

- 2,100 accessions of apple (*Malus* spp.; dormant buds) at the National Seed Storage Laboratory, Fort Collins, USA;
- Over 100 accessions of pear (*Pyrus* spp.; shoot-tips) at the National Clonal Germplasm Repository of Corvallis, USA;
- Over 100 accessions of elm (*Ulmus* spp.; dormant buds) at the Association Forêt-cellulose (AFOCEL), France; and
- About 50 accessions of mulberry (*Morus* spp.) at the National Institute of Agrobiological Resources, Japan.

In addition some tropical and sub-tropical species are being cryo-preserved:

- -80 accessions of oil palm (Elaeis guineensis) at the L'Institut de Recherche pour le Développement, France (Engelmann 2004) ; and
- -National Bureau of Plant Genetic Resources, India holds collections of Citrus spp., jackfruit (Artocarpus heterophyllus), almond (Prunus dulcis) and litchi (Litchi chinensis) (Reed 2001).

Despite the progress made with cryopreservation, only a limited number of truly recalcitrant seed species have been successfully cryopreserved. There are many reasons as to why progress is so slow. A relatively large number of species, many of which are wild species, have recalcitrant seeds. Little is known about their biology and seed storage behaviour. Seeds are difficult to cryopreserve because they tend to be large and have high moisture contents when shed; excised embryos or embryonic axes can be an option. However viable tissue culture protocols needed to regrow embryos and embryonic axes after freezing are often non-existent or not fully operational. In addition, significant variation is often found in the moisture content and maturity stage of seeds and embryos of recalcitrant species between provenances, between and among seed lots and between successive harvests, making cryopreservation difficult (Engelmann 2010). Despite these hurdles, various technical approaches are being explored by various groups throughout the world to better understand and control desiccation sensitivity, and to improve knowledge of the mechanisms which are responsible for seed recalcitrance.

To improve the *ex situ* conservation of forest genetic resources using seed storage, significant effort has to be spent in developing post-harvest technology for proper handling and identification of storage behaviour. Once seeds of a particular species have been classified, then strategies can be developed for their conservation according to their storage behaviour.

1.2. VALUES AND IMPORTANCE OF FOREST GENETIC RESOURCES

This section reviews the immense value for humankind, and more generally to life on earth, that FGR represent.

1.2.1. Economic Values

FAO estimates that close to 1.6 billion people – more than 25% of the world's population – rely on forest resources for their livelihoods. The forest products industry alone is a major source of economic growth and employment, with global forest products traded internationally in the order of USD 186 billion, of which developing countries account for 20 percent in which forest based employment provides 32 million jobs (World Bank http://web.worldbank.org Accessed November 2012).

The contribution of FGR C&M to many countries' formal economies is important, when the forests and forest industry sectors are considered (e.g. Solomon Islands p4, Burkina Faso p2-3). Countries reported differing contributions of these sectors to the economy, both in terms of value of output and also as a proportion of GDP, export income, government revenue and employment. Contribution to GDP ranged widely, from 20% of GDP in Tanzania and valued at USD 2.2 Billion per annum (p 16, MNRT 2008), 20% of GDP or 478 Billion FMG per annum in Madagascar (p12), 6% of GDP in Gabon (p 8), 3-4% of GDP in Germany (pp5, 57) valued at 170 Billion Euros per annum to 0.026% in Cyprus (p7), to negligible for countries with no forest industries, such the Cook Islands[12].

Contribution to exports was substantial for many countries: in Canada the forest sector is the third largest contributor to balance of trade (Canada p11), while in Ghana the sector ranked fourth in contribution to export earnings (Ghana p47). For the Solomon Islands the export of round logs (1.4 M m^3 in 2008) provided over 70% of export earnings and 18% of total Government revenue: and is the mainstay of the economy (Solomon Islands pp xv, 4). In Swaziland (p 7) the contribution of the forest sector to national revenue was 26%. For countries that are net importers of forest products, import replacement can improve trade balances, and foster the development of domestic forestry and forest product processing industries (e.g. Ferguson *et al* 2003). Countries expressed their eagerness to increase production of forest products through the formal economy, to increase general economic well-being and to meet the domestic demand for timber, energy, food and medicines of strongly growing populations (e.g. China p4, Germany pp12-13, 57, 72, Madagascar p9e, Thailand p27). Degradation of forest resources can have significant economic impacts, for example, Ethiopia (p 9)

[12] In the case of Cook Islands forested landscapes such as dominate the main island of Rarotonga, are vital for water catchment and tourism. The type of tree cover is less important as use of local timbers for wood carving has almost disappeared, but important NWFPs such as maile (*Alyxia stellata*) for leis and herbal medicines may still be gathered, and endemic forest species may require particular tree species for their survival.

noted a decline of over 50% in contribution of forest sector to GDP between 2002 and 2011, with deforestation and degradation key causes of the fall.

Forestry and forest industries provide significant employment in many countries; for example, the sector supports 50% of the economic base in 500 communities in Canada as well as contributing to employment more widely (Canada p12); 2.8% of the workforce in Finland (p9) and 1.2 M people in Germany are employed in forest-based industries (Germany p57). The forest sector is a major provider of rural employment in Africa, e.g. In Swaziland (p7) 16-18% of the workforce, Gabon (p 8) 20-30%, Burkina Faso (p 10) and Ethiopia (p 55). Forestry is also the primary source of employment in rural areas of the Solomon Islands (p4). Many jobs in the informal economy are dependent on forests and trees: in Ghana, small to medium forest enterprises make up 75% of wood processing entities with a turnover of 70% of that the formal forest industry's total export earnings (Ghana p48).

The key economic values associated with FGR occur in both formal sectors, e.g. production, trade and employment associated mainly with timber, pulp and paper industries, but also with agriculture, horticulture and pharmacy; and informal sectors, such as through local, and often not well-documented, uses such as forest foods, fuelwood and herbal medicines. The World Bank has estimated that about 1 billion people worldwide depend on drugs derived from forest plants for their medicinal needs, while FAO reports that many developing countries draw on fuelwood to meet as much as 90% of energy requirements with fuelwood being the primary source of energy throughout sub-Sahran Africa.

In all, several billion people worldwide in the informal economy depend in some form on wood products and NWFPs from forests and trees, and the conservation of FGR and the development, distribution and deployment of improved forest trees for use by rural communities therefore offers immense potential to improve and increase security of livelihoods. Studies in Madagascar (p 12) have found that 80% of rural communites are living below the poverty line and have a strong dependence on forests for monetary income (26-30% of household income). In India, NWFPs are estimated to provide 50% of household income for one third of India's rural population (India p124) – a significant figure considering the country has 275 M rural poor, 27% of the total population (India p123). The harvest of NWFPS from trees and forests in impoverished rural areas can contribute to gender equality: in rural areas of one Indian state women obtained 2.5-3.5 times as much income from forests and common lands as men (India p125). The contribution that trees and forests makes to gender equality was also noted by China (pxi). NWFP may also provide significant additional income to small forest owners and traditional communities in developed countries ; for example maple syrup products and Christmas trees and generate over $350 M and $40 M worth of sales annually, respectively (Canada p12).

Trees play extremely important roles in supporting agricultural production, particularly in developing countries, through providing shelter, shade, protection of crops, soil structure and fertility improvement, reduction of erosion and flood mitigation, and provision of materials such as fencing, processing equipment, and tools. Ghana (pp 47-8) noted that 'the use of non-timber forest products in agriculture technologies is such that in their absence most farming activities would be impaired.' Trees also support agricultural production through provision of fodder, which may be critical during the dry season or through times of drought, e.g. in India (p 17) 'nearly 39% of cattle depend on forests for their fodder either partially or fully'; in Niger (p 2) 25% of the diet of ruminant animals is derived from tree leaves and fruits and vital during the dry season. Forests and trees also play a major role in alleviation of poverty in times of hardship and crop failure: Zimbabwe (p 28) noted that a period of national economic hardship resulted in substitution of kerosene with fuelwood by rural and urban families alike, meeting a critical domestic shortfall. Some countries reported that tree food crops are vital in times of drought, when other annual, rain-dependent crops may fail (Ghana p49); in Zimbabwe (p 35) 'the cutting down of fruit trees is in some areas prohibited by the traditional leaders as the trees are often the source of food in periods of poor crop harvests'. Climate change is predicted to bring about greater environmental stress that will impact on agriculture, increasing the role for trees both as food sources to help alleviate famine and for environmental protection in times of drought and flood (SP15).

For many NWFPs there is wide genetically determined variation in yield and quality of product obtained, and indeed some industries are only possible because of this variation. An example is UMF (unique manuka factor) honey, a highly antimicrobial type of honey which is only produced by bees feeding on the nectar of particular populations of *Leptospermum,* such as some populations of manuka (*L. scoparium*) in New Zealand (Stephens 2006). In Vanuatu certain individuals and populations of New Caledonian sandalwood (*Santalum austrocaledonicum*) from Malekula and Santo, produce a sandalwood oil which meets the international standard for East Indian Sandalwood oil and accordingly have much higher value as seed and wood sources (Page *et al*. 2010), and future replanting will be increasingly based on these sources (Stephens 2006). The rich tree and woody species diversity of tropical forests directly contributes to their provision of a wide range of NWFPs, e.g. in Brazil, honey bees have been found to produce a new type of medicinal red propolis through collecting resin from the bark of coin vine (*Dalbergia ecastaphyllum;* Silva *et al*. 2008).

The specific economic benefits arising from conservation and use of FGR are difficult to isolate from the economic benefits and impacts of the industries which are reliant on them. A common finding is that the use of selected better performing seed sources (provenances) will often give a 10-25% increase, sometimes several hundred percent, in wood yield above the mean or for the currently used seed source. Given that seed is a small proportion (e.g. 0.1 to 3%) of plantation establishment cost, major economic benefits are being accrued from using appropriate germplasm in plantation establishment and agroforestry (e.g. FAO, 2002). Economically important, although often threatened diversity, is contained in wild tree relatives of fruit and nut tree species. For example, germplasm of a wild and threatened central Asian apple species, *Malus sieversii*, collected in the 1990s from Kazakhstan has shown resistance to apple scab, fire blight, drought and numerous soil pathogens and is being used by the USDA Agricultural Research Service to improve disease resistance in current apple cultivars (Forsline *et al*. 2003; Pons 2006) for the USA industry worth USD 2.7 billion in 2011.

The genetic diversity available in tree species is often of economic utility and exploited in tree planting for amenity purposes, such as in urban landscapes. For example the cold hardiness of the Turkish provenance of the cedar of Lebanon (*Cedrus libani*) is valued for planting in the USA for its greater cold hardiness (Aiello and Dosmann 2007). Economic value was the most commonly cited reason for nominating species for priority for FGR C&M, at 46% of nominations. Economic values also ranked highest of the uses listed for the countries' most utilized species, with timber, posts/poles/roundwood, and pulp accounting for 32% of uses mentioned. Providing food security was reported as an important use in 12% of cases, and contribution to reduction of poverty in 11%. Energy accounted for 10% of nominated values, medicines 6%, food 5% and NWFPs 12%. There was an emphasis on tree species suitable for development of forest industries and plantations in the priority listings in country reports; the majority of these species were well-researched, widely-planted, globalised, industrial forestry species. Their widespread and major appeal lies largely in their proven, documented ability to perform in a variety of environmental conditions, the high level of genetic and performance information available and the relative ease of obtaining germplasm. Amongst the most widely used genera are *Eucalyptus* and *Pinus*; increasingly planted high value tropical trees include teak (*Tectona grandis*), mahogany (*Swietenia* and *Khaya* spp.) neem (*Azadirachta indica*), rosewoods (*Dalbergia* and *Pterocarpus* spp.) sandalwood (*Santalum* spp.) and agarwood (*Aquilaria* and *Gyrinops* spp.). In nominating priority species, many countries cited objectives such as meeting local demand for timber and wood products, import replacement, facilitating the development of forest industries, fostering exports, providing employment, and providing alternatives to unsustainable or illegal forest harvesting by rural communities and others.

The predominance of formal economic importance in country priority listings is represented by India's approach to prioritising species for *ex situ* conservation, which states that 'the efforts must be proportional to the present knowledge on the utility of the species' (India p25). Nonetheless, several country reports listed a myriad of tree species used for a multitude of purposes in rural areas, often by many Ms of people. Tanzania, for example, noted that focus on 'charismatic' species may draw conservation and development effort away from less recognised indigenous species, even though the latter help maintain ecosystems and at the same time as displaying excellent growth characteristics (Tanzania pp23-24). In some instances there appeared to be a discontinuity between the economic species nominated by countries for priority FGR C&M, and the patterns of use of trees and forests reported in countries. For example, the use of timber for fuel (as firewood or charcoal) was a primary use value in many developing countries, particularly in Africa (e.g. Ghana p25), as well as being recorded for Europe. Globally fuelwood ranked second in uses of trees at 10% after timber, posts, poles, roundwood and pulp combined at 32%. Similarly, medicinal uses of tree species were important in Africa, at 14% of nominated uses. However, the importance of these uses was not reflected in country priority lists of species for FGR C&M. A further preference was to prioritise species with uses and potential applications as recognised by countries' formal economies and forest sectors. This highlights the importance of addressing a wide range of a country's needs in both the informal as well as the formal sectors in the prioritisation of tree species. A heavy emphasis on a small number of exotic commercial species important to formal forest sector risks overlooking and underestimating the contribution of many other native tree species to national well-being, particularly in rural communities. It also demonstrates the importance of harmonising FGR strategies with other national objectives such as development goals. In some countries there is opportunity to address this matter through more direct and wider consultation and participation of communities in setting priorities for FGR.

Using the example mentioned above, the tendency to emphasise commercial timber and plantation establishment at the expense of other uses and values is illustrated in the Ghana report, where energy use now dominates demand for wood products: wood provides 86% of urban energy and more than 95% of energy consumption in rural areas, and it accounts for 91% of round wood production (Ghana p25). However, previous forestry policy has led to the establishment of timber plantations that do not address this demand, instead emphasising high value timber species: 'to date, a total of 260,000 ha of plantations have been established under various government-led programmes. The main forest plantation species are teak (*Tectona grandis*), cedro (*Cedrela odorata*) and gmelina (*Gmelina arborea*) which constitute 90% of the total plantings (Ghana p24). Thus in some countries there appear to be opportunities for closer alignment of species prioritised for FGR C&M with patterns of existing domestic demand.

The emphasis on high performing, 'globalised' plantation tree species can result in a tendency to overlook the potential for development of lesser-known but commonly used indigenous species in favour of prioritised, tried and tested exotic species, or 'charismatic' local utility trees (e.g. Tanzania pp23-24). Where a focus on priority species is at the expense of exploring the potential of local trees and conserving their genetic variability, there is a risk of losing opportunities for development of highly adapted, productive trees as well as important components of ecosystems.

Some regional differences were observed in country listings of values of most commonly used species, with the Pacific Island countries expressing a much wider spread of values than other regions (although this may be skewed due to inclusion of few Pacific nations in the figures). Food was the primary value listed in the Pacific Islands region at 22% of uses mentioned, followed by posts, poles and roundwood at 18%, eclipsing energy at 15% and timber at 14%. This compares with the predominance of wood products (timber, posts/poles/roundwood, and pulp) in other regions.

In summary absolute and relative economic values of forest and trees products and services vary tremendously from country to country, however an underlying and unifying theme from country reports prepared for the SoW-FGR is that continued availability, access and use of FGR underpin these economic values.

1.2.2. Environmental values, ecosystem services and resilience

Forest ecosystems are repositories of huge reservoirs of biodiversity, and support a vast number and wide range of species, most of which are forest dependent, and and ecosystem processes. As well as supporting the greater proportion of the world's biodiversity, there is increasing recognition of the role of forests and trees in environmental protection, rehabilitation, and provision of environmental services more generally.

Nevertheless, vital environmental services but these have traditionally been undervalued due to lack of markets for these services. Such services include biodiversity generation and maintenance; carbon storage and sequestration; water production – catchment management services; soil protection and prevention of erosion; assistance to agriculture, e.g. shelter and fodder for livestock including bees; as a habitat and source of animals with human utility and value, and tourism. The roles of forest genetic diversity in ecosystem adaptation and resilience are fertile topics for research, but in-depth scientific investigations are still in their infancy.

Trees contribute major photosynthetic inputs, drive carbon and nutrient cycling, and provide diverse substrates and physical structure to forested terrestrial ecosystems. Perhaps not surprisingly a very large proportion, nearly 90 percent, of terrestrial biodiversity is found in the world's forests. The most species diverse ecosystems on Earth are tropical lowland rainforests, and these are principally located in developing countries. Recently the vast richness of herbivorous insects in tropical rainforests has been shown to be driven by the phylogenetic diversity of their plant assemblages (Novotny *et al.* 2006). Temperate forests and forest tree species support and provide habitat for myriad other life forms. For example, two thirds of Canada's (p13) 140,000 species, two thirds occur in forest ecosystems. In the UK 285 different species of phytophageous insect have been found on the English oak (*Quercus robur*) (Southward *et al.* 2004) and while in Australia 306 species of invertebrates have been found on messmate *(Eucalyptus obliqua)* (Bar-Ness *et al*. 2006). In its native Australia, the globally widely planted river red gum (*Eucalyptus camaldulensis*) is sometimes referred to as 'nature's boarding house' in recognition of the number of mammals and birds that utilise is flowers and leaves for food and its hollows for shelter and nesting sites. In less tree-species rich temperate forests, the role of trees in promoting biodiversity is likely to be more associated with and attributable to their level of intraspecific genetic variation (e.g. Whitham *et al.* 2006). The work of EVOLTREE (EVOLution of TREEs as drivers of terrestrial biodiversity), launched in 2006 and now a network of 23 research groups in 13 European countries is testament to the growing interest and importance attributed to the new field of forest ecosystem genomics.

Resilience capacities of forest ecosystems are conferred at multiple scales, through genetic, species and landscape heterogeneity (Thompson *et al.* 2009, 2012). The abilities of different species, including tree species and genotypes, to substitute functions is key to their buffering of impacts of environmental change and maintenance of ecosystem functioning (Walker 1992; Lavorel 1999; Yachi and Loreau 1999; Elmqvist *et al*. 2003; Hooper *et al.* 2005; Winfree and Kremen 2009; Thompson *et al.* 2012). Accordingly the ability of an individual forest stand to adapt and recover from environmental changes will depend on the number of species, their diversity, individual adaptive capacities and abilities to substitute different functions.

Trees and forests, and their genetic resources, will play an essential and central role in helping to limit and rein in rises in atmospheric carbon, and slow climate change. While mature forests are more-or-less in carbon balance, their between and within-species diversity, helps to buffer them against change and destruction (whether mediated by climate, biotic, fire or combinations) which might result in damaging releases of CO_2. Vigorously growing tree plantations sequester vast amounts of carbon, e.g. maximally around 80 tonnes of CO_2 per hectare for eucalypt hybrids in Brazil, while trees generally provide fuel for billions of people without adding to the burning of fossil fuels. Tree breeders will require genetic diversity to develop faster growing, well-adapted trees for a diverse range of environmental conditions for generation of fuels, and carbon sequestration including through biochar, an important non-labile carbon soil additive to increase agricultural productivity.

Countries reported a range of environmental applications of trees and forests in their country reports, including contribution to biodiversity, water catchment management, carbon sequestration, nutrient cycling, improvement of soil fertility, erosion management and landscape protection, promotion of agricultural production and maintenance of ecological processes. Ecological values were mentioned in 97 cases or 3% of priority species nominations. In the North American region, ecological values comprised 35% of the species value nominations, followed by the Pacific Islands with 20% of nominations. Countries nominated 1023 tree species used for environmental purposes in report tables; total nominations including multiple listings of the same species by different countries totalled 2902, indicating that some of the same species were used in different countries. However it is clear that these figures grossly underestimate the number of tree species and the contribution of forests to environmental services, as all trees and woody plants, whether planted or of natural origin, fulfil ecological and environmental functions and provide a huge range of environmental services.

The tabulated results show biodiversity conservation as the most commonly nominated environmental use accounting for 27% of lisitngs, followed by soil and water, and watershed management at 23%; improvement of soil fertility at 12.5%. A number of countries included aesthetic, cultural and religious values under this category of 'environmental uses', accounting for 30.5% of total species use nominations. The vast majority of species used for environmental purposes were native (863 out of 1023 species or 84%), with 16% exotic. This contrasts with the species nominated as priority, where at least 85% of the 1451 priority species whose origins were known were exotic. The European region nominated the most number of trees used for environmental purposes, accounting for 1600 or 55% of the 2903 nominations – more than all the other regions combined, followed by Asia with 827, representing 28% of nominations. These figures may reflect the long history and advanced state of European forest management practice which recognises the role of trees in environmental protection on the one hand, and environmental imperatives in the case of Asia on the other, for example, high levels of environmental damage (e.g. flooding, landslides) attributed to illegal logging.

1.2.3. Social, cultural, medicinal and scientific values

Forest genetic resources have major social, cultural and spiritual values, mainly at tree species level with many individual tree species distinguished and named in local languages. Various native tree species are intertwined with local cultures, customs, stories/folklore, poems, and identity, and integral to the daily lives of indigenous peoples (Brazil p 18, India pp 9-10). Many thousands of tree species are utilized for social and cultural uses, including for a multitude of products and in customs, ceremonies and rituals that help give meaning and enrich the lives of hundreds of millions of people. For example in India, between 100,000-150,000 sacred groves have been reserved (p 67), with certain tree species having tremendous social and cultural importance, e.g. banyan (*Ficus religiosa*) in religious ceremonies, sandalwood (*Santalum album*) in burial ceremonies and neem (*Azadirachta indica*) in traditional medicinal culture. In many parts of sub-Saharan Africa, certain trees and forest areas are considered sacred and maintained in sacred groves or church plantings (Burkina Faso p 1, Chad p14-15, Ethiopia pp 5, 19, 56, Ghana p 22, Zimbabwe pp 8, 35). Throughout the Pacific Islands, *Intsia bijuga* has spiritual significance and in Fiji the common name for the tree, vesi, is also the name reserved for village chiefs. There are also numerous examples where intraspecific tree diversity has cultural importance. For example in the Pacific Islands, there are hundreds of named varieties of pandanus (*Pandanus tectorius*), mostly selected female plants and propagated vegetatively, with different varieties being used at different times for foods, for different types of leis, and in different types of thatched mats and other plaited wares (Thomson *et al.* 2006). *Pandanus* is also important for construction materials, medicines, decorations, parcelization, perfumes, and other many cultural uses. *Pandanus* is the ancestral tree for most Kiribati people from which, according to legend, the progenitors of the I-Kiribati came (Luomala 1953).

Medicinal uses were mentioned as extremely important uses in some regions and countries: many more trees were utilized for medicine in Africa than in other regions, with medical use nominated in 14.4% of total reported uses. As an example in Zimbabwe (p7) over 78% of the rural population uses traditional medicines at least once a year for humans and livestock, with the majority of these medicines being derived from trees and woody plants. In the Pacific Island countries medicinal use accounted for 8.6% of reported uses, and medicinal uses are important in Indian Ocean island countries such as Madagascar (p 18) and Seychelles (p 18, 40). Medicinal uses of trees were also noted as important throughout Asia 43ncluding China with nearly 1000 medicinal plants (pp7-8), mainly woody species; India (pp5-6, 17,71) and Nepal (p 29) and Indonesia (pp8, 24) with 2039 medicinal plants. The search for medicinal compounds, or biopreospecting, has potential to yield dividends to supplier countries where sound benefit sharing arrangements are in place; for example in the Pacific Islands, the Samoa Government has signed an agreement with University of California, Berkeley, to isolate the gene for a promising anti-AIDS drug from the mamala tree (*Homalanthus nutans*) and to share any royalties from sale of a gene-derived drug with the people of Samoa, while the Solomon Islands (p 20) flora's chemistry and medicinal values are being investigated through a collaboration with Japan. Given the vital importance of FGR for traditional medicines and the potential benefits from bioprospecting there is vital need for more research on the medicinal values of forest trees to help unlock the full potential of FGR (SP17).

FGR are of major scientific value, and intraspecific diversity can be used, for example, to help understand the genetic, biochemical and physiological basis for resistance to pests and diseases or environmental stresses such as climate (drought, flooding) and edaphic extremes (salinity, acidity etc), and biosynthetic pathways for production of important products and metabolites. A recent and surprising example of the potential scientific importance of previously little known tree species is provided by amborella (*Amborella tricopoda*), a small understorey tree endemic to the wet, upland forests of New Caledonia, and endangered by habitat destruction. *Amborella* is considered to have diverged earlier than other flowering plants (about 130 million years ago), and lacks vessels in the wood which are characteristic or other angiosperms. In 2012 the *Amborella* genome project (http://amborella.org/ Accessed 18/10/2012) produced a draft genomic sequence which will be used to provide key evidence for understanding the ancestral state for every gene, gene family, and protein sequence in flowering plants, and how they radiated through the history of flowering plants. The genomic information may provide insights into the evolution of flowering and vessel formation in wood.

Social, cultural, recreational, ornamental and gardening purposes accounted for 15% of the values reported as reasons for nominating species for priority listing, this compares with 46% for economic purposes and 24% for environment. Social values may be especially important in certain countries – for example, sacred and religious values are important in Burkina Faso (pp8, 16, 18), India (p67), Zimbabwe (p35), and Ghana (p22). Cultural, aesthetic and religious values accounted for the largest proportion – 30.5% – of 'environmental' uses of trees nominated by countries, ranging from African nominations at 21.5%, North America 26%, both Europe and the Pacific at 35% and Asia 38%. The great majority of species listed as serving environmental purposes, of which social, religious and aesthetic values comprised the largest part, are native, with 84% of species; in direct contrast to the proportions for priority species where only 15% of species were native. This is likely to reflect the close cultural affinities for native species a country's people develop over millennia and which help to shape national and cultural identity.

1.2.4. Preserving future development options

One of the most important values and characteristics of FGR is that they will be vital for preserving future options, some of which are becoming all-too-evident such as coping with climatic extremes and adapting to the new warmer climates brought about increases in atmospheric CO_2, but others for which we may currently have little idea. Based on geological records, the Earth is likely to return to a new period of glaciation possibly 3,000 to 20,000 years hence, but the impact of longer term impacts of current human-induced warming on global climate on a future glaciation event are unknown. In the meantime it would be reprehensible if we allow useful tree species and populations adapted to cooler climates to become extinct from global warming and other factors when their germplasm might be safely and relatively cheaply conserved long term in cool storage such as the Svalbard Global Seed Vault in Norway, i.e. for several hundred to thousands of years at -18^{o}C.

The importance of maintaining FGR for preserving options applies to both natural forests, where a key dimension is capacity to adapt to changing environments, as well as planted forests where the key dimensions may be the need for new products and services while and at the same time proving resilient. In the case of planted forest tree species, there is a need to maintain as much intraspecific diversity as possible to allow tree breeders to continue to select and develop improved and adapted germplasm to cope with new demands and growing conditions. This might include development of new wood products and NWFPs, especially pharmaceuticals and neutriceuticals, such as sources of antioxidants, anti-inflammatories and other chemo-protective natural compounds. There may be novel uses such as specifically breeding trees to sequester carbon, recycle plant nutrients from beyond crop root depth, or to 'harvest' precious minerals through phytomining, e.g. Wood and Grauke (2010) have found that tetraploid hickory (*Carya*) species are high accumulators of rare earths (almost 0.1% dry weight) and much higher than diploid *Carya* species, and non-*Carya* tree species. In New Caledonia, several hypernickelophore tree species, including *Geissois pruinosa* and *Homalium kanaliense* can accumulate the valuable metal nickel to up to 1% of leaf dry mass (Boyd and Jaffré 2009). The differential ability of plants to accumulate gold is also well known, e.g. Girling and Peterson (1980), but has not been commercially exploited to date. In future certain tree species and genotypes might be used or selected and bred for phytoremediation, viz. to remove or neutralize contaminants, as in polluted soil or water (e.g. Raskin and Ensley 2000; Pilon-Smits 2004).

In summing up it is evident that well-characterized[13], genetically diverse wild populations (or provenances) of different tree species will provide extremely useful genetic materials both for immediate planting programs and as the basis for any future selection and improvement programs. The diverse values and uses of forests and trees and FGRs identified in country reports underscore the need for national FGR strategies, and effective programmes and action plans to address not only the applications and requirements of the formal forests and forest industry sectors, but also their roles in the informal economy, the alleviation of poverty, in social, cultural, religious and identity areas, and their role in environmental services and rehabilitation. The major contribution of FGR to the informal economy highlights the need to consult with the widest range of forest users possible when preparing national strategies and programmes. Development of appropriate policy tools to provide a national framework for action and strengthening of institutional capacities constitute a fundamental strategic priority for conservation and sustainable use of FGR.

1.3. BETWEEN AND WITHIN SPECIES DIVERSITY

Most of this SoW-FGR report deals with intraspecific diversity, but it is also appropriate to consider the economic and other uses of trees and woody shrubs provided through diversity at species level. Indeed the future wellbeing of the human race, and the health and productivity of various ecosystems and communities, will often be reliant on genetic diversity both within and among tree species. A concise treatment of interspecific tree diversity (or diversity among and between tree species) follows, while Annex XXX provides a review on uses, products and services provided by different tree and woody shrub species, organized by phylogenetic relationship in plant families, throughout the globe.

1.3.1. Interspecific diversity (between species)

Trees and woody shrubs exist in two major groups of seed-bearing plants, viz. gymnosperms (cone-bearing plants) and angiosperms (flowering plants), with angiosperms having evolved and radiated into vastly more families, genera and species, including about 250,000 living species according to Kenrick (1999) over the past 290 million or so years. Approximately 80,000 to 100,000 tree species have been described and currently accepted as valid and unique: and together with larger woody shrubs they likely represent about 50% of all vascular plant species. Considerable research has been undertaken to understand how tropical forests develop and maintain their typically vast tree species

[13] By well characterized it is meant the growth and adaptability attributes, including genotype by environment interactions, and the type and quality of end products and/ or services that they will be able to provide.

diversity but answers remain elusive (e.g. Denslow 1987; Cannon *et al*. 1998; Ricklefs and Renner 2012). Tree diversity in complex ecosystems may not only be maintained, but may also have been in part generated, by host-pathogen and host-parasite interactions (Wills *et al.* 1997), as well as diversity in rainforest gaps or regeneration niches (Grubb 1977).

Research, development, conservation and utilization of tree species, in particular tropical species, has often been frustrated by insufficient and inadequate taxonomic knowledge, e.g. assessment of conservation status of different species (Newton and Oldfield 2008). Increasingly an array of more powerful and efficient genetic technologies is available to complement traditional, morphological-based, taxonomy and field studies. This is leading to a better circumscription of tree species and understanding of their phylogenetic relationships. The nature of variation in trees is such that species boundaries will not always be readily defined, including for example: species existing as morphologically distinctive and geographically disjunct populations which rarely exchange genetic materials and are best considered as provenances, varieties or sub-species; species which are readily discernible in most of the natural range, and have evidently been reproductively isolated for much of the recent evolution, but which form fertile hybrid swarms in small overlapping contact zones; species with polyploid races, often coupled with apomictic reproduction; and ochlospecies whose complex variation patterns cannot be satisfactorily accounted for by conventional taxonomic categories (Whitmore 1976).

Based on Country Reports and literature reviewed in preparing Annex XXX it is conservatively estimated that there are more than 34,000 tree species[14] in more than 1000 genera that are of socio-economic, environmental and scientific importance and utilized on a regular (daily or weekly) basis by peoples throughout the globe. This number is comprised of both angiosperms (33,500 species in 976 genera and 131 families, including bamboos and palms) and gymnosperms (530 species in 67 genera and nine plant families, excluding cycads).

In practice, this vast diversity at species level in trees means that, for a given product like wood (e.g. fuelwood or timber) or service, local people and foresters may have the choice between hundreds of species, which are locally available and/or suitable options in different ecological conditions. As well as providing opportunities this vast species genetic resource can throw up challenges for ascertaining which species to prioritise for R&D and replanting. In north-east Thailand a framework species selection approach was adopted to identify a small number of local tree species for revegetation, from more than 350 local tree species, so as to most efficiently restore forest cover and catalyse return of biodiversity, and regeneration of hundreds of other tree species (Elliot *et al.* 2003).

Conservation of FGR, including a vast diversity at the tree species level, is seriously hampered by a lack of taxonomic skilld, inventory and knowledge of species distributions as indicated in many country reports. Accordingly there is an urgent and ongoing need to strengthen national FGR assessment, characterization and monitoring systems (SP1).

1.3.2. Intraspecific diversity (within species)

Intraspecific diversity or genetic diversity within tree species can be characterized at different levels and is manifested in different ways. These include at a molecular level through nuclear DNA (such as RAPD Random Amplified Polymorphism DNA – neutral markers), chloroplast DNA (especially

[14] This includes large woody shrubs attaining more than 2-3 m in height, given that the unclear boundary between trees and woody shrubs, and that individual species may exist as either trees or shrubs depending on environmental factors

useful for providing evolutionary information), direct RNA sequencing (providing information on gene regulation and proteins) and enzyme variation (gene products assessed through isozyme electrophoresis). Genetic variation is also observed at expressed levels such as through quantitative variation in growth and other traits as assessed through field trials, and including morphological, physiological, entomological and pathology studies. Sometimes variation is discontinuous, giving rise to the identification of varieties including chemotypes, morphotypes and alike. Intraspecific patterns of genetic variation in tree species have been found to vary due to factors such as the evolutionary history of the species; distribution of populations and connectivity; reproductive biology and mating system; dispersal of pollen and seed; introgression and hybridization with related species; chance factors and genetic drift. Observed patterns of genetic variation can vary between different genomes of the same tree species, if inherited differently, and with associated differences in dispersal of pollen and seed, e.g. Japanese beech (*Fagus crenata*) in Japan (Tomaru *et al.* 1998).

Humans have long been interested in utilizing and influencing tree diversity, especially tree species producing edible fruits and nuts, e.g. domestication and selection of walnut (*Juglans regia*) in Azerbaijan (p 22). Another well-documented case is the selection, translocation and domestication of tropical nut trees in Melanesian arboricultural systems in Papua New Guinea and Solomon Islands and dating more than 3,000 years (Yen, 1974; Lepofsky 1992; Lepofsky *et al.* 1998). However, the vast majority of traditional knowledge and improvement of FGR is undocumented and national-level assessments are needed a priority, especially in tropical countries, and before the information dies out with the holders of such information (SP2).

The forestry profession has had a long-time interest in studying and utilizing variation in trees, including investigations of geographic variation in economically important planted forest tree species through field trials, e.g. IUFRO coordinated provenance trials of Scots pine (*Pinus sylvestris*) established in 1907, 1938 and 1939 in Europe and the USA (Wright and Baldwin 1957, Langlet 1959, Giertych 1979). After the hiatus of World War II, provenance field trial research recommenced with earnest, e.g. ponderosa pine (*P. ponderosa*) provenance trials established in USA in 1947 (Callaham 1962) and new *P. sylvestris* provenance trials in Sweden from 1952-1954 (Eiche 1966; Erikkson *et al*. 1976). During the 1960's and 70's, assessments of genetic diversity in forest tree species gathered pace and extended to tropical and southern Hemisphere species: these assessments were focussed mainly on morphological attributes including wood traits, adaptiveness, quantitative growth characters, disease tolerance, and genotype x environment interaction. This information was determined through series of field trials, often undertaken in several countries and referred to as provenance trials. Some of the tree species studied in these early investigations included yellow birch (*Betula alleghaniensis*; Clausen 1975), cordia (*Cordia alliodora*; Sebbenn *et al.* 2007), river red gum (*Eucalyptus camaldulensis;* Lacaze 1978), Timor mountain gum (*E. urophylla*; Vercoe and Clarke 1994), European beech (*Fagus sylvatica*; Giertych 1990), gmelina (*Gmelina arborea;* Lauridsen *et al.* 1987), khasi pine (*Pinus kesiya;* Barnes and Keiding 1989), patula pine (*P. patula*; Barnes and Mullins 1983), radiata pine (*P. radiata;* Nicholls and Eldridge 1980), teak (*Tectona grandis*; Lauridsen *et al.* 1987), and limba (*Terminalia superba*; Delaunay 1978). Based on the success of the earlier provenance trials, the provenance trial approach has been continued and extended, including to national trials with native species – some examples include mulga (*Acacia aneura;* Ræbild *et al*. 2003a), ear-pod wattle (*A. auriculiformis*; Awang *et al.* 1994), Senegal gum acacia (*A. senegal*; Ræbild *et al*. 2003b), red alder (*Alnus rubra*; Xie 2008), neem (*Azadirachta indica*; Hansen *et al*. 2000), beach sheoak (*Casuarina equisetifolia*; Pinyopusarerk *et al.* 2004), chukrasia (*Chukrasia tabularis*; Ratanaporncharern 2002), Melanesian whitewood (*Endospermum medullosum*; Vutilolo *et al.* 2005), gao (*Faidherbia albida*; IRBET/CTFT 1985-88), pochote (*Pachira quinata*; Hodge *et al.* 2002), Caribbean pine (*Pinus caribaea*; Hodge and Dvorak 2001), pinabete (*Pinus tecunumanii*; Hodge and Dvorak 1999) and chicha (*Sterculia apetala*; Dvorak *et al.* 1998).

Country reports tabulated species/provenance trials, often extensive, which have been undertaken. However, a good many of these trials are in progress or not yet mature, and haven't been reported and readily available in the published scientific literature. Bulgaria's research has been focussed on 38 tree species, including 57 provenance trials (Bulgaria p 6). Canada reported 983 provenance tests comprising 7,493 provenances that have been established for 41 forest tree species and hybrids, eight of which are exotic (Canada p 111-112). In recognition of their wide planting in reforestation programs, six native species have been extensively tested both nationally and provincially, viz. white spruce (*Picea glauca*), black spruce (*Picea mariana*), jackpine (*Pinus banksiana*), lodgepole pine (*Pinus contorta* var. *latifolia*), Douglas fir (*Pseudotsuga menziesii*) var. *menziesii*, and western hemlock (*Tsuga heterophylla*). China commenced provenance trials in the early 1980s and has now conducted trials for more than 70 important planted species such as Asian white birch (*Betula platyphylla*), Chinese fir (*Cunninghamia lanceolata*), Dahurian larch (*Larix gmelinii*), Prince Rupprecht's larch (*Larix principis-rupprechtii*), Korean spruce (*Picea koraiensis*), Chinese white pine (*Pinus armandii*), Masson's pine (*Pinus massoniana*), Korean pine (*Pinus koraiensis*), Chinese red pine (*Pinus tabuliformis*), Yunnan pine (*Pinus yunnanensis*), oriental arborvitae (*Platycladus orientalis*), Chinese white poplar (*Populus tomentosa*), tzumu (*Sassafras tzumu*), Chinese coffin tree (*Taiwania cryptomerioides*), Siberian elm (*Ulmus pumila*) and various key exotic species (China p 11-13). In Madagascar (p 14) provenance trials of important and promising forest plantation species, mainly exotics, have been undertaken for *Acacia* spp, *Cupressus lusitanica*, *Eucalyptus* spp., *Khaya madagascariensis*, *Liquidambar styraciflua*, *Pinus* spp. and *Tectona grandis*.

Provenance/progeny trials continue to be undertaken amongst the first steps in domestication and improvement of wild tree species: the range of attributes being assessed is diversifying depending on the particular envisaged and sometimes specialist end uses, such as pulping and fibre properties, timber uniformity, as well as wood and leaf essential oils, fruit and nut characteristics for multipurpose species. There has been a continual increase over the past two decades in the number of species being developed in tree improvement programs, especially in response to wide interest in utilising native species in planting programs and utilizing the approaches and technologies developed for exotic species. For major industrial timber plantation species the improvement work has been undertaken through private sector and tree-breeding cooperatives, whereas early domestication and less intensive improvement of a broader range of species is being undertaken by National Forestry Departments, often in association with NGOs, and with international donor support or organizations such as ICRAF.

Internationally coordinated provenance trials of tree species will become increasingly important in providing data to better assess the modelled impacts of climate change on plantation productivity and to determining which species/provenances will be best adapted to the new and modified climates, e.g. Booth *et al.* 1999, Leibing *et al.* 2009 (SP15). Provenance trial data can also be used to assist interpretation of the likely impacts of predicted climate change on native species and populations, e.g. for *Pinus* species in tropical Asia and Americas; van Zonneveld *et al.* 2009ab, and for *Eucalyptus* species in Australia where minor changes in climate will expose at least 200 *Eucalyptus* species to completely new climatic envelopes (Hughes *et al.* 1996) and for which their adaptation potentials are unknown.

Increasingly, and gathering momentum over the past twenty years, detailed genetic information is being obtained for tree species often selected for study on the basis of their economic importance, conservation status or for use as representative model species. Many of the early molecular studies of diversity in tree species, in 1980s and 1990s, focussed on high priority timber trees and were mainly undertaken in forest genetic laboratories in developed countries using electrophoresis techniques. Detailed genetic evaluations using DNA and enzyme markers have now been undertaken for many important forest tree species in Europe and North America (e.g. Canada p 26-29 tabulated intraspecific genetic studies for 28 Canadian tree species). Until recently, in most developing countries there have been few detailed studies of intraspecific genetic variation. Such studies are needed for the formulation of scientifically-based gene conservation programs. Increasingly as evidenced in the scientific literature (and reported in country reports prepared for SoW-FGR) the patterns of genetic diversity for a much greater range of tree species, and from throughout the globe, are being determined and using a wide range of genetic markers, e.g. Thai tree species, Chantragoon *et al*. (2012) and more than 100 tree species in China over the past decade (China p 13- 14). In Burkina Faso, shea (*Vitellaria paradoxa* subsp. *Paradoxa*), néré (*Parkia biglobosa*), tamarind (*Tamarindus indica*), palmyra (*Borassus aethiopium*) baobab (*Adansonia digitata*), Senegal gum acacia (*Acacia senegal*) and marula (*Sclerocarya birrea*), have been studied with intra-specific methods from simple description morphological characters of the organs by enzyme electrophoresis or neutral markers of DNA (RAPD).

The planning of specific and efficient programs to both conserve and exploit the genetic diversity in target forest tree species requires a detailed knowledge of the species patterns of intraspecific diversity, notably a knowledge of how genetic diversity is distributed between and among populations (genetic snapshot), and complemented by a knowledge of the species ecology, especially regeneration ecology, reproductive biology and including relationships with other species, including pollinators, dispersers, symbionts, predators/parasites and competitors; in short the selective and evolutionary forces which had resulted in its genetic makeup.

Increasingly the data from genetic studies is being used to inform conservation of FGR in particular tree species. For example, yellow cypress (*Xanthocyparis nootkatensis*) and western red cedar (*Thuja plicata*) are mentioned in Canada's report (p 30). Other examples in the published literature include:

- -Red calliandra (*Calliandra calothyrsus*) in Mexico and Central America indicating need to conserve representative populations in four identified evolutionary significant populations Chamberlain 1998);
- -Pau-Brazil (*Caesalpinia echinata*) in Brazil indicating need to conserve different populations in different geographic areas (Cardoso *et al.* 1998); and
- -Marula (*Sclerocarya birrea*) in Kenya indicating need to conserve specific populations with high genetic diversity (Cardoso *et al.* 1998).

Sometimes genetic studies together with provenance trial/quantitative variation data, e.g. pino candelillo (*Pinus maximinoi*; Dvorak *et al*. 2002) or morphological quantitative data, e.g. he guo mu (*Paramichelia baillonii*) in China are used to inform conservation plans (Li *et al.* 2008). Various genetic studies are demonstrating the importance of glacial refugia for conserving tree species and their diversity, e.g. for broad-leaved trees such as oaks (*Quercus* spp.) in Europe (Iberian Peninsula, Appenine Peninsula and the Balkans) (Potyralska and Siwecki 2000); for bush mangoes (*Irvingia* spp.) in central and West Africa (central southern Cameroon, south-western Nigeria and central Gabon; Lowe *et al.* 2000) for Chinese firs (*Cunninghamia*) in east Asia (Huang *et al*. 2003). On the other hand, species growing in marginal environments or at the extremes (climate and soils) of the range may contain unique diversity and specific adapatations that warrants special attention for evaluation and conservation (SP9).

The increased information being generated through DNA studies is also being used to make generalised recommendations on how to conserve genetic diversity e.g. Hamrick (1994) suggested that five strategically placed populations should maintain 99% of their total genetic diversity when more than 80% of the total genetic diversity resides within populations. The review of Newton *et al.* (1999) noted that application of molecular techniques to diversity studies in a variety of tree species had highlighted a greater degree of population differentiation than indicated by previous isozyme analyses: in the absence of detailed information of the genetic structuring of a species, it may be prudent to conserve as many populations as feasible and resources allow.

In many countries the organizations involved in undertaking DNA research on trees, such as Universities and Research Agencies, are often different and not well linked up with the agencies tasked with developing and implementing FGR conservation strategies such as Forestry and Environment departments, land managers and others. Accordingly improved FGRC&M planning and outcomes will require closer communications between both groups both in identifying priority species for study and subsequent planning, implementation and monitoring of conservation and management strategies based on research findings.

1.3.3. Conserving distinct and unique tree lineages

It is logical that national conservation efforts will focus on maintaining the genetic diversity and evolutionary potential of high priority tree species at national level, and that international efforts will focus on those priority species whose distributions overlap the national boundaries and have wider socio-economic importance or have much more economic importance as planted exotics than in their country of origin. There is also a case to made, from both an international and scientific viewpoint, for conserving those tree species (families and genera) which are genetically most distinctive, e.g. monotypic families and genera, and representing the most evolutionarily divergent lineages. These genetically distinctive lineages and assemblages, may later be found to hold genes or combinations of genes which turn out to be incredibly useful to future generations, and are briefly discussed below and need to be considered in the context of SP11 (when prioritizing genera/species of scientific importance).

The gymnosperms (cone bearing plants) are replete with ancient, separate evolutionary lineages many of which are vital FGR. The order Ginkophytes comprises one family Ginkgoaceae and a single living tree species viz. *Ginkgo biloba*, a living fossil apparently almost unchanged in form for nearly 175 million years and an important source of herbal medicine. *Cunninghamia lanceolata* in its own subfamily Subfamily Cunninghamhioideae, while Taiwanioideae consists solely of *Taiwania cryptomerioides* and the subfamily Sequoioideae includes three renowned monotypic tree genera/species, viz. *Metasequoia, Sequoia* and *Sequoiadendron.* Many other coniferous genera comprise a single tree species which is highly valued for its timber, NWFP, cultural and/or environmental purposes, e.g. *Cathaya, Fitzroya, Fokienia, Lagarostrobos, Manoao, Nothotsuga, Papuacedrus, Platycladus, Pilgerodendron, Pseudolarix, Sundacarpus, Taxodium, Tetraclinis* and *Thujopsis.* Several of these monotypic conifer genera are at high risk of loss of intraspecific diversity, some threatened with extinction in the wild, including *Neocallitropis pancheri* in New Caledonia (which has yet to be assessed by IUCN). Many of the endangered and evolutionary unique lines of conifer subfamilies, genera and species are endemic to China and Vietnam; New Caledonia (France) and other Gondwanaland flora, and a continuing strong conservation effort for these taxa is needed in these countries.

The most primitive angiosperm or flowering plant is considered to be *Amborella tricopoda:* this species has been placed in its own order Amborellales and is of major scientific importance. Whilst its conservation status has yet to be assessed, it is likely to be at risk from climate change and fire entering previously unburnt, wet forest ecosystems in New Caledonia. The monotypic *Arillastrum gummiferum* from New Caledonia is important for forest science as an ancestral genus/species for eucalypts. Many angiosperm genera comprising a single tree species which may be highly valued for its timber, NWFP, cultural or environmental purposes and/or endangered including: *Antiaris, Aralidium, Argania, Aphloia, Aucomea , Bagassa, Baillonella, Bertholletia , Bosqueiopsis, Cantleya, Chloroxylon, Crossopteryx, Cyclocarya, Deckenia, Delavaya, Elingamita, Eusideroxylon, Faidherbia, Falcataria, Franklinia, Gomortega, Gymnostemon, Haldinia, Hartogiella, Itaya, Ixerba, Jablonskia, Jubaea, Kigelia, Kleinhovia, Koordersiodendron, Kostermansia, Krugiodendron, Laguncularia, Limonia , Litchi, Maesopsis, Muntungia, Neobalanocarpus, Noltea, Ochroma, Olneya, Oroxylum, Platycarya, Pleiogynium, Rhoiptelea, Spathodea, Ticodendron, Triplochiton, Umbellularia, Umtiza, Veillonia, Vitellaria, Xanthoceras, Veillonia and Zombia.* Monotypic wild fruit tree ancestors, such as *Clymenia polyandra* from Melanesia, may hold importance for future citrus breeding. Several angiosperm orders and whole families of woody tree species are represented by one or very few taxa. Barbeyaceae comprises the monotypic *Barbeya oleoides*; a small tree with medicinal uses present in north-east Africa and the Arabian Peninsula. Degeneriaceae includes two Fijian timber tree species, ancestral angiosperms in the genus *Degeneria*. Sladeniaceae includes three tree species in two genera, viz. *Ficalhoa laurifolia* a timber tree from montane forests in east Africa, and two Chinese tree species of *Sladenia* that have potential as sources of novel biochemicals, including for use in insecticides. The order Trochodendrales and family Trochodendraceae includes two East Asian tree species both in monotypic genera, viz. *Trochodendron araloides* and *Tetracentron sinense*. These two tree species are notable in angiosperms for their absence of vessel elements in the wood, which unlike *Amborella*, is thought to have been a secondarily evolved character and of scientific interest. The monotypic *Cordeauxia edulis* is an important multipurpose woody shrub in Ethiopia and Somalia is classified as vulnerable (IUCN) while the monotypic *Canacomyrica monitcola* is an endangered tree species (IUCN red list) endemic to New Caledonia. The 194 palm species in Madagascar are almost all endemic at both generic and specific levels (p 16) and together with several monotypic palm genera in Seychelles include unique and endangered genetic lineages.

1.4. THREATS

The unprecedented threats to FGR in recent times are almost exclusively of human origin. With the exception of geological events the categories of threat to species identified by the IUCN are residential and commercial development; agriculture and aquaculture; energy production and mining; transportation and service corridors; biological resource use; human intrusions and disturbance; natural system modifications; invasive and other problematic species; pollution; geological events; and climate change/severe weather. Major modern-day human impacts on the environment involve massive changes in land use systems, destruction and fragmentation of natural habitats, air and soil pollution, salinization and soil acificication, climate change, overexploitation of biological resources, homogenization of biota and biodiversity loss; these impacts interact with one another in complex ways and may result in non-additive cumulative effects (Yachi and Loreau 1999). In recent times and in the future, greatly increased threats to FGR are likely to come from forest cover reduction, degradation and fragmentation; climate change; forest ecosystem modification especially from invasive, ecosystem transforming species and interactions of different threat factors and these factors are discussed below in more detail.

1.4.1. Causes of genetic erosion, threats and risk status

Forest cover reduction, degradation and fragmentation

Over the past few hundred years, the main negative impacts on forest genetic resources, including loss of tree species, have been attributable to human-mediated forest cover reduction, forest degradation and fragmentation. This will almost certainly continue to be the case while the world's population continues to rise. India (pp 45-53) lists 261 tree and woody species whose genetic diversity is threatened, including 94 species in highest threat category: the identified threat types are almost entirely related to forest cover loss, degradation and fragmentation, including combinations and interactions of these threats. The major threats identified for 22 priority tree species in Chile come from deforestation and land use change (72%), with a high proportion also threatened by overexploitation (28%) (Hechenleitner *et al.* 2005; Chile pp 33-34). It is estimated that 20-33% of the Brazilian Amazon's more than 11,000 tree species, especially rare and narrowly distributed endemics, will go extinct due to habitat loss (Hubbell *et al*. 2008), and a broadly similar situation can be expected for much of the tropics. The main needs of the world's growing human population that impact on FGR found in native forests are additional land for agriculture, infrastructure and housing, mining, and to grow wood in plantation for building, paper and fuel.

Mining may cause the loss of entire local tree populations and Burundi (p iv) noted mining and quarrying as threats to FGR as did Papua New Guinea (p 17) and Solomon Islands (p 23) in the south-west Pacific. Cutting of trees for firewood was listed as a threatening process in several countries (e.g. Egypt p28 and Tanzania p 14). Ethiopia is a prime example of major loss of forested landscapes with forest cover diminishing from more than 50% in the middle of last century to currently around 3-11% cover (depending on forest cover definition, p 7). Ethiopia is rich in FGR, including more than 1000 woody plant species and two biodiversity hotspots, Eastern Afromontane and the Horn of Africa, but the viability of populations of important woody species is threatened by fragmentation (reduced gene flows), coupled with utilization pressures, fire and invasive species which increase the risk of local extinctions.

Whilst globally the rate of forest loss is slowing, as indicated in FRA 2010, the impacts of further forest loss on FGR are proportionally increasing because the losses of forests are affecting a smaller residual base of native forest, are concentrated in more biodiverse rich forests, and leading to greater fragmentation (e.g. Spain) with long-term impacts on associated animal species and gene flow and viability of more fragmented species and populations.

Atmospheric pollution, rising CO_2 levels and climate change

Since the Industrial Revolution atmospheric pollution has caused damage to Europe's forests, but is a diminishing direct threatening factor to FGR, with most damage likely to result from stressed trees being more susceptible to insect pests and diseases e.g. Poland. Of greater global concern for FGR are the increasing and accelerating CO_2 levels. These result from human activities (burning of fossil fuels, forest destruction etc) over the past half-century and are are already, as predicted by IPCC, contributing to more extreme climatic events. Worsening and changed climate, including prolonged drought is mentioned as a threat to FGR in many of the Country Reports to this SoW-FGR, including Burkina Faso, Chad, Niger and Tanzania and the same applies for many other Sahelian zone countries in West Africa. Temperature and precipitation are the two main climate drivers for forest ecosystems such that any significant changes will impact on species composition and forest cover. Impacts can range from extreme disturbances such as forest fires or pest outbreaks to more subtle changes in temperature affecting physiological processes. The ability of tree species to survive the current rapid climate changes will depend on the capacity to quickly adapt to the new conditions at the existing site, manage the changing conditions through a high degree of phenotypic plasticity without any genetic change, and/or migrate to an environment with the desired conditions for that species.

Some forest types are more vulnerable than others to climate change. For example, with tropical forests, small changes in climate are likely to affect the timing and intensity of flowering and seeding events, which would in turn have negative impacts on forest biodiversity and ecosystem services. Increased frequency and intensity of extreme events, such as cyclones may result in shifts in species composition. Mangroves are especially vulnerable with projected sea level rises posing the greatest threat to mangrove ecosystems. Mangroves potentially could move inland to cope with sea-level rise, but such expansion can be blocked either by infrastructure, or by the lack of necessary sediment, such as in the reef-based island archipelagos in Melanesia. Temperature stress will also affect the photosynthetic and growth rates of mangroves (McLeod and Salm 2006).

The area covered by forests will alter under climate change, with the ranges of some species being able to expand, whereas others will diminish; shifts will also occur between forest types due to changing temperature and precipitation regimes. For example, boreal forests would shift polewards with grassland moving into areas formerly occupied by boreal species. There is evidence of the migration of keystone ecosystems in the upland and lowland treeline of mountainous regions across southern Siberia (Soja *et al*., 2007). For temperate forests range reduction is expected to be more rapid at low elevation and low latitude, but at high elevation and high latitude their range is expected to increase to a greater extent than the boreal forests, thus reducing the total area of boreal forests. Thuiller *et al*., (2006) have shown that at low latitudes in Europe there will be a greater impact on species richness and functional diversity.

In the sub-tropical forests of the Asia-Pacific region, where key biodiversity hotspots are found, endemic species are predicted to decline, resulting in changes in ecosystem structure and function (FAO, 2010). Changes in precipitation rather than temperature may be more critical for these species and systems (Dawson *et al*., 2011)

Changes in water availability will be a key factor for the survival and growth of forest species, although the response to prolonged droughts will vary among tree species and also among different varieties of the same species (Lucier *et al*., 2009). In arid and semi-arid lands, increased duration and severity of drought has increased tree mortality and resulted in degradation and reduced distribution of forest ecosystems, including pinyon pine-juniper woodlands in south-western USA (Shaw *et al*. 2005) and Atlas cedar (*Cedrus atlantica*) forests in Algeria and Morocco (Bernier and Schoene, 2009). Indirect impacts must also be considered, for example, in Africa where drought is limiting the output from adjoining agricultural land, many communities with limited economic alternatives are likely to use the forests for crop cultivation, grazing and illicit harvesting of wood and other forest products, aggravating the local loss of forest cover (Bernier and Schoene, 2009).

Choat *et al.* (2012) have found that 70% of 226 forest tree species from 81 sites worldwide operate with narrow hydraulic safety margins against injurious levels of drought stress and therefore potentially face long-term reductions in productivity and survival if temperature and aridity increase as predicted. While gymnosperms were found more tolerant of lower conductivities than angiosperm trees, safety margins are largely independent of mean annual precipitation with all forest biomes equally vulnerable to hydraulic failure and drought-induced forest decline. These finding help to explain why climate-induced drought and heat can result in forest dieback across a broad range of forest and woodland types across the world. Examples can be found from southerly parts of Europe, and in temperate and boreal forests of western North America where background mortality rates have increased rapidly in recent years (Allen 2009). These dieback problems have occurred at a time when increases in temperature have been relatively modest, which does not bode well for future temperature predictions. Greater mortality rates can be expected with the more likely increase of 4^{o}C of warming, and significant long-term regional drying in some areas. Some climate change models predict a very significant dieback in parts of the Amazon and other moist tropical forests which would exacerbate global warming (Bernier and Schoene, 2009).

Changes in temperature and water availability will also influence the incidence and spread of pests and diseases. For example, the absence of consistently low temperatures over a long period of time (unusually warm winters) supported the spread of the mountain pine beetle, *Dendroctonus ponderosae*, in boreal forests and allowed an existing outbreak to spread across montane areas and into the colder boreal forests with a total of more than 13 million hectares of forest being under attack. Finland is expecting an increase in infestation of root and bud rots in their coniferous forests, due to the spread of a virulent fungus, *Heterobasidion parviporum*, favoured by longer harvesting periods, increased storm damage and longer spore production season (Burton *et al*., 2010).

Severe water stress will directly weaken and kill trees, or indirectly through supporting insect attack, for example, bark beetles, which can destroy trees already weak due to stress induced by climatic extremes (McDowell *et al*., 2008). A thorough analysis of historical records and adequate knowledge of insect population dynamics is needed before outbreak frequencies can be linked to climate change. The availability of such information has enabled researchers to link drought stress due to climate change to the extensive damage caused by insects to pinyon pine (*Pinus edulis*) in south-western USA (Trotter *et al*., 2008)

The global spread of harmful forest pest species is a possible outcome of climate change (Regeniere and St-Amant, 2008) with global trade facilitating the movement of mobile insect species to find hospitable habitats which are being increasingly provided by changes in the climate. There is significant evidence accumulating regarding insect distributions, however, the complexity of insect responses to climate factors makes predictions difficult. Generic modelling tools, such as BioSIM, attempt to predict the geographic range and performance of insects based on their responses to key climate factors. The basic premise is the ability of the insect to complete its life cycle under a specific climate with all requirements to sustain that cycle available. Using these models, distributions can be predicted by mapping climates that provide viable seasonality and overlaying the distribution of resources essential for (or most at risk from) that species. Further refinements can be achieved by also considering survival of that species under extreme climatic conditions. This approach has been applied to three species of importance to North American forests within a climate change scenario where there is a 1 percent rise per year in atmospheric CO_2. One of these species, the gypsy moth (*Lymantria dispar*) is prevalent in the USA and some parts of Canada however its northern limit in Canada is set by adverse climatic conditions. The model established for this species shows that it will be a considerable threat to hardwood forest resources as climate change allows for its expansion further north and west into Canada. It has been estimated that the proportion of forest at risk from this pest will grow from the current 15 percent to more than 75 percent by 2050 (Logan *et al*., 2003).

In the regions where temperate and boreal forests are found reduced snow cover, timing of snowmelt, shorter frost periods are contributing to the extent and severity of different climate conditions, such as drought and heatwaves. Reduced snow cover has been shown to be responsible for the yellow cypress (*Xanthocyparis nootkatensis*) decline which is affecting about 60 to 70 percent of the 240,000 hectares of yellow cypress, a culturally and economically important tree found in south-eastern Alaska, USA and adjacent areas of British Columbia, Canada. The snow normally protects the vulnerable shallow roots from freezing damage. Coastal Alaska is predicted to experience less snow, but persistent periodic cold weather events in the future, which will support the spread of dieback (http://www.fs.fed.us/pnw/news/2012/02/yellow-cedar.shtml).

Sensitivity to spring temperatures will affect fecundity. In central Spain a decline in cone production in stone pine (*Pinus pinea*) over the last 40 years has been linked to warming, in particular the hotter summers (Mutke et al., 2005).

A changing climate provides the opportunity for some species more suited to a wide range of climate conditions to invade new areas (Dukes 2003), resulting in the spread of invasive species, such as *Leucaena* spp. and *Eupatorium* spp., already known to have adverse impacts on biodiversity in subtropical forests in South Asia. Invasions of new genes via pollen and seed dispersal may have a negative impact on local evolutionary processes but there could be opportunities for finding sources of new adaptive traits (Hoffmann and Sgro, 2011)

Changes in the climate could impact on seed production due to asynchronous timing between flower development and the availability of pollinators, resulting in low seed production for outbreeding species dependent on animal vectors. Pollinators worldwide are being affected by climate change, and this will likely have a major impact on breeding systems and seed production with derimental impacts on forest health and regeneration.

A greater incidence of intense cyclones, extreme drought, fires, flooding and landslides have been observed in tropical forest ecosystems which have experienced increased temperatures and more frequent and extreme El Niño–Southern Oscillation (ENSO) events. Some climate change models predict a catastrophic dieback of parts of the Amazon and other moist tropical forests which would exacerbate global warming. It is clear from the evidence to date that the changes in the climate are already having an impact on forests throughout the world. Current and future climate change impacts on forests will vary from abrupt negative impacts to more subtle negative and positive impacts that arise in some regions or at particular sites, often only for certain tree species. There is an urgent need for countries to be assisted to cope and deal with impacts of climate change on FGR and to promote and utilise FGR to help with climate change adaptation and mitigation (SP15).

Changed fire regimes, including expansion of grasslands, and altered hydrological conditions

Climate change could alter the frequency and intensity of forest disturbances such as insect outbreaks, invasive species, wildfires, and storms. In recent years, wildfires consumed more than 2.5 million hectares of forest in Alaska; warm temperatures and drought conditions during the early summer contributed to this event (CCSP, 2008). Forest fires can be the greatest threat to biodiversity. In 2006 fires in New Caledonia engulfed more than 4,000ha near Noumea, destroying rare fauna. New Caledonia’s tropical forest ecosystems are unique, of the 44 species of gymnosperms that exist, 43 are endemic. In Siberia, Alaska and Canada extreme fire years have been more frequent (Soja *et al*., 2007). Interactions between disturbances can have an accumulative impact. For example, drought often reduces tree vigour, leading to insect infestations, disease or fire. Insect infestations and disease will add to the fuel available and therefore increase the opportunity of forest fires, which in turn can support future infestations by weakening tree defence systems (Dale *et al.*, 2001). Increased fire frequency could result in the erosion of fire-sensitive species from woodlands and forest. In regions where fires are not normally experienced, a rapid transition could occur from fire-sensitive to fire-resistant species. Throughout Africa, Near East and central Asia, countries reportedforest fires as a seriousthreat to forests and FGR e.g. Algeria (p 35), Burundi (p 10),Ethiopia (p 18), Iraqi Kurdistan (p 5), Jordan (p18), Kazakhstan (p 23), Lebanon (pp2,8), Mauritania (p 38-39) and Zambia (p 26).

Altered hydrological conditions are a major emerging threat to FGR. This includes increases in severity and duration of flooding, associated with climate change which can kill whole stands of trees. Even inundation-tolerant species, such as river red gum (*Eucalyptus camaldulensis*) and coconut (*Cocos nucifera*), are killed by waterlogging if the trees have not been regularly exposed to waterlogging and inundation through their development. Coastal inundation due to sea level rise beginning to kill coastal vegetation, in Kiribati a single king tide can kill established breadfruit (*Artocarpus altilis*) trees which major impacts on food security and livelihoods (as these trees harbour seabirds such as terns which are used by local fisherman to locate schools of fish). Studies with salt-tolerant non-halophyte trees (Thomson *et al.* 1987; references in Marcar *et al* 1999), have frequently demonstrated considerable genetically-based resistance to salinity. Given the substantial genetic diversity in breadfruit, including putative salt tolerance in particular varieties and natural hybrids between *A. altilis* and dugdug (*A. mariannensis*) (Morton, 1987; Ragone 1997), it is almost certain that salt- tolerant breadfruit can be selected and further developed – this is an urgent task given the impacts of sea level rise on Kiribati, Tuvalu and other atoll island nations in the Pacific Islands and elsewhere, and yet another example of the need to conserve and make use of genetic diversity in multipurpose tree species.

Invasive species: plants, pathogens, insect pests and grazing animals

Invasive species, including plants, insect pests and microbial pathogens, are increasingly being identified and noted as major threats to ecosystem integrity and individual species, including trees. In the USA, for example, 46% of all federally-listed threatened and endangered species are considered at risk primarily due to competition with or predation by invasive species, and interactions with other threat factors.

Invasive plants

In the case of invasive plant species the main threat comes from 'transformer' plant species which have the capacity to invade natural or slightly disturbed forest associations, becoming the dominant canopy species and totally modifying and displacing entire ecosystems, with the loss of many of the existing tree and other species. In East Africa (Kenya and Ethiopia, p 30 country report) the introduced tropical American tree *Prosopis juliflora* is taking over large swathes of natural forest and woodlands, considerably negatively impacting on native tree populations (both species and genetic diversity) and also damaging local livelihoods in the process (e.g. Mwangi and Swallow 2005). Since its introduction in the early 1900's, including later plantings to drain swamps, the Australasian tree *Melaleuca quinquenervia* has invaded up to 200,000 ha in South Florida (USA). In the process *M. quinquenervia* has transformed various ecosystems in the Florida everglades and causing major environmental and economic damage (Carter-Finn *et al.* 2006). Even minor climatic changes can seemingly result in native tree species becoming more invasive, spreading into neighbouring regions and dramatically changing the forest dynamics, structure and species composition, e.g. sweet pittosporum (*Pittosporum undulatum*) and coast tea-tree (*Leptospermum laevigatum*) in south-eastern Australia. This is likely to be a portent of future developments and challenges for *in situ* FGR management with predicted more extreme climatic changes favouring disturbance-adapted pioneer and early secondary tree species.

Island ecosystems are especially vulnerable to invasives: in a just a few decades African tulip tree (*Spathodea campanulata*), introduced as an ornamental, has taken over large areas of secondary and primary rainforest, and abandoned agricultural fields, in Fiji and threatens to become a major invasive tree in many Pacific Islands, including Australia and Papua New Guinea. The tropical American velvet tree (*Miconia calvescens*) has become one of the world's most invasive species and has completely taken over more than a quarter of rainforest in Tahiti, French Polynesia. The spread and impacts of invasives are frequently exacerbated by climate change or other major environmental disturbances. In the South-western Pacific, excessive opening of forest canopy due to intensive logging, coupled with major cyclones has greatly favoured the spread of the light-loving *Merremia peltata*. This native vine has now taken over large swathes of Pacific Islands' forest ecosystems, thickly draping all trees and shrubs, and maintaining these communities in a state of arrested natural succession in Samoa and Vanuatu.

Pathogens

There are many well-documented cases in the northern Hemisphere where virulent introduced pathogenic fungi have wreaked havoc on economically and environmentally important tree species. One often cited example is the accidental introduction of Asian chestnut blight fungus (*Cryphonectria parasitica*) into USA early last century which wiped out almost the entire population of American chestnut (*Castanea dentata*) including more than three billion trees over 70 million hectares; this was accompanied by the extinction of other species dependent on chestnuts including ten species of moths. Ironically, early salvation logging may have removed some of the few American chestnut trees which showed resistance to the disease. Programs have been implemented to backcross surviving American chestnuts with blight resistant chestnuts from Asia for reintroduction into the former natural range of the American chestnut. Since its introduction into North America around 1930, Dutch elm disease (*Ophiostoma*) has killed more than 95% of American elms (*Ulmus americana*), millions of trees, and it is estimated that only 1 in 100,000 trees is naturally resistant. A few resistant individuals in Canada have recently been cloned (Shukla *et al*. 2012), and along with newly identified resistant diploids and triploids in USA (Whittemore and Olsen 2011) and interspecific hybrids derived from crossing with resistant Asian *Ulmus* species are paving the way for American elms to be reintroduced in North America. In 1967 a virulent strain of Dutch elm disease (*Ophiostoma novo-ulmi*) introduced into the UK wiped out most of the elm (*Ulmus procera*) trees, although they often survive as suckers and in hedgerows, in UK and continental Europe (http://en.wikipedia.org/wiki/Dutch_elm_disease; accessed November 2012). Various selection and breeding programs with *Ulmus*, including development of interspecific hybrids, have produced clones which are resistant to the fungus in Europe. These two examples for elms in USA and Europe are illustrations of the benefits of retaining genetic diversity in tree species in order to deal with introduced exotic diseases. Various pathogenic diseases, many only identified or found over the past ten years, are now threatening important tree species in the United Kingdom (http://www.forestry.gov.uk/ accessed November 2012) including *Aesculus hippocastanum* (horse chestnut) – a new bacterial bleeding canker (*Pseudomonas syringae* pathovar *aesculi*) which was first detected around 2002, and now afflicts 70% of trees and likely to eventually kill them; *Fraxinus* species (ash) – chalara dieback caused by the introduced fungus (*Hymenoscyphus pseudoalbidus*), a serious disease first identified in 2012 and often resulting in tree death and spreading throughout Europe; and *Quercus* species (oaks) **-** recently a new disease, Acute Oak Decline, of bacterial origin which threatens to wipe out oaks in the UK.

In the past there have been fewer reported outbreaks of exotic pathogens causing major damage in natural and planted forests in the tropics and Southern Hemisphere, but the situation seems to have been changing over the past decade, perhaps as a result of increased movement of goods and people with more opportunities for disease to be spread, and accelerated by climate change and other environmental disturbances. Poplar rust was one of the first major exotic tree diseases to be reported from the Southern Hemisphere. Two species of poplar rust (*Melampsora medusae* and *M. larici-populina*) appeared in Australia in 1972-73 and rapidly spread in eastern Australia and across the Tasman Sea to New Zealand and devastating poplar plantations. However, considerable genetic variation in resistance to poplar rusts has been found between poplar species and clones (and alternate conifer hosts) and disease impacts can be managed by planting mixtures of more resistant clones. Selection for poplar rust resistance has been complicated by the appearance of different races. Another rust fungus (*Atelocauda digitata*), and other fungal pathogens, is a major concern for the productivity of the more than one million hectares of *Acacia* plantations in Asia, mainly *A. mangium* and *A. auriculiformis* and their hybrids and *A. crassicarpa* (See Old *et al*. 2000) Nevertheless there appears to be considerable variation between different *Acacia* provenances in susceptibility to disease, indicating a potential for selection of resistant genotypes and underscoring the importance of genetic diversity in dealing with forestry diseases of economic importance. A new disease to California, pine pitch canker, caused by the fungus *Fusarium circinatum*, has become established along the coast, having a devastating effect on all three mainland populations.

The native mainland California (USA) stands of radiata pine (*Pinus radiata*) are being devastated by the introduced pine pitch canker (*Fusarium circinatum*) with more than 90% of the trees likely to succumb to the disease (Devey *et al*., 1999). In the Republic of South Africa, pitch canker has recently been isolated from *P. radiata* (Coutinho *et al.* 2007), and seriously threatens the future of the pine plantation industry in South Africa, comprising 670,000 ha and half the country's wood and fibre assets. Pitch canker has also been recently identified on *Pinus* species in Colombia (Steenkamp *et al.*). In southern Africa and Colombia, and in other parts of the world where pitch canker has spread to (perhaps originally from Mexico) there will be a need to alter management practices, but also to change to more pitch canker-resistant *Pinus* species and provenances, such as to *P. tecunumanii* from low-elevation sources and *P. maximinoi* in Colombia. In 2010 a new pathogen myrtle rust or guava rust (*Puccinia psidii*), originating in South America, was detected in New South Wales that could fundamentally alter Australia's forest ecology. There are more than 2000 plant species in the family Myrtaceae, Australia's dominant plant family, including eucalypts, and most have the potential to become infected to some degree by *Puccinia* (Morin *et al.* 2012). Myrtle rust will likely alter the composition, function and diversity of many of Australia's eucalypt-dominated forest and woodland ecosystems and impact severely on forest industries. Doran *et al.* (2012) have recently identified resistance to myrtle rust in one family of lemon myrtle (*Backhousia citriodora*) an economically-important essential oil producing plant through evaluation of a comprehensive provenance/ family/clone trial. These authors have recommended further germplasm collections and evaluations of this seed source, once again illustrating the importance of genetic diversity, its conservation in native stands, and provenance/family trials in combating threats from pathogens, especially newly introduced strains and species. Because pathogens are continuously evolving, a combination of management measures is needed to deal with forest pathogens including deployment of diverse resistant genetic materials and continuing breeding programs with access to genetic diversity. Other successful examples of breeding for pathogen resistance include radiata pine (*Pinus radiata*) for resistance to red band needle blight (*Mycosphaerella pini*) in New Zealand (Carson 1990) and western white pine (*Pinus monticola*) for resistance to white pine blister rust (*Cronartium ribicola*) in North America (Sniezko 2006).

Insect Pests

As part of the Global Forest Resources Assessment 2005 (FRA 2005), countries reported on area affected by insect pests, diseases and other disturbances, and this information was used to undertake a global review of forest pests and diseases (FAO 2009). This review revealed major and increasing threats to forests from insect pests, both native and exotic. Some examples of how exotic pests threaten FGR, and the economic and environmental values of forests are discussed below, and are mainly derived from the FAO review.

The invasive European wood wasp (*Sirex noctilio*) has affected thousands of hectares of plantation pine forests around the globe including South Africa, South America and Australia, and is continuing to spread and is now threatening native pine and Douglas fir in North America. The leucaena psyllid (*Heteropsylla cubana*) is a significant pest of *Leucaena leucocephala*, a fast-growing multipurpose tree legume native to Mexico and Central America that has been widely planted throughout the tropics. In the mid-1980s, this insect spread rapidly across the Asia and the Pacific region (FAO, 2001); the spread of the psyllid was especially rapid as most leucaena plantings consisted of a very narrow, near identical genetic base. The Asian longhorned beetle (*Anoplophora glabripennis*) has increased in range in Chinese plantation forests as a result of widespread planting of susceptible poplar hybrids (EPPO, 1999). In China more than 200 million infested trees have been removed to control outbreaks of the Asian longhorned beetle, and authorities in USA and Canada have implemented emergency control measures anytime the pest has been detected. Strains of black poplar (*Populus nigra*) resistant to attack by the Asian longhorned beetle have been developed, through inserting a Cry1Ac gene from *Bacillus thuringiensis*, in China (Hu *et al*., 2001). Around 1986 the cypress aphid (*Cinara cupressi*) reached Malawi, and soon spread to Kenya where it rapidly caused major damage to *Cupressus lusitanica* (cypress) plantations which constituted half of Kenya's plantation estate. The cypress aphid killed a total of USD27.5 million worth of trees in 1991 and was causing a loss in annual growth of around USD9 million per year (Murphy *et al.* 1996). This is one example, of many, of the perils and risks of plantation and farm forestry becoming too reliant on a single exotic species, especially when grown in monocultures, cf. planting more diverse polycultures.

In Malawi the cypress aphid also attacks and kills the highly endangered conifer and national tree *Widdringtonia nodiflora* (Bayliss *et al.* 2007), but genetic resistance has yet to be found. Mountain pine beetle (*Dendroctonus ponderosae*) is a bark beetle indigenous to western North America that primarily feeds on lodgepole pine (*Pinus contorta* var. *latifolia*), that can erupt into large-scale outbreaks and cause significant losses of mature healthy stands. A devastating outbreak, initiated in the 1990s, has affected over 14 million hectares of forest land in western Canada (Nealis and Peter 2008) killing 50% of the standing volume in British Columbia. Increased warming associated with climate change is enabling the beetle to expand its range, including into Alberta in 2006, and may eventually cause large scale destruction to jackpine (*Pinus banksiana*) in boreal forest (Cullingham *et al.* 2011). The extent to which jackpine might show genetic resistance to mountain pine beetle is unknown, but natural hybrids with lodgepine are expected to display some resistance. The blue gum chalcid (*Leptocybe invasa*) is a relatively new threat to planted eucalypt forests in Africa, reported first from Kenya in 2002 and from South Africa in 2007, and this pest has also been reported in Asia and the Pacific, Europe and the Near East. The FAO review (2009) identified major insect pests of trees introduced into African continent in the past decade, including *Cinara pinivora* in Malawi, *Coniothyrium zuluense* in Ethiopia, *Thaumastocoris peregrinus* and *Coryphodema tristis* in South Africa and *Gonometa podocarpi* in the United Republic of Tanzania, and noted that these insect pests all pose threats to adjacent countries. The severity and frequency of insect pest outbreaks is projected to increase in concert with extreme climatic factors. China has already reported increased forest pest outbreaks in 2009 following a major snowstorm in South China, and the severe widespread drought of 2008 (China p 18-19).

Grazing animals

Grazing animals, especially introduced goats and rats have wrought havoc on tree vegetation in many parts of the globe, especially on island communities. Radiata pine (*Pinus radiata*) is amongst the most important plantation forestry trees species in the world, but the unique island population on Guadalupe Island (Mexico) is now highly threatened with surviving trees very old, and predation by goats removing any regeneration (Spencer *et al.* 1999). Whilst the Guadalupe provenance is secured through *ex situ* conservation efforts, a loss of the tree in its natural habitats would exclude continued evolution and adaptation in the environment that has resulted in highly drought tolerant germplasm.

By 1945 goat predation on Three Kings Island of the north coast of New Zealand, had reduced the entire population of Three Kings kaikomako (*Pennantia baylisiana*) to one individual female tree incapable of sexually reproducing itself. Treatment of latent pollen with hormones by researchers in 1985 induced some seed including a self-fertile individual and the future of this species has now been secured. In French Polynesia, rats have prevented the natural regeneration of Eastern Polynesian sandalwood (*Santalum insulare*) by eating more than 99% of fruits before ripening (Meyer and Butaud 2009).

Given the major and increasing threats posed to FGR from invasive species (animals, plants and microorganisms) a key strategic priority is to promote national assessments of invasive alien species, networking and collaboration among concerned countries and IPCC and research to avoid their further spread (SP18).

Unsustainable harvesting and use

Many country reports have detailed over-exploitation and unsustainable harvesting threats to FGR. Overharvesting by itself rarely leads to extinction, but can seriously erode genetic diversity and recovery can be very slow for species which occur naturally at low frequency (e.g. Gabon p 22). However, for narrowly distributed and naturally rare species, overharvesting can directly lead to or threaten extinction. Sichuan thuja (*Thuja sutchuenensis*), a critically endangered narrowly distributed endemic tree in Chongqing Municipality was driven to the brink of extinction from overharvesting for its precious scented wood and only rediscovered in 1999 and accorded protection (China p 18). Overharvesting usually involves highly valuable species such as ebonies, sandalwoods, agarwoods and frankincense, but in areas with high population pressure and poverty, overharvesting may be associated with lower value products such as fuelwood and charcoal. Even an activity as seemingly innocuous as harvesting trees for Christmas trees may threaten FGR, e.g. in Guatemala, uncontrolled cutting of pinabete (*Abies guatemalensis*) branches for use as Christmas trees is reducing the regenerative capacity of the species which has now disappeared from some areas (Lopez 1999), while in Tonga, harvesting of ‘ahi sandalwood (*Santalum yasi*) saplings for Christmas trees is limiting recruitment and one of the major threats to the species (Tuisese *et al.* 2000).

One remedy to overharvesting can be the greater involvement of indigenous and local communities in management of the forest and their FGR, especially if this is backed by appropriate technical support (SP10). Technical support may include application of improved silvicultural practices to ensure sustainable production of desired products and regeneration of preferred species. There is also need for better legislative protection, including implementation and monitoring of the legislation, and development of alternative sources of wood, NWFPs and AFTPs, such as through highly productive plantation systems and improved agroforestry systems.

Mixing of gene pools and hybridization

A major risk to FGR conservation and utilization is the uncontrolled and undocumented mixing of genepools of forest tree species. This can occur at the within-species levels whereby genetically diversified local populations, which may possess valuable attributes, interbreed with non-local germplasm introduced for forest plantation establishment. Hybridization of local and introduced gene pools may reduce local adaptation in subsequent tree generations (Millar and Libby 1989; Palmberg-Lerche 1999). Mixing of genepools can also inadvertently lead to incorporation of undesirable genes, resulting in a diminished economic value for production forests, and vastly complicating and increasing the costs of tree breeding in cases where breeders may need to ‘unscramble the omelette’.

Interbreeding can also occur when formerly allopatric related species are brought together. If the taxa are not fully reproductively isolated and share the same flowering times and pollinators, then hybridization is likely, and if the resulting progeny are fertile, then the eventual outcome can be loss of a species through assimilation. Factors that threaten extinction by hybridisation, viz. habitat destruction, fragmentation, and species introductions are all increasing and often act synergistically (Rhymer 1996). The threats from ‘genetic pollution’, as specifically related to tree species, are discussed in Potts *et al.* (2001). Outbreeding depression from detrimental gene flow may reduce the fitness of a locally rare species making it vulnerable to extinction. Alternatively, pollen swamping may result in its loss of genetic integrity and it may become assimilated into the gene pool of the common species. FAO’s International Poplar Commission’s Working Party on Poplar and Willow Genetics, Conservation and Improvement has drawn attention to the fact that populations of some native poplar species were rapidly disappearing, because they spontaneously hybridize with cultivars and/or are being displaced by agriculture or other land uses. Natural stands of black poplar (*Populus nigra*) have almost disappeared in Europe and the situation for eastern cottonwood (*P. deltoides*) in North America has become very serious as a result of interbreeding.

Hybridisation, with or without introgression, can easily threaten a rare species’ existence (Rhymer and Simberloff 1996). However, there are few documented examples in the literature for tree species, although presumably this has happened often during angiosperm evolution. The main cited example of this risk is Catalina Island mountain mahogany (*Cercocarpus traskiae*), a rare island endemic in California, USA, which has been reduced to about seven mature pure individuals and hybridises with the more abundant California mountain mahogany (*C. betuloides*; Rieseberg *et al.* 1993). In Fiji and Tonga, ahi sandalwood (*Santalum yasi*) hybridises freely with the introduced East Indian sandalwood (*S. album*) producing more vigorous F_1 hybrid off-spring (Bulai and Nataniela 2005) which may eventually lead to the disappearance of pure yasi due to natural selective pressures and the commercial choices of smallholder sandalwood growers (Huish 2009).

There is an increased awareness amongst the forestry profession of the risks posed by hybridization on local gene pools. For example in order to protect the genetic integrity of the national tree of

Lebanon (Lebanon cedar, *Cedrus libani*), a Ministerial decision has been taken which prohibits the import of *Cedrus* germplasm into Lebanon (Lebanon country report, p 19). In Australia, Barbour *et al.* (2008) have formulated a framework for managing the risk of gene flow from exotic Tasmanian blue gum (*Eucalyptus globulus*) plantations into native eucalypt populations in southern states which could serve as a useful model for other tree genera and species. The same authors ascertained there was a low risk of genetic pollution of large-scale planting of *E. globulus* for pulpwood plantations in southern Australia on other native eucalypts species in the same sub-genus Symphyomyrtus: however, there are clearly risks of loss of genetic integrity of native blue gum populations near plantations of different and limited variability, including to different sub-species such as eurabbie (*E. globulus* ssp. *bicostata*) in central Victoria.

1.4.2. Loss of ecosystems, species and intraspecific diversity

Loss of ecosystems

There are increasing threats to loss of FGR due to disappearance or significant modification of the ecosystems of which they are a constituent. For much of last century and until recently the major threat came from habitat conversion of forest to a different landuse, mainly an agricultural landuse. Examples of major habitat loss include Brazil's Atlantic forest (2-5% of original, p 7 Brazil Report), Ethiopia's forests (most forest types reduced down to fractions of their former extent, including conversion to more open woodland formations), eastern Australia's sub-tropical lowland rainforest (7.2% of original; http://www.environment.gov.au/biodiversity/threatened/communities/pubs/101-listing-advice.pdf accessed December 2012), and many smaller countries, such as Haiti, and Samoa which have lost almost their entire lowland tropical forests. Forest ecosystems are breaking down and with dramatically changed function and structure, increasingly attributable to climate change, and associated extreme events such as uncontrolled wild fires, and alien invasive species. Isolated montane forest ecosystems, including cloud forests, in tropical and subtropical zones will be impacted differentially by climate change, especially as often these forests have a high proportion of unique endemic associated species, which may have no possibility of migrating to other climatically suitable habitats, e.g. tropical Central and South America and the Caribbean, East and Central Africa, the Philippines, Malaysia, Indonesia and Papua-New Guinea. Foster (2001) has described a scenario of complete replacement of many of the narrow altitude range cloud forests by lower altitude ecosystems, as well as the expulsion of peak residing cloud forests into extinction.

Other forest ecosystem changes are associated with changes to keystone animal species. In their recent literature review, Ripple and Beschta (2012) concluded that predation by large mammalian carnivores, notably sympatric grey wolves (*Canis lupus*) and bears (*Ursus* spp.), limit densities of large mammalian herbivores in boreal and temperate forests of North America and Eurasia with impacts on tree and shrub recruitment. The same authors have previously reported that cougars (*Puma concolor*) limit mule deer (*Odocoileus hemionus*) densities releasing woody plants from browsing and maintaining biodiversity in western North America (Ripple and Beschta 2008). Increasingly large carnivores, such as the tiger (*Panthera tigris*) and lions (*P. leo*), are being threatened in many parts reducing their natural ranges, and reductions in top-chain predator populations and changes to other keystone species, such as elephants (*Loxodonta* spp.) in Africa, will result in changes, both major and subtle, to forest and woodland ecosyems and alter the FGR contained in them.

Loss of tree species

Scientific consensus is building that we have entered a new era of mega species extinction, with current rates of extinction at least three orders of magnitude more than background. In late 2012 the International Union for Conservation of Nature Red List[15] of Threatened Species included 65,518 species, of which 20,219 are threatened with extinction with 795 already extinct. This categorization included a recent assessment of Madagascar's unique palms which found that a staggering 159 species of the total of 192 are threatened with extinction. Export of indigenous palm seeds is becoming an important export market for NWFPs (Madagascar p 14) and is a contributory threat factor for some species.

Through the Global Trees campaign and under the auspices of IUCN's Species Survival Commission certain plant groups and regions have been partially or fully recently assessed for their conservation status including conifers (Coniferae), cycads (families Boweniaceae, Cycadaceae and Zamiaceae), Magnoliaceae, maples (*Acer* spp.), oaks (*Quercus* spp.), palms (Arecaceae), rhododendrons (*Rhododendron* spp.); and central Asia, Guatemala, Ethiopia and Eritrea, Mexican cloud forests. However, most families and genera comprising mainly tree and woody species have yet to be subjected to comprehensive assessments of their level of endangeredness, which will help inform where conservation effort and resources are best directed.

An assessment of conservation status of tree species in Guatemala found little correspondence between earlier assessments with suggestions that tree species data and information in and outside of the country may have been a factor in earlier discrepancies (Vivero *et al*. 2006). The new assessment identified 79 endangered tree species in Guatemala including 10 critically endangered endemics. Approximately 60% of the 762 tree species in 85 botanical families in the floristically rich, and replete with endemics, cloud forests of Mexico were assessed as threatened (González-Espinosa *et al.* 2011). Central Asian forests and woodlands are under severe threat from over-exploitation, desertification, pests and diseases, overgrazing and fires. A combination of factors including the cessation of subsidized timber from the former Soviet Union, rural poverty, a lack of alternative energy sources and the lack of institutional capacity to protect and regulate forests have all added to the pressure on vulnerable forests of the region (Eastwood *et al.* 2009). Of 96 tree taxa assessed in Central Asia, including Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, 46% (or 44 of them) were found to be threatened with extinction in the wild. The preliminary assessment of 428 endemic and near endemic woody plants in Ethiopia and Eritrea determined that 135 species (including 31 trees) were threatened (Vivero *et al*. 2011).

Of the 151 species assessed in the family Magnoliceae, approximately 74% (or 112 species) have been found to be threatened (Cicuzza *et al.* 2007). Approximately 45% of *Quercus* species are considered endangered (or 79 out of 176) for which data was available and sufficient for assessment (Oldfield and Eastwood 2007). The conservation status of 125 species of maple trees (123 *Acer* spp. and 2 *Dipteronia* spp.) has been assessed with at least 54 taxa (28% of maple taxa) found to be threatened (Gibbs and Chen 2009). Of the approximately 1018 known *Rhododendron* species, mainly woody shrubs, approximately 25% (or 316 species) have been found to be threatened (Gibbs *et al.* 2011).

Developed countries with greater available Government resources, but often less species diversity, sometimes maintain their own Red lists. Sweden, for example, maintains its own Red List which includes European ash (*Fraxinus excelsior*), broad-leaved lime (*Tilia platyphyllos*), wych elm (*Ulmus*

[15] The IUCN Red list included is widely regarded as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species

glabra), European white elm (*U. laevis*) and field elm (*U. minor*): the main threats coming from exotic diseases (Sweden p 18 and 20). More often than not, threat assessments for tree species in developing countries are lacking due to a shortage of trained botanists and conservation biologists and supporting resources for field surveys. Currently available threat assessments where these have been undertaken, are typically several too many years old and are in need of updating. The taxonomic assessment of many tropical tree genera, including those with important FGR, such as ebony (*Diospyros*), mangoes (*Mangifera*), *Syzygium* and *Terminalia*, is often incomplete. Furthermore, updated taxonomic information and botanical keys may not be readily available in the countries where the species naturally occur. The Global Tree Specialist Group, part of the IUCN-Species Survival Commission has identified major challenges for conservation of individual tree species. They estimate that approximately 8,000 tree species are threatened with extinction, with about 1,000 tree species critically endangered and likely to go extinct unless urgent action is taken (Oldfield *et al*. 2008; Global Trees Campaign http://www.globaltrees.org/about.htm). Of threats to the 52 endangered tree species profiled at the Global Trees website, and covering different plant families and geographic regions, the main threats were from overharvesting (37%), followed by biological factors including naturally rare and restricted (23%), habitat loss and conversion (21%), fire and overgrazing (13%) and climate change and invasives (6%), but many species are threatened by a combination of threat factors and their interaction. These data are from a small sample (about 5 % of threatened tree species) and overharvesting is likely to be overrepresented due to deep concerns about precious timber tree species. Overharvesting, including poorly regulated, unregulated and illegal harvesting, is arguably the most currently important threat factor for FGR, because this activity causes a loss of genetic diversity and populations on those tree species which have most economic value and utility. Over the next century, climate change and interactions with other threats will be become the most important threat for tree species and populations. Thomas *et al*. (2004) have shown through modelling that between 18-35% of the world's animal and plant species are on the path or committed to extinction due to climate change, and this figure is not taking into account interactions with other threats; these authors have also shown that the climate change threat to survival of species is much greater than from habitat loss, but varies depending of the biome under consideration.

Loss of Intraspecific diversity

The loss of intraspecific diversity in economically important tree species has been a major concern of the forestry profession for many decades. Despite the many continuing and longer-term threats to FGR a high, but variable, level of success has been achieved for conserving and utilizing the genetic diversity of many commercially important tree species for timber and paper pulp production. This has often been achieved under the auspices of tree breeding programs in developed countries, and for which there are many examples, and increasingly led by private sector consortia. Similarly there has been vital genetic resources work undertaken in the developing tropics by national agencies for some major topical timber and NWFP species. This has usually been done with international, support including national donor funded projects and agencies operating in international mode; e.g. teak (*Tectona grandis*), gmelina (*Gmelina arborea*) and neem (*Azadirachta indica*), assisted by FAO and Danida Forest Tree Seed Centre, many African ATPs species assisted by ICRAF; big-leaf mahogany (*Swietenia macrophylla*) through CATIE; tropical American pines supported by CAMCORE, and chukrasia (*Chukrasia tabularis*) and beach sheoak (*Casuarina equisetifolia*) supported by ACIAR and CSIRO Australian Tree Seed Centre.

The main threats to intraspecific diversity in tree species are essentially the same as those which cause species extinction (see 1.4.2.2). The loss of entire populations or genetically distinctive provenances (for species exhibiting clinal variation) has both short and long term adverse consequences. The short term consequences include potential major changes to ecosystem function and services for native forests in which they occur through to loss of documented seed sources of known performance. The longer term consequences are that loss of populations is a well-identified pre-cursor for species extinction, and loss of vital genetic material for selection and tree improvement programs. For trees introduced into a new environment with a broad genetic base, better adapted land races may often evolve in a small number of generations, but the same is not true for recovery of lost diversity. A study on red pine (*Pinus resinosa*) has indicated that very long time periods, possibly on scales of tens of thousands of years, are required for long-lived, long-generation organisms like trees to recover genetic diversity following a genetic bottleneck and loss of diversity (Mosseler *et al.* 1992).

Major losses to diversity have also occurred for high value species which have been selectively and most heavily harvested both for their timber and for NWFPs – paradoxically this has meant that some of the most economically useful tree species have been the most genetically denuded. This has consequences not only for immediate seed supply for replanting, but also the limited genetic diversity, often with only lower quality or less desirable phenotypes remaining, reduces the opportunities for selection and breeding. Cornelius *et al.* (2005) have assessed the maximum negative dysgenic response to a single selective logging-mediated phenotypic selection event in big-leaf mahogany (*Swietenia macrophylla*) to be small, i.e. ≤5%, and rather insignificant, but for different species with more heritable traits (e.g. chemotypes) and/or several to many cycles of selection of superior phenotypes then dysgenic selection is more problematic.

Below are listed just some examples, from around the globe, of the many hundreds of valuable tree species which have already lost, or are at imminent risk of losing important intraspecific diversity:

- Frankincense (*Boswellia papyrifera*) – an economically important NWFP tree in Ethiopia and Eritrea but which is rapidly declining and predicted to be commercially extinct within the next 15-20 years. The causes of decline are related to resin tapping which reduces reproductive and recruitment potential (Rikers *et al.* 2006; Eshete *et al*. 2012). Trees dying from attack by long-horned beetles and other causes are failing to be replaced through seedling recruitment due to excessive firing and increased grazing pressures (Groenendijk *et al.* 2012). Forest reduction and degradation and competition for land use have also been identified as threatening factors (Ethiopia p 15).

- Thailand rosewood (*Dalbergia cochinchinensis*) – intraspecific variability is highly threatened (Thailand p 52), and this species has been heavily and selectively overharvested throughout its natural range in Cambodia, Laos, Thailand and Vietnam and continues to be cut, often illegally. Good seed sources from native stands are scarce, as surviving populations are reduced to scattered and isolated trees of poor phenotypes.

- Melanesian whitewood (*Endospermum medullosum*) – the fastest-growing trees originate from east and south-east Santo in Vanuatu (Vutilolo *et al.* 2005), but these populations have almost disappeared due to land use change, absence of regeneration in coconut plantations and cattle properties, and harvesting of remnant trees (Corrigan *et al.* 2000; Vanuatu).

- Chi ye cai (*Erythrophleum fordii*) is a valuable timber tree threatened by overexploitation, which in China now only occurs in small, fragmented and degraded stands and with greatly diminished genetic diversity (China p 18).

- Shining gum (*Eucalyptus nitens*) – the mountain-top populations in northern NSW, Australia which have shown potential for timber production in South Africa are committed to extinction from climate change.

- Euphrates poplar (*Populus euphratica*); and Tana River poplar *(Populus ilicifolia*) – fast-growing, multipurpose riparian trees from the Middle East, Central Asia and China, and Kenya, respectively, with a remarkable range of tolerance to edaphic and climatic extremes, but declining and endangered throughout its range by clearance, overharvesting, and modification to hydrological regimes (Viart 1988, Ball *et al*. 1996, Cao *et al.* 2012).

- African cherry (*Prunus africana*) – bark harvested for use in treatment of benign prostatic hypertrophy. The species has been CITES listed (Appendix II) since 1995 but almost all native populations of this keystone afromontane species in central, eastern and southern Africa are threatened by overharvesting which often kills trees, and also from land use and climate changes. In Republic of South Africa close monitoring and controls may provide a greater level of protection than other parts of its range (Republic of South Africa p 45). Populations of *P. africana* on Madagascar are morphologically distinct and likely constitute a different taxon, are similarly threatened but no longer exported due to previous overharvesting (Madagascar p 22).

- *Pterocarpus santalinus* (red sandalwood) - this highly valuable timber and NWFP timber species from Andhra Pradesh State in India has been overharvested especially during the 1950s and 1960s. The species was CITES Appendix II listed in 1995, but an illegal smuggling trade continues with concern for loss of genetic diversity (MacLachlan and Gasson 2010; India p 63).
- *Swietenia mahogani* (West Indies mahogany) – native to the Caribbean Islands and southern tip of Florida (USA). This is the most valuable mahogany timber producing species and has been commercially exploited for more than five hundred years: the small residual populations are thought to have undergone dysgenic selection (Styles 1972). Dysgenic selection is most likely if successive regeneration cycles are derived from only a small residual number of poor quality phenotypes (Ledig 1992), but whether this has occurred for this species is now difficult to determine. Hybridization with other *Swietenia* species, such as with *S. macrophylla* on Cuba, is another threat to the species genetic integrity and resources.
- *Santalum* sp. (Western Province sandalwood) – An undescribed species of sandalwood exists in three small populations, each consisting of only a few individuals, in coastal areas of Western Province, Papua New Guinea. This sandalwood, referred in literature to as *S. macgregorii*, has been shown to have highly fragrant heartwood with high santalol content (Brophy *et al.* 2009), but is at high risk of being harvested which would cause the species to go extinct as there is no natural regeneration or *ex situ* conservation actions.

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 1968 (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 (e.g. Burkina Faso, Canada, Ecuador, Fiji, India, Iran, Sri Lanka, Russia Table) 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 (e.g. Brazil, Canada, China, Iran, Solomon Islands, Sweden, and Republic of South Africa). Increased yields of superior forest products generated at lower cost from genetically improved trees, can reduce the harvest pressure on natural forests (e.g. Ghana; Philippines, Thailand), 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 (Cyprus, USA). 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 (Canada, Ghana, Germany, USA, Zimbabwe). 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 (Ghana, Thailand). 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 (Brazil, Burkina Faso; Denmark, Germany, India, Norway). 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 (p 28) 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 (e.g. Indonesia).

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 (such as Canada, Denmark, Finland, Germany, Norway, Sweden, and USA), 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), supported by the 1994 Montréal Process[16]. 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 (e.g. Iran) several countries noted important differences between conservation of biological diversity and

[16] 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.

FGR (Finland, Germany, India). 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 changing conditions' (Canada). Germany suggests the introduction of external genetic material into forests 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: Germany noted that some conservation reserve provisions may prohibit actions necessary to ensure the regeneration or maintenance of FGR, and notes that FGR conservation has not played a great part in that country's nature conservation measures. Finland remarked that 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 (e.g. Finland p22, Sweden p24)
- 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 (p35), 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 (e.g. Finland, Germany, India). 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 (e.g. Finland).

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 links closely to SP6 which aims 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 and 5. 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
- 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.

Climate change is already impacting tree reproductive biology, pest damage and health, and is expected to bring about major shifts in the distribution of plants and vegetation communities (e.g. Canada). Thailand anticipates that tropical dry forest ecosystem will expand into subtropical moist forest, and further predicts 'a profound impact on the future distribution and health of forests' in the country. Conservation efforts and priorities need to be informed by modelled future climates: in the Thai example, wet forest species face a highly uncertain long-term future compared to the more secure dry forests. The importance of considering adaptation to climate change in prioritising FGR C&M effort for was mentioned by several countries including Germany, and Sweden.

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, (e.g. Australia, Egypt, Ethiopia, Sri Lanka, Tanzania), with small island ecosystems especially at risk (e.g. Fiji, Papua New Guinea, Seychelles; Pacific Island Ecosystems at Risk http://www.hear.org/pier/). 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. 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 (pp8, 14, 26), highlighting the need to consider the invasive potential of species developed and promoted for planting and ensure that risks are minimised (cf. SP18).

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 (e.g. Madagascar). 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 sylvestris* 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 Forest Gene Experts, commencing in 1968, 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 [17]. 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 6). 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.

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

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 (Sweden, USA) priority must be assigned to a limited number of the most important or model species (e.g. Canada). 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 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[18], 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* p 13), or else are threatened and the subject of conservation management interest (e.g. Canada).

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 (e.g. Finland p24).

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* Australia p22 Butcher *et al.* 2005; *Baillonella toxisperma*, Gabon p 18, Ndiade-Bourobou *et al.* 2009; *Dalbergia cochinchinensis*, Thailand p 26 Soonhuae *et al.,* 1995). Assessment of genetic variability plays a vital role in conservation planning and guides decision-making and management: as Germany (p 20) 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'.

Brazil's genetic characterisation programme involves a number of components and numerous individual projects; it is described in its report (p 22): *'Studies in Plant Taxonomy are essential to the understanding of biodiversity, to inventory the flora, to provide subsidies to other areas of botany and related fields, and to bolster conservation programs…The Dendrogene project, for instance, sets the main strategies for botanical identification, including training and production of identification sheets*

[18] 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)

and folders. Hosted at the Embrapa Eastern Amazon research station…the…Project has relied on a multidisciplinary approach and multi institutional participation…An expected product is Dendrobase, a database of genetic information for tropical tree species that organizes and systematizes existing information, flowering and fruiting, sexual system, pollination, genetic information and seed dispersers.'

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 are often need to be measured to provide the information necessary for conservation and management of a species' variability.

Canada, (p 26) with a highly developed FGR C&M system, surveyed the range of methods used from 1987 to 2011 to describe the genetic variability of its forest resources, and noted that the use of provenance tests and phenotypic analysis has been constant, while the use of molecular markers has developed significantly in recent times: *'In the 1980s–1990s, most analyses were conducted by allozymes and isozymes, accounting for 62% and 28%, respectively, of studies surveyed. In the late 1990s to early 2000s, random amplified polymorphic DNA markers were used, and from 2000 to 2011, a shift is seen from RAPD markers to other DNA-based markers, including mitochondrial and chloroplast DNA, single nucleotide polymorphisms (SNPs), and chloroplast sequence specific primers (cpSSPs). From 2000 to 2011, DNA markers were used in 81% of studies surveyed, whereas usage of allozyme and isozymes markers declined to 19%. The uses of provenance tests and phenotypic analyses have been used consistently throughout the 24 years surveyed.'*

China (pp10-11) has also provided an informative description of the development of its progress and the new methodologies used to characterise variability: *'Intra-species genetic variation of forest trees is mainly evaluated by morphological, growth and adaptive characteristics as well as wood properties… Variation of morphological characteristics was usually evaluated through sample surveys of the wild natural populations using those characteristics usually without environmental influences such as shapes of seed and fruit….The analyses and evaluation of geographic variation patterns of different provenances were usually based on the provenance/family trials, progeny trials and clonal tests…Isozyme and DNA markers have been widely used in the evaluation of genetic diversity…Before the 1990s, isozyme analysis was mainly used to evaluate genetic diversity, and more than 20 enzyme systems, for example ADH, PGM, PGD, have been frequently used. After the 1990s, with rapid development of molecular techniques, analysis of DNA markers became the major method, frequently used DNA markers include RFLP, AFLP, RAPD, ISSR, SSR and others. In recent years, new technologies such as molecular chip and sequencing have been gradually applied.*'

The requirement for advanced facilities and highly trained personnel, and substantial recurrent operational expenses for molecular characterisation techniques have generally precluded their wider use in developing countries; these countries are more likely to use morphological characterisations to investigate variability. For example, Ethiopia (p 17) notes that 'molecular characterization studies have been made for very few tree species … On the other hand, several studies have been made on morphological characterization of tree species including provenance and progeny evaluation trials'. Developing countries are increasingly availing themselves of the opportunities to conduct molecular marker studies of their native trees in developed country laboratories through postgraduate research studies and research sabbaticals.

Characterising interspecific variability

. Characterisation of diversity at the species level is a key element and priority for FGR C&M (SP1). 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 (e.g. Brazil, Ghana, India).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 (e.g. Australia, Canada, France, Germany and USA), while countries with fewer resources have a greater need for further characterisation at the species level (India, Madagascar, Papua New Guinea; Solomon Islands). 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 (for example, parts of Brazil e.g. p15, Papua New Guinea) and/or with security challenges (DR Congo).

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 (e.g. Canada, Denmark, Germany).

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 (p6) 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 (Madagascar pp6, 19). 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 (USA). 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); similar risks were also noted by Indonesia and Thailand. Ethiopia recognises that ‘the most important threats to genetic diversity comes 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 (e.g. India). 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 (e.g. India). 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)The hotspot approach is described in the Brazil country report:

> *‘[An] example is the Rapid Assessment Program (RAP) created by the nongovernmental organization Conservation International in 1992. The RAP method addresses the need to generate fast information, accurate and quantitatively significant when time and resources for a more detailed assessment are not available. This method serves to fulfil several objectives, estimating species richness in areas that are highly threatened with loss of diversity.’* (Brazil p22)

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 (e.g. Zambia), 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, as evidenced by the efforts of the USA and CAMCORE in Mexico; Burkina Faso is undertaking its second national inventory with assistance from Luxembourg, and India has received assistance for its forest inventory programme from FAO and UNDP since 1965.

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 (Burkina Faso p2, Canada pp21, 111, 106, Chile pp 14-15, Gabon pp 17-18, Germany p18, Iran p112, Norway p 16, Solomon Islands p23;Thailand pp20-21; USA pp16-18,33) .

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 (Canada p32). 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' (USA); 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 (USA), 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.

Use of morphological traits

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 (e.g. Chile, Germany; Myanmar, Papua New Guinea, Sudan, Zimbabwe). 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 (Zimbabwe p41), 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 (e.g. Bulgaria has identified 449 morphological variants in 27 tree species, China, Kazakhstan; Papua New Guinea, Zimbabwe), 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 (Germany); 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 (Zimbabwe). 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 (e.g. Zimbabwe). 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 (e.g. Canada, Germany, USA). This contrasts with many molecular marker tests, which while evaluating genetic difference or similarity do not necessarily identify genes conferring adaptive or productive advantage (Germany). Several countries considered research to identify provenances better adapted to new climate change-induced conditions as a priority (Germany, and prior to geographic translocation of tree germplasm to facilitate adaptation to climate change (Tanzania). 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…'* (USA).

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.

Molecular markers

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 (e.g. China, USA); 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 (p42) noted the high cost of molecular characterisation constrained its use. Nonetheless it is recognised that these techniques offer great potential – Ghana (p 20), 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 (USA). 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.

As an example, Thailand states that at ‘the regional level, Thailand is in a good position to serve as a hub for assessment of genetic diversity of forest trees resources in the Lower Greater Mekong Sub-region and beyond, since the DNP has an excellent facility in its…DNA and Isoenzyme Laboratory’ (Thailand). 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 opportunities for greater integration, coordination and cooperation in areas of common interest is exemplified by the Ethiopian example 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.

Burkina Faso describes its approach to genetic characterisation of its priority tree species and the role of biotechnological methods as follows: *‘The methods used range from simple morphological description of organs such as leaves and fruit, color of the scratched bark of the trunk, the shape of the crown on a number of collections, using enzyme electrophoresis and DNA with neutral markers RAPD (Random Amplified Polymorphism DNA). Sophisticated methods have been used through a partnership with Western universities in Denmark, France, Great Britain and the Netherlands.’*

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.’ (China). 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 (Mexico).

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 (e.g. USA), 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 (SP1, SP3, SP15). Germany (pp. 23, 71) 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.

Level of knowledge of intraspecific variability

The level of knowledge of variation within tree species varied greatly between regions, countries and species as discussed below.

Asia: China has evaluated more than 100 tree species and genera amounting to 5% of its tree flora for genetic diversity and variation using morphological assessments, provenance trials and DNA marker analysis. Since the 1980s provenance trials have been conducted for more than 70 important afforestation species. The majority of Chinese tree species studied exhibit significant inter- and intra-population genetic variation; and displayed significant geographical variation as reflected in morphological characteristics, growth, adaptability, and wood properties. The growth and adaptability were correlated to location and climate of provenances (China pp10, 11). India noted that studies on intraspecific variation are limited in relation to the number of tree species with studies mainly confined to a few economically important species that are under the process of domestication.' (India p25). Nonetheless, the country lists 104 species for which evaluation of intraspecific variability has been undertaken, using a variety of measures (India pp58-62). Thailand has gained detailed genetic information on several indigenous tree species that are both threatened and of high commercial value through molecular marker studies (isoenzymes, microsatellites; RAPD, AFLPs), e.g. genetic diversity and mating system information for *Dalbergia cochinchinensis* which is being used to inform conservation programmes (pp30-31).

Europe: Sweden states that 'the knowledge about the amounts and distribution of genetic variation within and between natural populations of most species, including forest trees, is in general very low' (p23h), and proposes a set of guiding principles for conservation decision-making.

North America: Twenty eight of Canada's 126 tree species have been subjected to studies of intraspecific variation representing 22% of the tree flora (Canada pp26-29), and there is information on the relative level of diversity for 32 species (25% of Canadian trees); a subjective review of research suggests that 59% had high diversity while four species had low diversity; these latter species were of extreme conservation concern (Canada p 64). In the period 2001-2011, 41 studies were published in scientific journals, describing the genetic diversity of 29 of Mexico's forest species, mostly of *Pinus* with some species of *Abies*. Allozyme studies showed genetic diversity (expected heterozygosity) averaged 0.19, and ranged from 0.07 in *Abies guatemalensis* to 0.39 in *Pinus lagunae*. The genetic diversity of Mexican species estimated through isozyme studies was overall similar to the genetic diversity (0.17) reported elsewhere for the majority of gymnosperms (Mexico p3).

Africa: In Burkina Faso (pp1, 14, 16) intraspecific variation has been investigated seven economically important tree species, viz. *Vitellaria paradoxa subsp paradoxa, Parkia biglobosa, Tamarindus indica, Borassus aethiopium, Adansonia digitata, Acacia se*neg*al* and *Sclerocarya birrea.* The methods used ranged from simple description of morphological characters though to isoenzyme electrophoresis and neutral DNA markers (RAPDs). Ethiopia (p 18) has assessed genetic variability for ten tree species, five native and five exotic; morphological traits were assessed for three species, adaptive and production characters in seven, and molecular characterisation in three instances: Molecular characterization has been carried out in overseas laboratories including Inter-Simple Sequence Repeat on *Coffea arabica* and *Hagenia abyssinica*, AFLPs on *Juniperus procera* and chloroplast microsatellites on *H. abyssinica* and *Cordia africana*. Increasing use of DNA markers is being in Gabon (pp17-19) where DNA markers have been used since 2001 to study economically important timber and NWFP species (*Acoumea klaineana, Baillonella toxisperma, Milicia excelsa* and *Santira trimera*) for a wide range of purposes related to intraspecific diversity (reproductive biology, seed dispersal, genetic structure, evolutionary process including forest refugia and phylogeography). Intraspecific variation studies have only recently commenced one in Ghana (p 20) with one study focusing on resistance to insect attack and another on identification of conservation management requirements.

2.3.1. 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 (e.g. Ethiopia, Germany); 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 (e.g. USA, Sweden), 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 (e.g. Canada; Germany). 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 ('Forests Europe'), and this may provide a suitable avenue for harmonisation (Germany).

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 (e.g. Canada p14, Indonesia p10, Thailand p35). 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 (e.g. China, Denmark, Finland, Germany, Philippines, USA), 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. 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.

FGR information needs and systems

The type of information on genetic variability a country may require is determined by its conservation and management goals and priorities, as well as factors including the nature of the FGR, availability of skills, funding and resources, organisational/institutional capacity, and the needs of the end-users. The need for adequate information and data management systems was frequently identified in country reports, and it was reported that countries' ability to collect, manage, store and disseminate information on FGR can be seriously limited by lack of resources and expertise in this area. The level of development and effectiveness of country information systems varied greatly.

In Zimbabwe ageing computer systems, and unreliable internet connectivity constrain its FGR information programme, while further training in database formulation, documentation and information management is also needed. Ghana noted that it had no established information systems for intraspecific variation, while several countries expressed the need for establishment of a national data base and effective information system for FGR C&M (Ethiopia, Kazakhstan, and Madagascar) or even forest resources more generally (Jordan). Some systems were under construction: India's Forest Genetics Resources Management Network will develop and maintain a national information network on FGR (India). China has established a website for the national FGR platform but identified the need for increased investment in information management systems including in expertise and personnel. Uzbekistanhas developed a crop wild relative information system including for wild fruit tree relatives.

On the other hand many well-resourced, developed countries with long-established NRM administrations had functioning information systems, though even these were felt to be under-resourced and sometimes deficient with respect to the tasks expected of them, and were identified as priority areas for capacity building. Networks and associations that include government, academia, can make significant contributions to and maintaining FGR information systems in some countries, such as Canada's Forest Genetic Resources Information System (CAFGRIS) under the auspices of the Canadian Program for Conservation of Forest Genetic Resources (CONFORGEN) and NatureServe (Canada):

> *'CAFGRIS and NatureServe Canada are examples of information systems that are integrating information from various agencies to generate either a pan-Canadian (e.g., CAFGRIS) or a species range-wide (e.g., NatureServe Canada) perspective'* (Canada)

European nations have developed a common forest genetic information system:

> *The pan-European collaboration program EUFGIS (European Forest Genetic Information System) has developed an online information system and a documentation platform for the inventories of forest genetic resources in Europe. One objective is to support the countries in their efforts to implement gene conservation of forest trees as part of sustainable forest management. The EUFGIS Portal provides geo-referenced data on dynamic conservation units of forest genetic resources in Europe…Presently the EUFGIS database contains data on 2 360 units for about 106 tree species in 31 countries. The units harbor a total of 3 139 tree populations* (Sweden).

A number of countries reported using pre-existing databases and information systems operating in various NRM administrations to manage FGR, rather than establishing dedicated systems; for example Ghana uses the Forestry Commission systems to monitor and ensure effective management of its forest genetic resources while Brazil has developed a National Forestry Information System which include information on use and conservation. Many countries have data bases on their rare and threatened plant species (e.g. Thailand). Nonetheless in some contexts the particular needs of FGR C&M may require a dedicated, centralised, integrated information and data management system. Canada notes that effective national information systems require the harmonisation of information and databases from different jurisdictions and areas, preferably operating on a common software platform, and observed that poor cross-jurisdictional database integration impeded access to information on species variability, thereby reducing opportunities for monitoring and identification of vulnerabilities (Canada). The same principle applies to the development of regional and international databases; Germany noted that the monitoring the trajectories of inter- and intra-specific genetic variation across regions and international borders also requires integration and harmonisation of information systems (Germany). Ideally harmonisation would also address the issue of consistency in the measures, tests, and analyses used characterise variability. There are often well-established databases for storing trial information on species/provenance/family/clone performance, tree improvement (e.g. Japan; Papua New Guinea) and varieties registered for PBR (e.g. Australia), although with private sector increasingly taking lead in tree breeding, much of the information is in private domain (e.g. Chile).

Information systems must be easily accessible to the people using them (e.g. Madagascar p19) including researchers, conservation managers, tree breeders (institutions and private sector companies), people selection appropriate stock for particular seed or genecological zones, including private companies, cooperatives, farmers, villagers and rural communities. An information system that is capable of supporting an effective germplasm and deployment system is considered essential (see below).
Countries that lack the means to undertake their own genetic characterisations may seek assistance and collaborate with other countries and organizations to do this. Alternatively they may need to engage international partners through networks, member organisations, and donor programs to access plant materials with known genetic characteristics. This highlights the importance of international cooperation, the role of networks and the exchange of reproductive material and accompanying information; these issues are discussed below. Donor programmes may contribute significantly to the development and management of information systems in developing countries.

In summary, information needs for FGR C&M referred to in country reports include:

- Commitment to information system in national FGR strategy, including a system for prioritising information needs, with provision of funds and resources
- Requirement for facilities, resources and expertise in characterising FGR at all levels (area, inter- and intra-specific)
- Comprehensive inventories of interspecific variation and biogeographical information
- In-depth information on intraspecific variation of priority or model species
- Information needs of particular conservation, management and improvement programmes
- System for monitoring of the state and trajectory of FGR and genetic variability e.g. forest cover, forest health, species threat status, impacts of conservation or forest

management (Ethiopia, Germany); including comprehensive baseline data on overall FGR at a nationwide level, with detailed information of priority FGR (areas, species, populations) against which changes may be measured

- Data management system for collecting, inputting, collating and safely storing information, with centralised functions
- Harmonisation of data collection, storage and platforms across administrations, jurisdictions, and international borders (e.g. Canada; Germany)
- System for facilitating sharing FGR information across national, regional and international borders, such as provided by networks (Brazil)
- Systems for disseminating information must be tailored to the needs of end users, including with respect to accessibility (e.g. consider level of national internet coverage)
- GIS systems to assist in mapping, documenting, researching, monitoring and assessing changes in forest cover and FGR (Canada, Ghana; Iran)
- Use of donor assistance in establishment, development and maintenance of information systems (e.g. Ghana)
- Use of external sources to obtain information where required including expertise and outsourcing

The importance and role of information exchange

The sharing of information on species' genetic variability is crucial to the development of effective FGR C&M. This is in part achieved through international collaborative research (applied and basic forest genetic research, such as conifer genome), publishing results of studies in scientific journals (such as intraspecific variability studies e.g. Mexico). Diverse networks and associations also play a vital role in facilitating information exchange, both nationally (e.g. CONFORGEN and the Canadian Forest Genetics Association (Canada), France's GENOAK project) and internationally (e.g. FAO Forestry Department and Panel of Forest Gene Experts; Species Networks; Biodiversity International, ICRAF, CAMCORE).

Although important for developed and developing countries alike, a high level of appreciation of the role of networks was expressed by developing nations, who rely heavily on information and research conducted in other countries, especially where they face significant constraints in resources and expertise (e.g. Burkina Faso, Ghana, Zimbabwe). Indeed, 46% of all network participation was by African countries (237 memberships out of a global total of 510), and 62% of these involved international networks; this was more than twice the number of the next largest network participation by the Asian region. There are 25 networks for collaboration and information exchange on *Pinus*, 12 on *Picea*, and 8 for *Populus*; networks for *Eucalyptus* and *Tectona* are also important. Knowledge and information exchange accounted for 28% of all activities reported for networks, the largest category of activities, ahead of research at 17%. They are also extremely important for many developing countries in the exchange or obtaining of germplasm for their breeding and planting programmes (e.g. Brazil, FORTIP/Philippines, Republic of South Africa, Sri Lanka, Tanzania, Thailand, Zimbabwe).

Integrating and harmonising databases across administrations and jurisdictions, referred to above, is essential for effective sharing of knowledge and information on FGR (Canada pp6, 8, 32, 33, 72).

These quotes from the Brazil and Ghana country reports help illustrate these points:

> *'…international cooperation and open exchange of genetic resources are…essential for food, fiber and energy security. And that is when information systems and the use of information technology come necessary, for its capacity to support and facilitate the management of large scale databases as biodiversity and genomic datasets usually are.'* (Brazil)
>
> *'For teak (Tectona grandis), the most widely planted exotic tree, differences in provenances brought from different countries are well noted and described.'* (Ghana)

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, 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 (e.g. India, Seychelles); 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 (e.g. Germany, Iran, Seychelles), 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 (e.g. Sweden). 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 (e.g. Germany).

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). 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 (e.g. Germany)

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 (e.g. Tanzania)
- Preparation and implementation of sustainable forest management plans, that ensure genetic variability is not diminished in areas subject to harvesting and use (e.g. Germany, Brazil)
- 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 (e.g. Germany, Estonia, Vanuatu)
- 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 (e.g. Ghana).

Protected areas provide significant *in situ* conservation initiatives for most countries (e.g. Sri Lanka). 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' (CBD). The contribution of the CBD to the conservation of forest genetic resources cannot be underestimated (e.g. Burkina Faso, Canada, India, Sri Lanka,). 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 (e.g. Iran, Thailand, USA). 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 (Seychelles); Canada has 9.8% of its land area protected (Canada).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 (India), 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 (0.017%) under formal protection in two formal protected areas, Queen Elizabeth Park which is largely degraded (1093 ha) and east Rennell World Heritage site (37,000ha) . 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' (Solomon Islands). 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 strategy, 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 strategy 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 strategy 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. Brazillists 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 (China, Sweden), protection forests (Japan), national parks game management areas and bird sanctuaries (e.g. Zambia), Ramsar sites (India), scenic parks (China), ecoparks (Sweden), forest reserves (Thailand, Tanzania), watersheds (Thailand), mangrove forests (Tanzania) and UNESCO biosphere reserves (India). 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 (e.g. Australia, Canada, Germany, Finland, USA). Private (e.g. Finland pp8, 9, 23, 25) 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 (e.g. Canada; India). Lands under indigenous or customary ownership and/or management are extensive in some countries e.g. almost all land (85-100%) in Melanesia (Fiji; PNG; Solomon Islands; Vanuatu). In Brazil 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 Canadawith 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 (e.g. USA, Sweden); private forestry lands managed under SFM principles or dedicated as reserves (e.g. Sweden); and other private lands subject to conservation management or vegetation retention regulations (Brazil). 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 (e.g. Canada). 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.'* (Sweden)

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 (Brazil).

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 (Brazil).

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 (e.g. Sri Lanka, Finland). 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 (e.g. Algeria, Bulgaria, Burkina Faso, China, Ecuador, Kyrgyzstan, Myanmar, Nepal, Senegal, Sweden, Thailand, Tunisia). 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 (e.g. Finland, Thailand, Sweden). 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); 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 (Zimbabwe p31). 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 (e.g. Sri Lanka). Even well-resourced countries noted the impracticality of surveying all populations of all tree species (Sweden, USA); 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 (Thailand). 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 (Sweden):

- 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 (p22) 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 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 opportunity 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 (e.g. China, Denmark, Zimbabwe). 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 (Thailand), 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 (e.g. China pp21-22, India p67). Conserving large areas of forest in reserves serves well in the absence of detailed genetic information on priority species (e.g. Sri Lanka p29). 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 (e.g. Brazil pp32-33; Ghana p28, Iran p 14). 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 (Brazil pp30, 32, 33, 37-48). Ethiopia (pp19-20) 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 (Ethiopia p23) 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.

A variety of approaches were used by other countries to identify and prioritise areas for *in situ* FGR conservation. Zimbabwe (pp31,37) 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 (USA p22); Sweden (pp17, 21h, 23h) 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 (e.g. Canada p 72; Sri Lanka p28).

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 (Brazil p7); much of Thailand's teak resources have been lost to agriculture (Thailand p35). Differential rates of clearing of agricultural areas (e.g. USA p8) 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' (Thailand p30). 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 (p21h) 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 (Sweden p26h).

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 (Thailand pp35, 39), 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%, common 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 (Germany pp35, 36). 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 (pp23-24): '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 (Canada p37). 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 (SP8) 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' (China), 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).

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 (e.g. Germany p30, Sweden pp22-23).

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' (Iran). 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 (Brazil). 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 (e.g. Brazil, Denmark, Ghana, Thailand, USA, Zimbabwe). 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 (e.g. Ghana). 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 (e.g. Brazil p32), more effective enforcement (Ghana), 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 (e.g. Brazil) 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…'* (Thailand)
>
> 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.'* (Thailand)

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' (Thailand). There may be particular needs to research the regeneration requirements of threatened species (e.g. Ghana).

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 (e.g. Ethiopia). 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 (e.g. Iran). 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' (Iran). 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 (Zimbabwe). Ghana uses artificially propagated stock to enrich forests that have been depleted by over-exploitation and that lack adequate natural regeneration (Ghana). Denmark has re-established the previously locally-extinct *Pinus sylvestris* to its former range in the country, using germplasm from adjacent countries (Denmark). 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 by most countries. A number of the more common ones identified by countries are listed below: Canada's report (pp93-97) 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 (Chad, DR Congo, Ethiopia, Iran, Mauritania, Morocco, Niger, Senegal, Seychelles, Solomon Islands , Thailand, Zambia)
- Encroachment on *in situ* conservation areas (Myanmar, Nepal), including as a result of poorly delineated boundaries (Ethiopia, Philippines)
- 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 (Kazakhstan, Mauritania, Sri Lanka, Solomon Islands) associated with insufficient funds and resources for training, survey, identification, management and monitoring as reported by many countries (e.g. Bulgaria, Cameroon, China, Ecuador, Estonia, Iran, Ireland, Jordan, Kenya, Myanmar, Netherlands, Nepal, Niger, Philippines, Senegal, Spain, Tanzania, Tunisia, Ukraine)

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 (India)
- Loss of traditional knowledge and beliefs leading to decrease in valuing of conservation and traditional species and forest management (Tanzania)
- Low participation or lack participation of communities (Chile, Ecuador), and lack of benefit sharing arrangements for communities adjoining forests resulting in conflict over forest resources (Ethiopia)
- Lack of public awareness, interest and/or support (Hungary, Iran, Ireland, Jordan, Kazakhstan, Myanmar, Netherlands, Senegal, Ukraine) , including lack of political awareness and/or support (Finland, Solomon Islands)
- Lack of alternative livelihood options for local populations (Cameroon)

Policy, Legislation and enforcement

- Lack of coordination between policies, laws, government departments and sectors impacting on *in situ* conservation of FGR (Ethiopia, Kazakhstan, Kenya, Madagascar, Thailand, Zambia), including insufficient policy support (China)
- Legal uncertainties and shortcomings (e.g. Chile, Ecuador) including lack of adequate legal framework (Lebanon), lack of knowledge of relevant policies, laws and regulations on the part of stakeholders, including those charged with law enforcement (Ethiopia, Iran, Madagascar), lack of legislative protection for designated areas (Seychelles), inadequate enforcement of regulations and laws (Ghana, Jordan) and monitoring (Cameroon)
- Lack of policy on how to increase benefits of trees on farms and *circa situm* conservation (Nepal)
- Concentration on charismatic, priority species at expense of conservation of other indigenous and traditional species (Tanzania).

Technical and operational issues

- Lack of coordinated national plans (Uzbekistan) and integrated approaches to FGR conservation linking *in situ* and *ex situ* strategies (Gabon, India)
- 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 genetic resources and processes, and genecological zones, including of those assets already conserved *in situ* (China, Estonia, Iran, Jordan, Philippines, Sri Lanka, Tanzania)
- Management issues of *in situ* conservation areas including exotic/ invasive weed species suppressing growth of species conserved *in situ* (Poland, Tanzania), inappropriate fire management (Tanzania), and minimalist or close-to-nature management approaches limiting opportunities to conserve light-demanding/disturbance-dependent species in more strictly protected areas (Netherlands, Poland).
- Climate change reducing regeneration of conserved species (Ethiopia, Niger); causing range shifts of species and vegetation communities due to shift in climatic zones (Sri Lanka)
- Threats to FGR in protected forests from invasive species (including insects), fire and climate change (USA; Australia).

<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 (Brazil, Bulgaria, Sweden, Tanzania, Vanuatu)
- Capacity building – including education, training, expertise, resources, networking (Burkina Faso, Bulgaria, Estonia, Iran, Jordan, Kenya, Kyrgyzstan p, Papua New Guinea, Philippines, Spain, Sri Lanka, Sweden, Tanzania, Tunisia, Turkey)

Public awareness, involvement and support

- Ensuring sustainable livelihoods, sustainable access arrangements, benefit sharing for communities and forest users adjoining FGR *in situ* conservation areas (India, Ethiopia, cf. CBD art8)
- Expanded use to increase valuation by community of indigenous FGR and complement *in situ* conservation (Thailand)

- Greater focus on indigenous and traditional species in use, research, documentation, evaluation of potential, promotion of values in rural communities, and *in situ* conservation (India,Tanzania)
- Payments to compensate traditional forest users where access to forest revenues is denied (Ghana p9); incentives for stewardship of FGR.
- More education and awareness for forest owners and users through extension and general public (Estonia, Norway, Papua New Guinea, Philippines, Tanzania p29, Thailand)
- Communications strategy, including media campaigns, to raise awareness of FGR conservation matters in general public and youth (Cameroon, Germany, Senegal, Ukraine)

Policy and enforcement

- Strengthen legal framework for FGR *in situ* conservation (Germany, Ukraine), including review and revision of policies and legislation (e.g. Sweden, Tunisia, Uzbekistan) and addressing FGR currently on unprotected lands (Kenya, Madagascar)
- More effective enforcement of regulations and laws (Ghana, Senegal, Zimbabwe)
- Poverty alleviation and employment creation strategies (e.g. Uzbekistan, Zambia)

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 (Germany, Spain, Sri Lanka , Tanzania, Thailand, Turkey, Ukraine, Zimbabwe p)
- Inventory of FGR in protected areas (Kyrgyzstan, Philippines), including to identify centres of diversity (Lebanon)
- More knowledge of effective *in situ* conservation techniques including selection, establishment, monitoring, restoration and rehabilitation and management (Chile, China, India, Iran)
- Prioritisation of species (e.g. India, Ireland, Japan, Madagascar, Senegal)
- More knowledge on species importance in maintaining ecosystem function and services as a focus for *in situ* conservation (Thailand)
- Research on autoecology and species genetic diversity, including monitoring, to inform and assess effectiveness of FGR conservation strategies and activities (Burkina Faso, Cameroon, Japan, Kazakhstan, Madagascar, Poland , Spain),
- Development of low cost control technologies and better controls for invasive species (Chile, Mauritius, Zimbabwe)
- Research for methods to improve participatory forest and FGR management, including to reduce deforestation (Madagascar, Tanzania, Thailand)
- Research into socio-economic aspects of *in situ* conservation (Philippines, Thailand)
- Impact of predicted climate change on effectiveness on *in situ* conservation reserves (Hungary)

Technical and operational issues

- Better planning including national network (Brazil), better defined guidelines for designation and management of FGR conservation reserves (Germany) and preparation of *in situ* conservation strategies and action plans (Ukraine, Cyprus),
- Rehabilitating and restoring degraded ecosystems and promoting recovery of threatened species (Ethiopia, Ghana, CBD article 8)
- Assessment and monitoring of existing FGR conserved *in situ* (China, Madagascar)
- Protection of identified high priority species (Philippines, Thailand) including rare species (Germany, Norway), and endangered populations (Spain)

- Conservation of marginal range populations as part of integrated gene conservation efforts (Norway, Sweden)
- Better management of *in situ* sites (China), including silviculture and actions to ensure regeneration (Thailand), management plans for and demarcation of protected areas (Ethiopia)
- Better knowledge sharing, coordination and networks at national level e.g. between government agencies, researchers, parks managers, forest and local authorities and farmers (Chile, Madagascar, Spain, Zimbabwe)
- Improving connectivity of the protected area network and reducing fragmentation (India)

Opportunities

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 (Morocco, Senegal) and improvement of production forestry, through identification and delineation of areas for forest development, improvement of germplasm quality to boost plantation industry and restoration, (Ethiopia); better natural resource management (Zambia).
- Involvement of private sector in *in situ* and gene conservation reserve systems, funded through environmental service payments (Costa Rica) or with Government assistance (Australia); with long term security through purchase and incorporation into public estate (Finland)

Resourcing and capacity

- Involve Universities, training schools, NGOs and others in conduct of FGR inventories (Cameroon)
- Increase involvement of donors and NGOs in *in situ* conservation (Ethiopia)
- Information exchange and participation in regional and international networks and collaborations (Papua New Guinea, Sri Lanka, Tunisia, Zimbabwe)

Public awareness and support

- Greater and continued involvement of local communities in management (Burkina Faso, Cameroon, Ecuador, Jordan)
- Sustainable and equitable use of natural resources and benefit sharing by local communities (Ethiopia, Madagascar)

Policy and enforcement

- Development supportive policy regimes for protected areas (Cameroon)
- Legislative protection for threatened, ecological keystone and cultural species, including iconic trees and populations (such as champion trees project, Republic of South Africa)
- Better land use planning policies and tenure systems (Ethiopia)

Adding value and improving functionality of protected areas and landscape matrix

- Increased use as seed sources for priority FGR (e.g. Ecuador), 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 (Nepal)
- Use to raise living standards of local people (Cameroon)

- Ecotourism to generate income from non-consumptive uses of *in situ* conservation areas (Ethiopia)
- Enrichment planting and regeneration of high priority and threatened FGR in protected areas, including restoration of degraded areas (Jordan, Kenya, Madagascar, Mauritius)
- Restore connectivity of protected forest fragments (Costa Rica, Madagascar)
- Promote on-farm/*circa situm* conservation of priority FGR including fruit trees and their wild relatives (Lebanon, Uzbekistan)
- Payments for environmental services such as carbon sequestration, e.g. REDD+ (Ethiopia, Papua New Guinea, Zambia) and bioprospecting licences (Nepal)
- New employment opportunities including from NWFPs, such as increased market for specialist organic forest produce (Ethiopia)

Technical issues

- More wider use of gap analysis to identify priority areas for FGR conservation (Indonesia, Kenya)
- Translate research findings into practical conservation plans and actions (Madagascar)

2.4.2. Sustainable forest management

The importance of a range of public, private and traditional lands outside of protected areas in providing *in situ* FGR conservation outcomes has been noted above. Furthermore, a range of uses, activities take place within protected areas, both legally and illegally. It is vital that these activities are conducted in a way that minimises impacts on the genetic resources of the forests, areas, and species subject to use, and where possible, improves their condition. This may be achieved through applying sustainable forest management principles (SFM).

There are many SFM strategies, approaches, initiatives and programmes undertaken by countries to ensure that impacts on FGR and forest productivity are minimised. These include SFM certification schemes for forest operations, promoting the use of indigenous species, ensuring natural and artificially regenerated stands contain sufficient genetic variability, replacement of monoculture conifer plantations with mixed species of hardwoods, and promoting community participation in forest management, maintaining traditional valuation, knowledge and management of forests.

While protected areas make a vital contribution to FGR, they make up a small proportion[19] of forests worldwide, and the extensive areas of forest used globally for multiple purposes including production of wood products, NWFPs, and non-consumptive purposes also have extremely important roles in the *in situ* conservation of FGR; as the Zambian report notes ‘conservation of FGR…takes place within and outside the protected areas..’. Indeed, almost all extant forests and trees provide a level of *in situ* conservation benefits for FGR, until the variability is lost or diminished through destruction or degradation. One of the primary requirements for *in situ* conservation of FGR is ongoing, permanent application of a management regime that addresses and preserves genetic diversity of the tree species contained within the forest, regardless of the tenure and use. Another basic requirement is achieving security of conservation tenure over the area, for example through gazettal as a protected area or

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

conservation reserve, or as a production forest permanently subject to FGR-appropriate sustainable forest management (SFM). The Solomon Islands report describes the need to provide a framework for and implement SFM initiatives as ‘urgent’.

The importance of the SFM approach is illustrated by considering that forests subject to harvesting and use under SFM regimes that specifically include FGR management will offer more effective conservation of the resource than poorly managed or uncontrolled protected areas subject to threats such as illegal incursions, unsustainable harvesting, wildfire, grazing and invasive species.

SFM and utilization, aided by low human population pressures, has been practised in many areas under traditional and customary management for many centuries if not millennia (e.g. Ethiopia, Pacific Islands, Tanzania, Thailand, Zimbabwe). An SFM approach was described in a German forestry text as early as 1713. Attention is increasingly focused on SFM as a means of achieving conservation outcomes simultaneously with multiple productive uses 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).

The requirement for the sustainable use of forests is enshrined in Articles 8 (c) (*in situ* conservation) and Article 10 (sustainable use of components of biological diversity) of the CBD:

> Article 8 (c) : ‘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’;…(i) Endeavour to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its components’

> Article 10: ‘(a) Integrate consideration of the conservation and sustainable use of biological resources into national decision-making; (b) Adopt measures relating to the use of biological resources to avoid or minimize adverse impacts on biological diversity; (c) Protect and encourage customary use of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements; (d) Support local populations to develop and implement remedial action in degraded areas where biological diversity has been reduced; and (e) Encourage cooperation between its governmental authorities and its private sector in developing methods for sustainable use of biological resources.’

Germany (p92) 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, through ensuring the widest range of variation is available as a basis for adaptation in both natural forests and genetically improved forestry plantings; this ensures the continuation of evolutionary and ecological processes, and a continued flow of goods and services including WPs and NWFPs as well as the maintenance of social and cultural values. It is essential to explicitly recognise and incorporate FGR C&M 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’

Traditionally the SFM approach has been applied to forestry and timber harvesting operations, in particular through use of the sustained yield principle; however, as noted above forests are used for many other extractive uses as well as timber production and these also require appropriate management through application of this and other SFM initiatives. Recognising this, the NLBITF definition is expansive, referring to ‘all types of forests’. As mentioned earlier, wood products (timber; posts, poles and roundwood; pulp and energy) accounted for the largest category of reported values for species currently used by countries at 42%; the remaining nominated values included in order food security and production, non-specific NWFPs, medicines, agriculture and agroforestry, fodder and artisanal uses. Non-consumptive uses, such as tourism, also need management plans taking into account FGR, as these can also have negative impacts, for example, introduction of invasive species or pathogens, manipulation of or changes to regeneration patterns, or changes to fire regimes. 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. Thus, this section adopts the expanded meaning and application of the term SFM, as applying to all activities and uses of forests and trees, in addition to its traditional application in formal production forestry contexts.

Production forestry nonetheless remains a major focus of SFM, as large areas of the globe’s forests are managed primarily for this purpose. The area of forests subject to timber harvesting varies significantly between countries. Some countries have legislated to discontinue logging of natural forests (e.g. Thailand) or limit it to small areas (e.g. Seychelles). On the other hand, in Indonesia60% of total forest area is production forest; Germany manages most of its forests jointly for production forestry and conservation, including of FGR. In the Solomon Islands only 38,000 ha or 0.017% of the forests, which are considered globally outstanding, are under formal protection, while logging concessions are held over 843,600 ha or 38% of forests.

As noted in the previous section, it is vital to ensure that adequate management is applied to protected areas and other categories of land where conservation of biodiversity and FGR are key objectives, as these also require active intervention to ensure that the FGR are maintained. This may include management of threats or maintenance of ecological processes. This is also sustainable forest management, where the use is conservation and management of FGR and biodiversity.

Development and implementation of national SFM policies and plans is at the core of the SFM approach. The development of SFM plans that include FGR conservation goals and objectives will be straightforward for areas where maintenance of conservation assets (e.g. FGR, biodiversity) is already defined as a primary objective and the forest is gazetted and managed for this purpose. In such cases there will be fewer potentially detrimental alternative uses to manage compared to production and multiple use forests, and management agencies are more generally more familiar with appropriate management techniques for FGR.

The need to address the particular requirements of FGR conservation in management plans for protected areas and conservation reserves has been referred to above. This especially applies to formal FGR conservation reserves for priority tree species or areas which may require specific silvicultural or disturbance regimes to ensure adequate regeneration that may be inconsistent with conventional biodiversity management approaches for strict protected areas.

Many productive uses occur in various categories of protected areas. Most 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 (e.g. Canada, Seychelles). Many countries also noted that despite their conservation designations, many protected areas were subject to illegal occupation, use and harvesting activities (e.g. Thailand). 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 impacts.

There is a risk that SFM as currently practised in some places may not adequately address the requirements of *in situ* conservation of FGR, as there is a tendency to focus on the principle of sustained yield and maximising ongoing production of timber from forestry operations rather than achieving genetic and ecological outcomes that are important components of SFM. Therefore it is essential to ensure that all SFM protocols address the requirements for conservation of FGR, both of major commercial timber species as well as the other forest tree taxa, especially those providing NWFPs, whose continued presence and variability may be impacted by utilization activities.

Nonetheless, for countries where logging currently takes place with inadequate controls and at unsustainable rates, applying the basic forest management principle of sustained yield is one of the most significant tools for achieving FGR conservation (e.g. Solomon Islands).

Implementing SFM in production forestry as a means of ensuring *in situ* conservation of FGR will become increasingly important in coming years, due to the challenge of increasing global demand for wood products. For example, China has identified that population growth, increasing wealth and consumer demand for timber and wood products will result in a significant shortfall between demand and supply, and these factors hold for many other countries (e.g. Seychelles).

Increasing demand for non-timber goods and services from forests is also increasing, due to population increases, economic development and climate change; for example, current and projected demand for water production and ecotourism have increased in the Seychelles, and although these uses are largely compatible, FGR conservation may still require particular management. SFM plans are required to address changes in demand, as the Seychelles have recognised:

> *'There have been significant changes in the types and diversity of products and services in the last 10 years. Demand for timber has increased primarily for the construction industry and also when the Seychelles were experienced some economic downfall. Similarly, the use of bamboo for the construction of [fish traps] has also increased so as the demand for coco de mer. As a result, Government had to develop sustainable guidelines and a new policy to accommodate the changing demands over forest resources in the next 10 years.'*

There is increasing interest and efforts directed at growing more productive forests for the purpose of sequestering CO_2 (e.g. Norway, 2009 Government White Paper) as part of climate change mitigation.

Sustainable forest management requires a good knowledge of the harvested species' genetic variability and its distribution, and also to some extent for other tree species in the area subject to utilisation. This has been addressed in an earlier section.

Impacts of forest harvesting and management on variability of FGR

The most serious impacts of timber harvesting on FGR occurs where it is uncontrolled, unregulated and occurs at rates far exceeding natural replacement or is a precursor to conversion to another land use. Impacts include potential and actual extinctions (e.g. Solomon Islands), drastically reduced populations containing extremely limited genetic variability (e.g. Seychelles), elimination of trees with preferred traits from the gene pool through selective harvesting (e.g. Seychelles), and failure of regeneration (Solomon Islands). Many countries, particularly those with high levels of poverty and lacking resources and capacity for effective administration, reported unsustainable harvesting of natural forests (e.g. Ghana, Seychelles; Solomon Islands, Vanuatu; Zambia), with risk of irrevocable loss of genetic variability.

A number of countries remarked that inappropriately managed harvesting may have a negative impact on genetic variability (e.g. Philippines). For example, harvesting practices in natural forests that prevented regeneration were identified as a primary cause of genetic erosion in 26 tree species in Canada, of which 75% were hardwoods, representing 21% of all Canadian tree species. In Thailand 'selective logging in the natural forests may have caused genetic selection towards [teak] trees with inferior stem form.' (Thailand); the over-harvesting of the threatened endemics *Mimusops sechellarum* and *Syzgium wrightii* in the Seychelles has left only extremely limited numbers of individuals with the poorest bole form (Seychelles). Zimbabwe noted the potential for genetic impoverishment and reduced regenerative capacity of wild populations resulting from over collection of seeds, for example of the fruit tree *Uapaca kirkiana*. The Malawi report remarks that preferential logging of desirable species in Miombo forests 'has pushed some of the preferred species into [the] threatened species category', and notes that heavy selection of better-formed Mulaje cedar has left only the poorer individuals to reproduce.

Forest harvesting and management that impacts on ecological processes and disturbs a wide range of plant, fungal and animal species naturally occurring in forests can reduce variability by interfering with pollination, nutrient cycling, water relations, mycorrhizal associations, resulting in failure of regeneration or loss of individuals or populations.

Relying on germplasm of limited genetic variability for regeneration of large areas of plantation can reduce variation; China, for example, noted that expansion of plantations can impact negatively on FGR C&M (China). Plantations can negatively impact FGR where a highly variable gene pool contained in diverse natural forest is replaced with plantation forests derived from a limited genetic base, as in some operations in Indonesia; in such cases FGR present in the original, natural forest will be irretrievably lost if not conserved elsewhere. 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 (Sweden, Indonesia, China).

As noted earlier, countries generally displayed a strong preference for using exotic species in their forestry programmes; these comprised 85% of country priority species listings for FGR C&M. Given the widespread sharing of genetic material and increasing use of the same superior variants (e.g. clones of hybrid Acacia and teak from Malaysia), this can lead to the replacement of natural variability with genetic material of low variability used widely around the world.

The movement of improved, uniform genetic material from improved plantings into reproductively connected natural populations can reduce variability, through increasing the frequency of the improved genetic material in the progeny of these crossings at the expense of alleles in the natural populations (e.g. Sweden, cf. China, Germany) in a process referred to as ‘genetic pollution’. The same process can also impact on the genetic integrity of populations of wild fruit tree relatives, such as through genetic contamination of wild apples (*Malus sieversii*) from apple orchard in Kazakhstan.

Finally, inflexible management regimes that lack the ability to detect and respond to undesirable impacts on genetic variability may lead to reduction in variation. This can occur where forest management regimes are locked in for long periods with no option for alteration or adaptation in response to the observed outcomes of previous management actions. This means that actions impacting on variability may continue unabated until the end of the management cycle. An example is the granting of 60 year licences for selective harvest of natural forests on public land noted by Indonesia. Where there is no requirement for review, adaptive management in relation to SFM and FGR are far less likely to be applied.

In relation to the loss of variation from production forestry, the Canadian report noted that:

‘Regeneration practices also have the potential to impact genetic erosion, where, in the extreme case of monoclonal plantations, virtually all genetic diversity is lost. The use of non-selected, non-local seed sources in artificial generation can potentially result in adverse genetic impacts due to maladaptation. It should be noted that most of Canada’s forest area has not been and will not be subjected to harvesting. However, forest management practices do constitute a threat in many areas; in particular, in highly productive forest types, which also tend to have higher levels of species diversity.’

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

Sustainable forest management should seek to maintain or enhance existing levels of genetic variation and evolutionary processes in the area subject to harvest or use. This includes especially the harvested or utilised species, any other priority species for FGR C&M also present, and, resources permitting, any other co-occurring forest tree species.

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:

- Relieving pressure on native forest harvest and utilisation through a) increased production of timber from existing production forests through implementation of SFM principles; b) increased area of natural forest by facilitating natural regeneration and reforestation; c) increased area of forest plantings, to meet demand for WPs and NWFPs; d) establishing alternative use-values and non-destructive income-generating forest-based activities, and e) increased value-adding of forest products to generate higher revenues and greater employment from smaller areas of harvested forest
- Forest land-use planning or 'zoning' approaches, including identification and protection of key areas for *in situ* FGR conservation; and delineation of those areas with least valuable and/or least vulnerable FGR and designation for more intensive harvesting or use (e.g. Thailand)
- Adoption of multiple use approach to production forestry areas – including the conservation of FGR, biodiversity and ecosystem processes in the suite of uses and management objectives, especially in production forestry settings (e.g. Germany)
- Adoption of 'close to nature' approaches to production forestry, e.g. mimicking natural regeneration processes for harvested species
- Use of suitable local species for use in plantation and production forestry (e.g. Canada, Germany, Finland, Norway and Sweden)
- Development of codes of practice that address FGR C&M for the sustainable utilisation of forests
- Preparation and implementation of forest management plans that integrate maintenance of FGR, biodiversity and evolutionary and ecological processes for areas subject to harvesting and use
- Use of harvesting techniques that minimise the impact on FGR; for example avoiding harvests which leave only the poorest phenotypes and culls to contribute to the genetic makeup of the next generation (e.g. teak in Thailand p35; Ledig 1992)
- Maintaining high levels of genetic variation in naturally and artificially regenerated stands, through application of an appropriate silvicultural system or regeneration techniques
- Replacement of monoculture plantings with indigenous mixed species (e.g. Germany, Sri Lanka, Sweden)
- Obtaining SFM certification for production and exploitation activities under management regimes that protect FGR (e.g. Estonia)
- Promoting the use of timber produced under SFM principles (e.g. European Union member states Germany)
- Involvement of local communities in forest management and conservation of FGR (e.g. Zimbabwe; Community Areas Management Programme for Indigenous Resources - CAMPFIRE)
- Retain and regenerate traditional knowledge, practices and values that supports SFM (Tanzania)
- Valuation of biodiversity and FGR to facilitate financial return on conservation of FGR e.g. through incentives, stewardship payments, biodiversity/FGR credits (e.g. Finland)
- Education of forest users, farmers, communities in sustainable harvest, non-destructive forest use and conservation of FGR (e.g. Estonia)
- Ensuring benefit sharing mechanisms in place so that communities receive a fair share of benefits from FGR thereby increasing financial value placed on and awareness of FGR C&M

The following section describes some of these approaches in more detail.

Reducing use and harvest pressure on natural forests through SFM strategies

Where application of SFM approaches increases the production and volume of timber or other produce from natural forests, it may have an enhanced effect on conservation of FGR through reducing the harvest pressure on other forests conserved for biodiversity and FGR purposes, or freeing up production forest for other uses. SFM can result in increased timber production from the same or even a 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. These results may be achieved through application of SFM practices such as improved genetic materials, altering rotation length (Sweden), species-specific minimum diameter cutting limits (Fiji, PNG, Philippines, Zambia, Zimbabwe), thinning operations (Sweden), retention of mother or seed trees (Philippines) and ensuring that the principle of sustainable yield is applied, where the amount of harvest does not exceed the annual increment (e.g. Estonia, Zambia). The possibility of increasing production from existing natural forests through better management was also noted by other countries such as 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.

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 (China, India and Vietnam), while in southern Europe (Spain, France, Italy, USA) there may be a large component natural regeneration on abandoned, marginal agricultural lands. Ghana has also proposed intensive forest plantation development to reduce pressure on natural forests. Solomon Islands identified the need to rehabilitate logged areas that had failed to regenerate as a matter of urgency, to restore areas to productivity. This strategy may extend to increasing farm and landscape plantings and expanding plantation area to meet the demand for forest products and services to reduce pressure on native forests; these plantings may include tree species and populations under pressure in *in situ*, thereby providing *circa situm* FGR conservation benefits (e.g. Iran).

The approach of increasing plantations to reduce pressure on native forests is an important element of a SFM strategy. 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.’ Solomon Islands similarly identified this approach as vital to reducing unsustainable logging of natural forests. From an FGR C&M and longer term sustainability viewpoint is essential that existing, genetically diverse natural forests are not replaced with exotic monoculture of limited genetic variation; Seychelles suggests 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 multi-purpose tree species as well as for forest-related cooperatives, and ensuring land for plantation establishment is affordable (Iran.

Applying basic forest management principles such as sustained yield is essential for conservation 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 plays 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 on-ground 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 certification schemes (increased marketability); 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 fuel wood and charcoal, which in a number of countries contributes to unsustainable levels of harvesting, may fall when alternatives are provided: in the Seychelles (p15), 'the demand for fuel wood 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; for example, the Solomon Islands has a government 'downstream processing' project to add value to logs rather than exporting them in the round, to increase financial returns to the population, increase government revenues and to provide greater employment, and thereby reduce the reliance on unsustainable and damaging native forest logging:

> *'…value added timber products attract higher price per unit quantity and [are] suitable for local operators and individuals to undertake compared to round log extraction…also, it enhances sustainable harvesting and reduces forest disturbance and destruction'* .

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 (Solomon Islands).

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 forests (e.g. cf. Thailand, Cyprus, Iran report to 5th session UNFF 2005); this may be facilitated by reducing or eliminating tariffs on wood imports. Certain countries are highly effective at producing forest products with less impact on FGR than others, and importing from these sources and reducing a country's own production and lowering pressure 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'. Imported goods that are efficiently produced with minimal FGR impacts may be substituted for forest products produced locally under regimes incurring high costs in terms of FGR impacts.

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 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 (e.g. Iran). 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 (e.g. Solomon Islands); the Philippines also noted lack of will as a contributor to failure to adequately protect forest.

In what can be considered an extension of this SFM principle, a number of countries use 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 (e.g. Thailand). It is essential that conservation of FGR is considered as an important objective in land-use planning exercises (Thailand; Tanzania, Indonesia, Zimbabwe).

The identification of important areas for SFM in FGR C&M requires detailed information about the genetic profile of tree species subject to harvest and use, priority species and other forest species potentially impacted by harvesting or use of the forest area; information and knowledge of ecological processes that sustain FGR are also required. The processes used by countries to obtain information and to identify priority areas for maintenance of FGR have been discussed above.

Adopting multiple use approach to production forestry areas

Adopting a 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, CO2 sequestration and environmental protection, 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 its '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. The multiple use approach is particularly useful for integrating FGR conservation and management objectives into the management of areas currently designated as single-purpose 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 corridors of native forest linking 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. Conversely, where harvesting or productive uses of a forest can be achieved through SFM while minimizing impact on FGR and evolutionary and ecological processes, it may be appropriate to allow activities in some categories of protected areas or conservation reserves in certain, albeit limited, situations. This may be the case where protected areas are subject to uncontrolled access, harvest and utilization by neighbouring, impoverished rural communities, many of whom previously or still inhabit and/or enjoyed access to protected areas and used them according to customary, sustainable-compatible management regimes (e.g. Tanzania, Zimbabwe; Thailand). Providing controlled access under FGR-appropriate sustainable forest management plans can reduce negative impacts on FGR and may even provide positive conservation benefits through informal surveillance by neighbouring communities and reduction in illegal access. This is discussed further below.

Adopting 'Close to nature' forestry practices

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 reporting . For some countries relying on natural, *in situ* forestry based on indigenous species this figure can be high: 85% of Canada's logged forests are allowed to regenerate naturally.

A number of countries applied a 'close to nature' approach to forestry management approach; for example 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'. Similarly 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 (Denmark). The approach is also under study in Iran. Germany's 'close to nature' forest management is described as follows:

> *'The close to nature forestry practiced in Germany makes use of natural processes and aims for ecologically and economically valuable forests. In this way, an increasing amount of mixed forests are growing with a high percentage of natural regeneration and long periods of regeneration. The natural regeneration methods used are intended to include as large numbers as possible of parent trees in regeneration in order to prevent, among other things, genetic constriction. Wherever suitable tree species or provenances are lacking for natural regeneration, additional trees are planted, i.e. artificially regenerated… The specifications of the [regulations] for the approval of seed stands and the minimum quantities of harvest trees are basic prerequisites for the provision of high-quality forest reproductive material and an important contribution to the conservation of genetic diversity in the forests'*. (Germany)

As for all SFM initiatives, the needs of FGR C&M must be integrated into the 'close to nature' forestry approach, that is, taking an inventory of genetic resources, 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 regime as appropriate.

Using local species

The use of local species in forestry plantings for activities such as timber production, fuelwood and afforestation can assist in maintaining local genetic variation, but only to the extent that genetic variability in the planting stock is maintained and germplasm is 'genecologically appropriate' and the management regimes do not excessively deplete variability in non-target species. This can yield particular 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 through 'swamping'. 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…' Indigenous species are increasingly being used for afforestation and environmental works: in the Seychelles 'the Forest Service intends to start planting indigenous species in its afforestation work'.

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 (e.g. Vanuatu, Solomon Islands). 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 harvest or utilisation of forest species or areas on public land, and may extend through legislation to 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. Some codes may be further developed as certification schemes and used to demonstrate production best practices to the market. 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 to ensure compliance, 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 of practice can (and should) be designed with end users in mind, thereby facilitating their adoption by people directly involved in the operational tasks. They are also vital in helping to translate complex legislation and regulations into an operational context. Codes must have legislative or legal backing to be enforceable. Most importantly, to effectively protect FGR, codes of practice must address the requirements of the genetic resources and evolutionary processes potentially impacted by the activity.

Several 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 (e.g. Solomon Islands). They may only be effective in the private forest estate where the government has jurisdiction over private-land harvesting activities for example through granting of permits, as are issued in Seychelles.

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 practice codes 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 (Iran). Information on the genetic resources and evolutionary and ecological process, the impact of use on these, and selection of appropriate SFM approaches to minimise impacts, is central to this process. 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 the 'adaptive management' approach.

Some countries remarked the difficulties of implementing SFM plans (e.g. Iran). Reasons included lack of funding, lack of organizational capacity, or lack of political support or will (e.g. Solomon Islands). In some instances SFM plans consistent with government guidelines could not be applied due to lack of jurisdiction over forests under customary or private tenure (e.g. Solomon Islands).

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 its conservation. Building capacity for effective administration capable of implementing SFM programs incorporating FGR is similarly important.

A number of countries reported supporting community participation in preparation of SFM plans to facilitate sustainable outcomes (e.g. Iran, China), 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 requirements of the particular target species, other woody species potentially impacted by the harvesting or use including any priority species, as well as evolutionary and ecological processes. Areas to be conserved for their FGR values must be identified and protected from harvest, the harvest intensity and techniques must minimise impacts on non-target species, and the harvest intensity and technique and regeneration practices must ensure that the genetic variability of the target species and the utilised area is retained as much as possible. Impacts of harvesting are many and include physical damage, introduction of diseases, pests, and invasive plants and animals, changes to soil, light and moisture conditions impacting on survival and regeneration of target and other species, and most importantly, a potential reduction in variability of the gene pool. Monitoring the impacts of harvest and utilisation and applying management are essential elements of the SFM process.

A number of countries noted negative impacts of harvesting regimes and techniques on the genetic resources (e.g. Solomon Islands). Most significant is harvesting at unsustainable levels resulting in serious depletion or extermination of the target and other forest species (e.g. Senegal; Kenya, Solomon Islands, Iran, Zimbabwe). Iran reported a research programme to investigate the damaging impacts of silvicultural practices.

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 (Canada). This is particularly important for countries whose forestry industries rely heavily on logging of natural forest, and even more important where these countries have few protected areas, such as the Solomon Islands. As noted, the majority of species utilised by countries were 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 (e.g. Solomon Islands). In some situations artificial regeneration may be the preferred method of restocking. Wherever stands are regenerated artificially, using germplasm that maximises the chances of maintaining variability is essential. For example, where stands are artificially regenerated e.g. through reseeding, 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. Canada's Criteria and indicators of SFM in Canada sets out a number of requirements for SFM; in relation to maintaining the variability of germplasm in the 15% of Canadian production forest which is artificially regenerated, it explains:

> *'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'* (Canada)

Ideally seed would be collected from the area to be harvested and regenerated beforehand; 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 optimally or well-adapted to local conditions. Ensuring that levels of variation are maintained requires knowledge of the genetic diversity of the harvested stand; if this is not known (as in the overwhelming majority of cases) then guidelines based on knowledge of the target or impacted species may be used to guide collection and use of germplasm for artificial regeneration to maximise variability.

Germany recognises the need to monitor the genetic impacts of its silvicultural practices on genetic diversity of its priority species, and is developing a methodology to facilitate this; early work suggests that losses to date are not excessive.

Some countries 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 (e.g. Solomon Islands).

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 (e.g. Canada, Cyprus, Germany, Sweden). 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 (e.g. Germany, Norway). 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 the need to manage for this.

Increasing variability in plantation establishment

In Indonesia, 'land preparation practices for forest plantation or agroforestry in ex-logged off conversion forest areas are often done by clear cut that clean up all other species that still survive' (Indonesia); the retention of some level of natural regeneration may assist in maintaining diversity.

To increase variability, several countries are considering or have promoted and undertaken conversion of monoculture plantations to mixed species plantings (e.g. Germany, Sri Lanka and Sweden). Reasons for conversion included to provide opportunities for adaptation to climate change, and to increase genetic connectivity between isolated remnants (Sri Lanka). Germany has identified that climate change may necessitate the transformation of pure spruce stands in many parts of the country to mixed stands; this will require identification of suitably adapted plant material. Increasingly, mixed species plantations serving multiple purposes are finding favour, for example, under initiatives for reafforestation of Low Forest Cover Countries (Iran).

Other practices to minimise losses of FGR from plantations may include avoiding further conversion of natural forest to plantation, documenting and conserving the FGR *ex situ*, and increasing genetic diversity within plantation stock across a range of traits whilst maintaining uniformity for desired production traits.

Certification and demand management: increasing market share for sustainably produced products

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, with withdrawal of certification the penalty for non-compliance. Certification of a product produced 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…'.

A number of countries reported achieving certification under several of these schemes. 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 (p4) 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.

Germany also adopts certification, and notes that measures including PEFC and FSC certification systems 'have positive effects on the conservation and sustainable utilization of forest genetic resources and have greatly limited the introduction of unsuitable reproductive material….certification under PEFC and FSC supports the sustainable management of the forests and thus promotes the conservation of genetic diversity of the entire forest ecosystem….In Germany approximately 66% of the forest area (7.3 M hectares) are certified according to PEFC criteria, 4.3% (0.48 M hectares) according to FSC criteria and 0.5% (0.05 M hectares) according to Naturland criteria'.

EU member states contribute to the reduction of illegal logging globally through EU Regulation 2173/2005, which establishes an approval and licensing system in supply partner signatory countries, to ensure that only legally harvested timber is exported to the EU. Partners include Congo, Cameroon, CAR and Indonesia. To prevent imports from non-participating nations, national legislation has been enacted in European countries in line with the EU Timber Trade Regulation (995/2010). In Germany this will be enacted through the Timber Trade Safety Act. Germany also supports SFM by promoting the domestic consumption of sustainably produced timber, through its 2004 Charter for Timber.

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. Explicit mention ought to be made of FGR values for assessing high conservation value forests, as it is essential that forest certification systems adequately integrate the requirements for effective conservation and management of FGR into their schemes.

Community and participatory management, poverty, reducing pressure on conserved areas

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 (e.g. Thailand pp12-13, 15), 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 (e.g. Tanzania pp25-26); d) poverty-driven increased use pressure amplified by climate change including encroachment of agriculture and pastoralism (Zimbabwe pp30, 52, e.g. Zambia p52), and e) 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 (e.g. Thailand p17)

This suite of 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 (e.g. Ethiopia p21, Zimbabwe p35).

This approach is discussed in more detail in a following section.

2.4.3. The state of ex situ conservation by region

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, China, Kenya, Lebanon, Madagascar, Mali, Mexico, Jordan, Saudi Arabia, South Africa, Tanzania and the United States (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 2516 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, 420 species reported as conserved in Latin America, 408 species in Asia, 402 in Europe, 101 in North America, 63 in the Southwest Pacific and 60 in the Near East. In all regions the majority of species conserved by *ex situ* means were native species.

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 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* ssp., *Eucalyptus* spp. and *Pinus* ssp. 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* ssp., *Picea* ssp. And *Pinus* ssp. 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

Latin America and Caribbean: There are similarities in the *ex situ* conservation activities in Brazil, Chile, Costa Rica and Ecuador. 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.

Near East*:* There were similarities in the priorities and constraints of FGRs among these countries namely Egypt, Iran, Iraq, Jordan, Lebanon and Sudan. 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. 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. 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[20]

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

[20] Data presented is based on the species for which there was specific *ex situ* data reported on

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.

Africa: 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.

Southwest Pacific *Ex situ* conservation data was reported only for Papua New Guinea where 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

Trees have been the subject of informal selection, breeding and movement for many hundreds if not thousands of years in traditional and rural communities around the world, and more recently through formal breeding efforts by governments and agencies, to serve a huge variety of purposes and produce goods including fuelwood, timber, fibre, craftwood, fruit, nuts, oils, traditional medicines, dyes, resins, thatch, and other NWFPs. In developing countries, particularly those less well-off, informally improved and aboriginally introduced trees make a significant contribution to livelihoods, although the benefit attributable to FGR improvement in these cases is difficult to quantify in economic terms.

Characteristics commonly evaluated as the basis for selection to improve performance and utility of commercial forestry plantation and farm forestry species include growth rate, volume, form, processing qualities, adaptability, and resistance to drought, fire, pests and disease.

Tree breeding is vital, both to meet the growing global demands in forest products and services, driven by population increase and greater wealth and to address climate change and emerging pests and diseases. Demand has increased for timber for construction, wood for fuel and energy (Germany), forest foods for food security (Zimbabwe) and various forest services, e.g. for water production (Seychelles),

Tree breeding programmes have substantial, but sometimes little developed or unrecognized, potential to improve the production of forest plantations and meet the local demand for forest products. This may be especially where logging in native forests is highly restricted or banned (e.g. Philippines, Thailand, Samoa, Sri Lanka), or for countries with limited and low yielding natural production forests (e.g. Algeria, Cyprus, Lebanon, Republic of South Africa).

A number of country reports consider plantations of improved tree species as vital for providing a sustainable supply of forest products and to reduce the pressure on their natural forests where these have been subjected to overharvesting. Indonesia has adopted this approach: '[t]o reduce pressure from natural forest exploitation, the Ministry of Forestry has increased permits for Industrial Plantation Forest from 4.5 million ha in 2000 to 8.97 million ha in 2010' (Indonesia).

The Solomon Island report states:

> *The Solomon Islands government must consider forest development as a priority national forest program so that provisions to rehabilitate logged over natural forest through natural forest enrichment and promote mass scale replanting program of high value forest plantation species are in place. The SI forest plantation logs are significant, primarily because it has the improved genetic material, technical expertise and climate to produce high quality timber such as Tectona grandis, Swietenia macrophylla, Pterocarpus indicus and Pometia pinnata* (SI)

The development of forestry plantation industries with the ability to produce large proportion of the world's wood requirements presents certainly has the potential to relieve the pressure on natural forests. 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 in 2030 (source: New Forests).

Future improvement gains will depend on the natural variability of FGR contained in wild populations, and in existing breeding programs and plantations, as Sweden notes:

> *'Genetic variation from autochthonous provenances gives the opportunity of future selection and development. Certain alleles may prove important for tree growth, vitality, fibre quality or phenology, and could therefore be incorporated in future breeding programs. In the end, a high quality forest reproductive material may be produced.'* (Sweden)

Breeding and genetic improvement has traditionally been mainly focused on tree species for commercial production of timber and pulpwood. The high costs involved in breeding programmes are more than compensated for through future productivity gains and higher commercial returns of plantations established with improved germplasm. Over the past two decades there has been a shift in focus to 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 programs with national partners in sub-Saharan Africa, south-east Asia and Latin America. Breeding programmes primarily focus on improvement of utility, productive and economic characteristics: traits commonly the focus of improvement programmes include growth rate, form, disease and insect resistance, wood characteristics, pulping properties and other processing traits, charcoal making properties, fodder properties, fruit and nut nutrient content for edible species, medicinal properties and essential oil composition.

Despite the focus on breeding for improvement of commercial and multipurpose productive species, there is also increasing interest in breeding trees for restoration programmes that are adapted to future climate change and/or have resistance to pests, diseases or other threats. These breeding programmes are primarily initiated by public sector agencies; the USA country report lists several forest tree breeding and restoration programmes. A prime example of breeding for conservation purposes involves programs to re-introduce American chestnut *(Castanea dentata)* and American elm *(Ulmus americana)* into the wild in US forests from which they have been eliminated by chestnut blight and dutch elm disease. Wild individuals resistant to these diseases may be identified and selected, and used in breeding programmes to introduce the genes conferring resistance into the gene pools. The inclusion of the broadest range of genetic variability in each identified genecological zone maximises the opportunity for the species to reoccupy their former ranges, perform vital ecological services and allow for future adaptation.

Breeding programmes have traditionally been geared towards improvement of traits to maximize economic gains in future plantation developments, and accordingly in most countries tree improvement is focussed on a limited number of commercially important traits in the major plantation species (e.g. Germany). The traditional focus on commercial species is related to the often high costs involved in a comprehensive breeding program, specialist expertise needed, and typically long periods before benefits are realised, measured in spans of several decades in cooler climates. However given the scale and unpredictability of environmental change (including climate change and interaction with pests and diseases and more extreme climate events,) new demands and requirements for trees for food nutritional security, environmental rehabilitation and high levels of carbon sequestration for climate change mitigation, the scope and role of tree selection and breeding programs is changing and diversifying. There is an increasing recognition by countries of the need to generate and deploy selected improved tree germplasm with multiple objectives in mind, including human food, biofuels, environmental and ecological purposes (e.g. Brazil, Cyprus, Germany, India). Adaptation characteristics which will be increasingly sought in particular breeding programs include improved drought resistance, resistance to and recovery from fire and an ability to withstand hurricane-force winds at different stages of canopy development. Germany notes that the introduction of more varied and likely better adapted genetic material, both inter- and intra-specific, will be required, as the rapid rate of climate change exceeds the ability of indigenous species to respond, through natural selection and/or migration

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’. However these cannot be considered long-term *ex situ* conservation strategies, as the facilities may be abandoned once the testing or breeding has been completed.

Information required by breeding and improvement programmes

Successful and efficient breeding increasingly depends on a country’s ability to undertake 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 developed and larger countries with more resources and advanced tree breeding programmes. Developing countries may undertake molecular studies with the assistance of external international partners, either in the form of donor assistance or on a commercial basis (e.g. Ethiopia).

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 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 generate results from breeding programmes employing trials of living material.

Brazil notes 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 especially true today, with entire genomes now being sequenced for 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, is only made possible through the introduction of new sequencing technologies and dramatic reduction in costs[21] 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).

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 and planting programmes.

Requirements of breeding and improvement programmes

High cost therefore need a lot of resources ----This has meant that some improvement programs initiated in Africa many decades ago such as in Cote d'Ivoire and Central African Republic often in collaboration with French and Danish Research Institutes such as CTFT and the Danida Forest Seed Centre, are no longer operational.

Long time lag for provenance and progeny trials.

Large numbers of trees required.

Areas of land for trials

Sophisticated research requiring expertise and trained personnel.

Laboratory and other high-tech facilities depending on the approach and techniques used

Data management.

Delivery and deployment system

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[21] 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).

Methods employed

Phenotypically selected plus trees, provenance and progeny trials, crossing techniques and protocols used

Hybrid breeding is used to produce trees with superior productive capabilities, for example by Germany. Hybrid work needs further development, e.g. success in Brazil with highly productive *E. urophylla* hybrids, e.g. India notes this. For increased performance, disease resistance.

Tissue culture is used to produce clones for testing (e.g. Germany), and for mass propagation of planting stock (eg).

Prioritising uses, traits and species for improvement

Should be specified in national FGR strategy coordinated and harmonised with national strategies for forestry, agriculture and development.

Many countries import improved genetic materials and undertake further breeding, to adapt it to local conditions. This can be exotic species (the majority), or species that are already indigenous to the country. A small number of high-performing species are used widely around the globe, and are the focus of many breeding programmes internationally. The most important species include Teak, Eucalyptus, Pinus etc.

Some countries may focus on adaptive screening of imported materials rather than breeding improved trees (e.g. Seychelles, Iran).

Demand for forest products influences the traits and the species selected for improvement. This should reflect goals set out in the national forests strategy, national development strategy, 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 yield firm results 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.

The private sector is not bound by tests of public benefit in its selection of traits and species for improvement; rather, it is guided by potential for commercial gain.

Increasingly limited public funding for breeding programmes suggests that individual organisations and institutions may pursue their own interests and priorities in breeding research, rather than through a coordinated national programme.

Environmental parameters changing in response to climate change will require planting stock adapted to the new conditions. Many 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 (e.g. Germany), and breeding for climate change is considered a high priority for many countries, including Germany.

Identification and domestication of indigenous species

Developing countries often contain large areas of native forests providing extensive reservoirs of genetic resources with potential for development for human use, and increasingly national forest agencies are keen to explore genetic diversity and domesticate and improve local or indigenous tree species (India). These approaches are being increasingly supported by donors. Mechanisms for protecting the rights of the countries and traditional owners and knowledge holders is vital component of any breeding initiative (Zambia).

Many countries have not explored their own indigenous FGR for species suitable for 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

The Seychelles have an extremely rich endemic tree flora, with many excellent timber species that have not been investigated for their forestry potential. 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 improved varieties of fruit trees.

"The domestication of native species is a great opportunity to be explored; included here are species already known and marketed by local and regional populations but whose national or international market penetration is low" (Brazil).

With its huge resources of genetic variability and perceived potential for providing a substantial portion of future world food demand, Brazil has undertaken extensive research through its Plants for the Future programme: the 'Ministry of Environment…has pioneered the identification and mapping of local races and wild relatives of some of the most important crops in Brazil…[including] an important Amazonian forest palm species: pupunha (*Bactris gasipaes*)'. This project has the following objectives:

> *'(i) prioritize new commercially underutilized species of flora, providing potential uses for small farmers, (ii) create new investment opportunities for entrepreneurs in developing new products; (iii) identify the degree of use and gaps in scientific knowledge / technology on the species used in local and regional scale, (iv) to enhance biodiversity, clearly demonstrating the importance to society and the possible uses of these resources, and (v) improving food security, widening the options previously available…The results show the importance of this project, as 755 species have been prioritized…'* (Brazil)

The identification of FGR suitable for domestication of local tree species may require:

- botanical survey to document the existence and distribution of tree species across genecological zones e.g. India's BIS, Brazil;
- taxonomic studies to identify and name unknown FTWPS
- identification of tree species suitable for utilisation
- identification and selection of trees demonstrating superior expression of desirable characteristics,
- undertaking provenance trials, where trees from different environments are grown in controlled conditions allowing comparisons to be made on the basis of genetics alone;
- undertaking progeny trials within- or between species to identify best crosses

National tree breeding programs – including coordination and roles of public and private sectors

Quantitative genetic knowledge has led to significant productivity gains in a small number of tree species that have high value as plantation timber

Genomic knowledge of forest trees lags behind that of model herbaceous species, but the entire genome of several tree species has been or is in the process of being sequenced and novel approaches have been developed to link markers to important traits. Genomic or marker assisted selection is close to being realised

- Provenance trials: 34 countries (No. spp.: Africa 99, Asia 247, Europe 91, L. America 52, N. America 35, Pacific 44)
- Genetic improvement: 42 countries (No. spp.: Africa 99, Asia 288, Europe 101, L. America 61, N. America 45, Pacific 24)

Countries showed great variation in their breeding programmes. China (pxi) has undertaken improvement programmes for 100 species. The USA has an exceptionally well developed tree improvement program with at least 150 public or cooperative breeding programs, representing over 70 species (USA).

Zimbabwe has undertaken provenance testing for identifying appropriate FGR for use in informal, communal and traditional sectors.

Whether or not a country has a breeding and improvement programme depends in part on its forest policy and the forest management and production systems used to extract economic value from forests. For example some countries did not have advanced improvement programmes due to a heavy reliance on logging of native forests to generate income, e.g. PNG, Solomon Islands

Smaller, developing countries often lack the resources or capacities to conduct their own domestication and improvement programs for important local tree species, and 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, Cook Islands). Cyprus does not have a forest industry because of low growth rates and conserve its forests for environmental protection. Countries lacking improvement programs include Burundi, and most of the 52 Small Island Developing States in the Pacific, Caribbean and elsewhere

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) (Seychelles): ‘no scientific plant breeding is done locally through lack of expertise, infrastructure and financial support.’.

Some 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, as has been noted above. This is the case in the Seychelles and Iran:

> *‘...taking into account that Iran is a Low Forest Cover Country [and requires material for reforestation], the primary activities were concentrated on adaptation and elimination trials using 330 different fast growing exotic (needle-leaved and broad-leaved) tree species and provenances in different ecological regions of the country’.*

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. 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). Where genetic material is contributed by a country to a collaborative improvement programme, fair and fair benefit-sharing arrangements must be put in place through a legally binding mechanism.

Coordination of breeding and improvement programmes

Coordination between government agencies and departments (especially agriculture vs forests; forests vs biodiversity conservation); research institutes; universities; 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.

The USA report lists a number of collaborative breeding programmes, involving government agencies, universities and the private sector.

Countries with diversified forest sectors and market economies tended not to have national breeding programmes (e.g. Germany), with work being undertaken by private sector forestry interests, and independent academic and other institutions. [Canada?]

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, at the expense of forest trees; in some instances tree breeding may be run as small independent activity separate from agricultural breeding, and in other cases tree breeding may fall under the auspices of agricultural departments (e.g. Seychelles, Iran). However, the importance of forest and tree foods is extremely important for many people around the world as as been noted earlier, and can provide vital sustenance when other crops fail due to drought, other environmental stress, or socio-political disruption (e.g. Zimbabwe quoted in section 2.1 value). A number of Central Asian countries contain progenitors or wild relatives of many important food tree species (e.g. Iran), and these too Other aspects such as propagation, distribution and deployment of germplasm and planting stock are generally run by forestry departments, for example in the Seychelles, '…forestry nurseries and genebanks are financed by the forestry division' (Seychelles). 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. [Cook Islands all forestry and related activity is run through Ministry of Agriculture]

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, 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".

Role of private and public sectors in breeding and improvement

Public agencies or parastatals fulfil institutional remits including provision of timber including through development of plantation industry. Public good/public benefit provision. May have colonial precedents, e.g. through British forest research institute models?

Private sector driven by search for commercial gains

Need long term security in a country in which to capture returns from improvement programmes which take a very long time to reach fruition. Government role in providing security of the state and also the investment environment is crucial for this.

Private companies and others need to be able to protect the IP resulting from their work – plant variety rights?

Private international companies may have extremely valuable experience they may be able to offer in establishing breeding and improvement programmes in a country, for example they may have wide international experience. Legally binding and firm agreements for benefit sharing according to the relevant agreements are necessary (eg cf. Brazil's contract with Novartis for bioprospecting and development?)

Opportunity to delegate genetic improvement through regional or international cooperation, sharing of benefits; i.e. each country does not have to have own improvement programme, e.g. one country may provide the raw genetic material (e.g. countries which lack capacity to undertake improvement programmes, but with significant utility FGR), while another may improve (e.g. countries with capacity in this field). However, very high levels of confidence are required for a country to entrust the development of its unique genetic resources to another country, as the risk of losing control of the process and not receiving a fair share of the benefits flowing from improvement may be perceived as high. This underscores the vital role of agreements that are firm, enforceable and fair, between parties engaging in such arrangements.

Community-based tree improvement

Gains from improvement

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.' China '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.'* (Brazil)

Benefit sharing arrangements

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 the recent Nagoya Protocol; however these may not 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. Brazil, for example, legislated Provisional Measure no. 2,186-16, of August 23, 2001, to regulate the relevant sections of the CBD in this area, and 'has the goal to regulate rights and obligations concerning access to components of the genetic heritage and to the associated conventional knowledge for purposes of scientific research and technology development, bioprospection or conservation for their industrial or otherwise application', along with other subsidiary regulation (Brazil).

Patents and plant variety rights may be important in ensuring that benefits of genetic improvement are returned to the parties undertaking the work. Patents do not play a significant role in some countries, such as Germany.

The state of tree improvement by region and Regional species priorities'

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 RSA, initiated more than sixty years ago (Dunlop *et al*. 2003). Improvement objectives were initially to improve tannin yields, growth, 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: ten African countries have improvement programs for *Eucalyptus* species, notably *E. camaldulensis* (7 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). 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), *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 trees being improved in several countries include *Acacia senegal* (3), *Adansonia digitata* (2), *Irvingia gabonensis* (2), *Tamarindus indica* (2), *Vitellaria paradoxa* (2) and *Ziziphus mauritiana* (2).

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. Thailand also has a long and successful history of tree breeding developed through collaboration with Denmark ((DANIDA Forest Tree 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* 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 Khazahkstan 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: All European countries reported having 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, 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 10-11 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. (4), *Abies* spp (2), *Cedrus* spp. (2), *Taxus baccata* (2) and the north American conifer *Pseudotsuga menziesii* is included in four 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* (5, mainly *Q. petraea*), *Prunus avium* (4), *Ulmus* spp. (4), *Alnus glutinosa* (4), *Fraxinus excelsior* (3) and *Juglans regia* (3). 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*. 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 UK.

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*. 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. globulus* in several Latin American countries and several other *Eucalyptus* species. 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*). 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*, *Tectona grandis* and *Terminalia* spp. A recent trend is to develop improvement programs on diverse native species: in Brazil one focus has been on indigenous fruit trees, while high value topical timber species now feature in Costa Rica and Ecuador's improvement programs, and four species of *Nothofagus* are being improved in Chile.

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 for 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 of Melanesia (Fiji, Papua New Guinea, Solomon Islands and Vanuatu) each have established tree improvement programs often with assistance from Australian institutions (CSIRO and Universities) and donors (ACIAR and AusAID). The species under improvement vary but are mainly high valuable timbers such as the exotic *Swietenia macrophllya* in Fiji and *Ochroma pyramidale* in PNG, native sandalwoods in Vanuatu and Fiji, 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 Solomons 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 material is now being widely used globally including through selections supplied to Malaysia.

International collaboration and donor programmes

International collaboration occurs through networks, commercial exchange, academic and research institutes, and donor assistance.

The important role played by international species networks was noted by many countries. Zimbabwe acknowledges the vital role played by CAMCORE in the development of improved exotic plantation species, through the sharing of germplasm.

Denmark has a thriving wood products industry, including furniture manufacture (Denmark) which in part relies on the importation of timbers, having limited forests of its own. It has actively engaged in assisting Thailand since the 1960s, assisting in breeding and management of Teak (Thailand).

The role for regional coordination and cooperation is enhanced where species, biogeographic and genecological zones are shared.

Donors 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.

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 (p xi), 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).

Solomon Islands: Through the AusAID - SPRIG project tree improvement and domestication has been extended to several promising indigenous timber species including *Cordia subcordata*, *Gmelina moluccana*, *Pterocarpus indicus*, *Terminalia catappa* and *Vitex cofassus*.

Importance of international germplasm transfer for breeding and genetic improvement

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, e.g. CAMCORE?

Whilst under the CBD FGR are recognised as the property of sovereign nations, in PNG 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 ballooning 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.'

Quoted earlier in this report: '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 (Sweden, Indonesia, China).'

The concentration of small number of economically important trees in plantations can contribute to loss of FGR: for example 90% of Ghana's plantations are comprised of only three species (Ghana).

Genetic pollution

Canada 'Regeneration practices also have the potential to impact genetic erosion, where, in the extreme case of monoclonal plantations, virtually all genetic diversity is lost. The use of non-selected, non-local seed sources in artificial generation can potentially result in adverse genetic impacts due to maladaptation. It should be noted that most of Canada's forest area has not been and will not be subjected to harvesting. However, forest management practices do constitute a threat in many areas; in particular, in highly productive forest types, which also tend to have higher levels of species diversity.

2.4.5. Germplasm delivery and deployment

The production, distribution and deployment of germplasm and planting materials derived from improved genetic sources is critical to the development of forest industries and the continued global supply of FGR-derived goods and services. The role is particularly important in commercial forest industries using exotic species in plantations. Similarly, propagation and deployment of trees with appropriate traits and levels of variability is increasingly important for in situ, ex situ and circa situm conservation and environmental restoration programmes. 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'.

Uses of germplasm and plant materials

The uses of germplasm include production of planting materials for forest plantations (e.g. Philippines, Madagascar), agroforestry, food, fuel, farm and other *circa situm* plantings, alleviation of poverty, FGR conservation and environmental restoration projects (e.g. USA), including following mining (e.g. Madagascar). Germplasm and plant materials are also required for research and improvement trials.

Prioritising for distribution and deployment

As noted earlier, priorities for the delivery and deployment of FGR and improved genetic materials are established at a national level, in national strategies for forests and FGR with reference to other relevant strategies. These may include commercial/utility objectives (e.g. Chile) and conservation goals, as well as broader national development, social and economic goals. Focal areas may include development of a plantation industry; supporting local, small-scale industries and employment growth; assisting rural communities and contributing to the alleviation of poverty; promoting environmental and restoration plantings and conserving threatened species. Parameters that may be prioritised include species, improved varieties, planting locations, and sectors of the economy and society identified for development or assistance. The private sector prioritises species and locations for deployment on the basis of financial returns, and in which government regulations, incentives and support may play a role.

The importance of matching delivery and deployment of plant materials with areas of most need has been noted previously – for example where fuelwood is of primary importance in a country, then improvement, production, distribution and deployment of fuelwood species may be appropriate (e.g.

Sri Lanka). The participation of communities in processes for prioritisation is important in this regard. China has remarked on the need to more closely match materials produced for deployment with their intended purpose and role of market guidance. National programmes for the achievement of various development and other objectives may require large-scale supply and deployment of appropriate germplasm, for example large scale carbon sequestration and environmental rehabilitation programmes such as the 'Green India' planting programme (India).

The exchange and transfer of germplasm

Exchange and transfer of germplasm and plant materials may occur internationally, regionally, or within a country for various purposes including research, genetic improvement, and supply of forest genetic materials for plantings.

Internationally, the contribution of genetic materials to global research and breeding efforts to develop improved trees contributes to global well-being, 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) 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.

Facilitating adaptation to climate change and assisted migration of species is likely to increasingly require cross-border transfer of genetic materials (e.g.Germany, Canada). Cross-border landscape-scale restoration projects may similarly require exchange of genetic materials between countries.

Notwithstanding the benefits of transfer, failure to regulate the movement of germplasm may result in loss of variability and loss of adaptation and improvement gains. China identifies that 'irrational transfer of seeds' contributes to genetic erosion, 'leading to decline of species diversity and within-species diversity'. Control of movement is required to ensure that plant materials used for planting are genecologically appropriate and sufficiently adapted to the planting locality (see below). Germany has strict controls on the movement of germplasm within its own borders subject to the Act on Forest Reproductive Material 2002, consistent with the relevant EU Directives, to ensure that appropriate provenances adapted to and suitable for local conditions are identified and used.

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 severely 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 (e.g. Canada). Indeed, lack of harmonisation of regulations, standards and transfer protocols create barriers to the efficient exchange of genetic materials, and delays in supply system may cause loss of viability in orthodox seed and complete mortality of sensitive, recalcitrant seeds.

There must be strict and legally binding materials transfer agreements (MTA) in place governing such exchanges to ensure the rights of suppliers are protected, for transfers both between and within countries (e.g. China). 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 (Canada).

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 (PNG). 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.'

Identifying genecological and seed transfer zones

The identification of seed transfer or 'genecological' zones within a country, that is, areas possessing consistent biogeographical characteristics to which local populations have adapted, facilitates the selection and deployment of appropriately adapted plant materials best suited to the local conditions. The use of germplasm from different genecological zones may lead to the loss adaptive advantage (e.g. including through potential genetic impacts on existing populations), as well as poor performance or complete failure of the introduced material.

Several countries have identified their seed transfer or genecological 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 (e.g. USA, India and most European countries). On the other hand many developing countries have not yet defined their genecological zones, nor identified or developed appropriately adapted species and improved materials for planting in these zones. Ethiopia identified a 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 genecological boundaries/seed transfer zones; for other countries the focus is on identifying, selecting and developing FGR that will perform best in particular zones. India is developing its 'Seed Zoning' system, with the intention of obtaining legislative support to facilitate its implementation. 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 (p50) 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 with their borders. For example Canada (p106), notes provinces develops their own propagation materials based on seed zones, often developed based on results from provenance tests, but that there is no national legislation or guidelines regarding transfer within the country.

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 (e.g. Germany), and perhaps undertake assisted migration for certain species to ensure their survival (e.g. Canada), runs counter to the strict enforcement of genecological zoning approaches. Germany and other countries (e.g. Sweden, USA) note 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 genecological zones. Germany is currently increasing its use of climate-change adapted species such as the introduced *Pseudotsuga menziesii*. Obviously, some flexibility in the genecological zone approach will be required to accommodate these changes, particularly while appropriately adapted species and genetic materials are being identified and developed.

Production, transfer and distribution of germplasm and planting materials

The production and transfer of germplasm for research, breeding and propagation purposes requires excellent documentation, including quality control and source-identification. Provision of germplasm for plantings for production, conservation, restoration, reforestation and afforestation is increasingly reliant on the availability of high quality, source-identified seed and plant materials, with larger scale projects requiring substantial quantities.

Sources of germplasm and planting materials

Germplasm sources used by countries include seeds from forest seed stands (Philippines, USA), seed, cutting and clone orchards (e.g. Philippines, China); and 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' (Philippines), 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 [are] 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). Vegetative materials for propagation from grafts, stem cuttings, micro-cuttings or somatic embryos may be sourced from selected clones or seedlings (e.g. Zambia). Cloned materials are favoured for plantations (Philippines), due to the ability to produce true-to-type, genetically uniform plants from improved material, and especially useful for utilizing gain present in F1 interspecific hybrids.

Plant materials used for commercial and utility plantings are largely derived from improved sources, although this depends in large part on the forest management systems practised; 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 from genetically improved seed. 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. Materials may also be obtained from *ex situ* gene conservation stands, which then serve a dual purpose of providing propagation materials for major plantation speciss (e.g. PNG).

In many countries germplasm is collected by farmers, small scale seed producers or communities living nearby forests for propagation for use in farms, homegardens, or for sale (e.g. Sri Lanka). In most cases this is done without selection, or with selection based on phenotype, and 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 with low levels of variability represented (e.g. Philippines). These practices present a challenge to the goal of increasing deployment of improved germplasm, although measures have been applied in some countries to overcome such barriers as discussed later.

Compared to germplasm used in commercial plantations, planting materials for conservation and ecological restoration works generally require and/or benefit from a much greater amount of variability to be represented.

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 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 available for transfer reported by countries was overwhelmingly in the form of seed, accounting for 66% of species 'availabilities' compared to the next highest category, scions at 12%. While seeds are particularly useful, 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 (e.g. Philippines). 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 many countries. Nonetheless industrial-scale production by micropropagation of species of commercial interest or for large restoration purposes is suggested by Madagascar, while noting the high costs. Several countries referred to the the need for research into propagating threatened and indigenous species for planting for *in situ* and *ex situ* conservation programmes (e.g. China and Philippines).

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, maybe 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.

Transfers of germplasm –patterns observed in country reports

Of germplasm reported 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 internatonal 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 private sector.

Globally, countries reported a total of 412 different species were available for national and international transfer, although this is a gross underestimate as much exchange of tree germplasm, especially ornamentals such as palms, occurs through private sector and not necessarily recorded by Government. 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.

Demand for planting materials and production requirements

The need to increase production of planting materials to meet demand was noted by many countries (e.g. Seychelles); Ethiopia has identified 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.'

As mentioned, a number of countries expressed an interest in cloning and other advanced techniques that offer opportunities to produce large numbers of genetically identical improved planting materials at a low cost; these may also be suitable for propagation for conservation purposes (Philippines, Madagascar, Ethiopia, China).

The lag time for seed orchards to produce improved seed is a factor in the availability of improved germplasm (China), often necessitating the continued use of unimproved seed (Canada). Advanced techniques in breeding and propagation, including for example reduced times and 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 etc, may shorten the time between improvement and deployment.

Actors in the production of germplasm and plant materials for transfer, distribution and deployment

Countries reported that germplasm and plant materials are produced by various actors. The public sector plays an important role in many countries, while the private sector generates large amounts of germplasm and plant materials for use in its own plantation and forestry activities (e.g. PNG); in many instances private seed collectors and producers offer germplasm and planting materials to the market.

Public sector departments, in particular forestry, conservation, natural resource and land management agencies play dominant roles in the production, distribution and deployment of FGR materials for a wide variety of uses, especially in developing countries. Many countries have national tree seed centres (NTSCs), nurseries or equivalents which serve as primary agents for the collection, storage, propagation and distribution of forest tree seeds, both domestically and internationally, to government forest and conservation agencies, and the private sector including nurseries, forestry companies, NGOs, communities and farmers (e.g. Sri Lanka). NTSCs may also play important roles in *ex situ* conservation and tree improvement and breeding. These are public institutions which may also generate funds through seed sales, consultations and/or receive private sector support for contracted services. Examples of countries in which NTSCs currently play major roles include Australia, Burkina Faso, Kenya, Nepal, PNG, Sri Lanka and Zimbabwe. Madagascar’s national tree seed centre the SNGF is the only seed centre in the country specialising in FGR, although private operators harvest, sell and export seeds of some ornamental and rare plants (Madagascar). The need to increase the productive capacity of tree seed centres was noted often in reports (e.g. Sri Lanka).

Many agricultural agencies have long-standing involvement in the production and distribution of improved plant materials, and in some countries these agencies may retain a close involvement in the production of planting materials for trees with agricultural value (e.g. Iran, Seychelles). There are opportunities to identify synergies and harmonise efforts.

Production of planting materials by communities, small holders, farmers

In many countries production of germplasm and planting materials is undertaken by small businesses, landholders or individuals, providing employment and income which may assist in alleviating poverty For example, Ethiopia’s traditional home garden agro-forestry practices provide employment for many people, and propagation and exchange of plant materials are part of the fabric of rural life (Ethiopia; see below). 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 (Sri Lanka); this highly decentralised informal system also produces much of it own plant materials (Sri Lanka). However resource-limited farmers on small holdings and other small scale producers in the informal sector may have little or no access to improved varieties (e.g. Philippines, Sri Lanka). The decentralised nature and lack of resources of this informal plant-production and utilisation sector presents a major challenge to increasing the deployment of improved FGR (Sri Lanka).

Germplasm collection and plant production in this sector is most often done informally and rarely conforms to accepted standards. For example, a Philippines study found that small-scale seed producers generally collected material from less than ten plants, inadequate for inclusion of sufficient variability. 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. This limits opportunities both for genetic improvement and maintenance of variability of FGR, and also limits opportunities for sale of germplasm to a wider market.

Nonetheless, there are major opportunities for both the development, increased use, and production of improved germplasm within the informal sector: this is contingent on its participants being supplied with appropriate materials, information and assistance; government tree seed centres and extension services may have an important role in distribution of information, practice guidelines, and improved FGR. 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 partnership approach to the production of high quality planting materials.

The Ethiopian report provides a useful insight into this type of germplasm production and utilisation system which typifies many developing countries: '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. 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.'

The germplasm collection and propagation activities of the informal sector may 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 (p 40) the Division of Environment intends to mobilize people to participate in conservation of endemic tree species, firstly through growing indigenous trees.

Country examples of production, transfer, delivery and deployment of germplasm and planting materials

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.

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 nurseries for the production of trees covering 668,000 ha around the country. 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. However most of the seed orchards and stands are first generation and quality was low, while major national forestry programmes need to increasingly make use of improved genetic materials. Germany has 425 forest tree nurseries producing 150-185 million plants annually, and 800 ha of seed orchards, including 215 for tree species, while most small developing countries would typically have less than 5 or 10 nurseries producing tree seedlings for production and environmental plantings.

In Burkina Faso forest seed sources have been identified for the production of seeds distributed nationally and internationally to projects and programs, state structures, NGOs and associations of producers with seed flow more developed and better controlled for export of seed cf. import. In Ethiopia the government through Forest Research Centre is sole supplier of tested seeds in the country, distributing 7.2 tonnes of seed capable of producing 570-880 million seedlings. Indonesia reported it produced 29 million kg of seed produced annually from 104,000 ha, through the Department of Land Rehabilitation and Social Forestry. In Madagascar, the national tree seed centre nursery produces 250,000 plants per year in its nursery. New technologies such as in vitro culture micropropagation would be valuable for the production of large numbers of plants for species lacking enough seed or for which knowledge of propagation techniques is available, for use in, for example, major mining restoration projects. For Vanuatu, national priorities for improving the production, distribution and deployment of improved trees include strategies developed through the SPRIG project, to upgrade seed storage facilities and develop seed orchards; forest extension programs are also a focus (Vanuatu). 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. 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.

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 and regional and national certification schemes, and/or adherence to procedural guidelines and protocols. Quality parameters may include source (e.g. improved stock, natural variability represented), 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 ensured, 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, EU regulations and OECD guidelines. Within the EU, germplasm exchange operates freely within and between members, consistent with the relevant EU directives (Germany p68); these directives also provide a standard classificatory system for improved reproductive material (Denmark p16). EU regulations allow members to import forest reproductive materials from external third parties as long as the exporting country is a signatory to the relevant OECD scheme (Germany p68). 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 (e.g. Germany, Estonia), have elements relating to the quality, nature and genetics of germplasm and forestry planting materials.

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 (Germany). The Act species 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. The German report notes: 'The specifications of the FoVG for the approval of seed stands and the minimum quantities of harvest trees are basic prerequisites for the provision of high-quality forest reproductive material and an important contribution to the conservation of genetic diversity in the forests.' As well as FoVG, private-public collaboration has produced two private certification schemes for forest reproductive material, which increases control over provenance of seed and plants (Germany).

China has a 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 (China). 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. Species are categorised into for suitability for six main uses such as agroforestry, reforestation and afforestation. 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 Chile . The example of the Lantapan cooperative in the Philippines, mentioned above, shows how this may be achieved through the establishment and operation of a small holder, farmer-operated association (Philippines).

Information management in distribution and deployment

An efficient, comprehensive and integrated information system is essential for managing and monitoring the transfer, deployment and delivery of germplasm and planting materials. Information may include seed source and origin, genecological/seed transfer zone, performance with respect to desirable traits, number of parents, amount of variability represented, germination percentage adherence to standards and whether it is certified. Adequate documentation allows purchasers and users to verify that the material is fit for purpose, and whether it is adapted for the conditions into which it will be planted (i.e. whether it has an appropriate genecological profile). 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 varied between countries and regions. For example, Germany's Act on Forest Reproductive Material requires the 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 (e.g.Philippines, Seychelles).

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 (e.g.cf Chile, Madagascar). For these countries there is a need to integrate and harmonise documentation and data gathering activities between the sectors, for example through industry organisations with joint public and private sector membership, such as exist in Canada. As noted by Sweden, the European Union has developed a regional system to document the origins and track the movement of FGR, through EUFGIS; 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 of germplasm production, storage 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. Zambia (p9) mentions 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.' Burkina Faso (p22) noted the potential for floods to impact on seed storage facilities. Newer freezers with defrosting cycling produce fluctuating temperatures which considerably shorten seed life span, but this information is not widely known in tree seed community.

Seed and clone orchards are subject to threats including poaching, illegal harvesting and encroachment of agricultural and other activities; political and social stability is required for ongoing maintenance and operation of these facilities, as mentioned by Zimbabwe and Tanzania.

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 highlight the risks of a single focal point for the production and distribution of germplasm – strategies to encourage widespread production by multiple organisations, companies or individuals reduces this risk.

International assistance

Many developing countries have received assistance from international partners 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 (Philippines p42); 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 (Thailand pp44, 52-53, 66-67).

Public and private sector involvement in delivery and deployment

It was evident from country reports that the public and private sector are both involved in the delivery and deployment of germplasm, albeit in different ways. Each may engage in the conceptualisation and design of programmes including selection of species and variants, collection, storage, propagation, distribution and deployment of germplasm and information management.

The public sector is the main actor in the creation, protection and management of public goods for which markets do not exist or are poorly developed. This includes activities which offer no immediate commercial rewards; activities yielding public social and ecological dividends, and long-term, high risk activities with a strong public benefit component. Examples are conservation of biodiversity and FGR, ecological protection, social development and the alleviation of poverty. 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. In many countries, various components of the system of delivery and deployment of FGR possess one or more of these characteristics.

The conservation of FGR is an activity yielding public benefits, often with little or immediate financial rewards, and therefore, as the China report notes (p19), the '…collection and conservation of FGR is a basic, long-term, public welfare and strategic work'.

Country reports showed involvement of the public sector in the following activities:

- Conceptualising, facilitating, catalysing and delivering programmes for delivery and deployment for
    - Conservation of FGR of threatened or potentially threatened species
    - National, economic and social development programmes
    - Maintenance and enhancement of traditional practices
    - the alleviation of poverty
- Collecting, storing, distributing, propagating germplasm for:
    - Implementing the programmes listed above
    - Research by local and international public and private organisations
    - tree improvement by local and international public and private organisations
    - supply of planting materials to government agencies, individuals, commercial operators and NGOs (e.g. Madagascar p37)
- Facilitating and coordinating research and facilities
- Facilitating and regulating private sector involvement in delivery and deployment through
    - making laws and regulations governing germplasm collection, delivery and deployment
    - Developing and enforcing standards, guidelines and protocols
- Establishment, facilitation and participation in organisations and associations involved in coordinating and regulating germplasm collection, storage, propagation, delivery and deployment (e.g. Chile, Germany), often involving government, industry and research institutions

Examples of public sector involvement in germplasm production, delivery and deployment include:

- Ethiopia's (p15) Forest Research Centre which is the sole supplier of tested seeds in the country, distributing 7.2 tonnes of seed
- Indonesia's Department of Land Rehabilitation and Social Forestry which produces 29 million kg of seed produced annually from 104,000 ha (Indonesia p14).

Private sector involvement in germplasm delivery and deployment

The private sector contributes to germplasm collection, storage, delivery and deployment through its pursuit of profit-making forestry enterprises; these include forestry plantings and development of improved tree varieties and propagation methods used for their own operations or offered for sale. Actors in the private sector include local and multinational companies, communities, small scale businesses and individuals. Its participation in delivery and deployment provides the following benefits:

- Able to provide important components of delivery and deployment where the role of the public sector is limited by the political system (including lack of funds, political will, institutional capacity, market signals and incentives)
- Generally responsive to market demand for goods and services
- Incentivised to achieve efficiency and innovation in collection, delivery and deployment
- Access to capital, technology and expertise e.g. through international company structure, ability to purchase
- Preparedness to take risks
- Ability to meet demand for germplasm and planting materials that may not be able to be met by the public sector

Issues for the private sector in germplasm delivery and deployment include:

- May lack consistency with national strategies in programmes for forests, FGR, and national and economic development
- Activities not publicly reported, e.g. not subject to public reporting processes, (commercial-in-confidence considerations,
- No incentive to deliver public goods and benefits for which markets are non-existent or are poorly developed; only obliged to address ecological and social objectives.

Private sector especially larger companies will generally undertake improvement, delivery and deployment themselves e.g. India. Companies improve, grow quality seedlings and distribute to farmers who plant on land, grow and get guaranteed returns; cooperation between sectors is important. In Madagascar (p37), the purchasers of seed from the SNGF were originally 90% forest service and other government agencies; currently however, the private sector and private individuals with NGOs comprise 60% of purchasers, with a contribution to demand from bilateral projects. In the Seychelles (p42), over 50% of all plant genetic samples used in commercial activities come from the national collections, although this figure includes tropical fruits and agricultural plants. Different roles are played by public and private sectors in the delivery of germplasm. In regard to plantings, the public sector may make available planting materials to assist meeting national development and other policy goals e.g. alleviation of poverty, greenhouse action, environmental protection, industry development. The private sector may sell unimproved or improved FGR materials for private or commercial use, or may enter into arrangements with private growers to facilitate growing of feedstock for industrial forestry activities, for example through contract growing of pulp or timber species by rural communities to supply a company's processing plant).

Jointly public and private

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 (e.g. Sri Lanka).

Governments may offer incentives to the private sector for the production of quality germplasm and planting materials (e.g.Sri Lanka).

A number of countries successfully coordinate public and private resources to supply materials for the forest industries, often using market mechanisms. For example in Germany, the owners of private forest stands or seed orchards from which seed is produced receive 'tenancy revenues'. 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' (Iran).

Despite China's laws requiring the use of improved genetic materials, their deployment has fallen short of expectations and the country report identifies lack of diversity in breeding objectives, limited geographic range suitable for some improved materials and lack of incentives for breeders, seed producers and end users to implement research results as barriers, and recommends the encouragement of investment by individuals and enterprises in FGR improvement. In another context the report mentions the lack of market guidance resulting in inappropriate plantings of monocultures in farm plantings, and recommends strengthening market signals to reduce the risk of this happening.

Private seed sources in Denmark are not 'an active part of the [ex situ] conservation strategy; there may be opportunities to harmonise these private seed production activities with public-good conservation programmes

Benefit sharing

"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 that the suppliers cannot benefit from the exploitation and utilization of the genetic resources whereas the users cannot get use right of the genetic resources." (China)

Priorities

- Coordination of public and private sector activities
- 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 coordination, effective priority setting, participation of communities in prioritization, and sensitivity to market signals
- Development of consistent standards for collection, storage, of germplasm for distribution and deployment and greater implementation of these
- More effective integration of data bases including access to information about deployment in the private sector
- Consider centralized organization to coordinate.

Chapter 3. TRENDS AFFECTING THE FOREST SECTOR AND THEIR IMPLICATIONS ON FGR

Highlights of the Chapter

Chapter 3 is not yet finalized, however the key findings, constraints and needs for efficient assessment of the effect of the various trends on FGR management and conservation are identified and presented hereafter

Key findings

The main drivers affecting forest genetic resources are identified by the countries as follow:

- Forest and forest ecosystems loss and degradation
- Increased threat on species
- Ecosystems restoration
- Decentralized and/or local management and development
- Climate change and need to promote adaptation ability
- Valuing non wood forest products

Constraints and knowledge gaps

- Lack of widely accepted indicators for monitoring genetic diversity
- Large programmes on ecosystems restoration and reclamation of degraded land lack sufficient and appropriate quantity and quality of forest reproductive material.
- Strategies and technologies adapted to local management of FGR is inadequate
- Lack of adequate statistics on the contribution of NWFP to countries economy and food security and their implications for sustainable FGR management.

Needs and priorities

- Development of indicators for sustainable FGR management
- Select and develop plant material and methods, and build capacity for restoration of ecosystems
- Develop strategies and methods, build capacity for conservation and sustainable use at local level
- Review/update conservation strategies in the context of climate change
- Integrate climate change into policy, programs and regulations

Chapter 4. CAPACITIES, INSTITUTIONAL AND POLICY FRAMEWORK FOR CONSERVATION AND MANAGEMENT OF FGR

Highlights of the Chapter

Chapter 4 is not yet finalized; however the key findings, constraints and needs in capacities, institutional and policy framework for FGR conservation and management and conservation are identified and presented hereafter.

Key findings

- Numerous and diverse institutions involved in FGR at national level - Capacity often inadequate
- Active regional cooperation: networks, strategies, programs
- Forest reproductive material regulations/schemes in place at national, regional and international levels
- Few Information systems on FGR

Constraints

- Many Countries have no specific low on forest genetic resources
- Indicators for monitoring genetic diversity
- Reproductive material and technology adapted to ecosystem restoration - Capacity
- Strategies and technologies adapted to local management – Capacity
- Strategies for adaptation

Needs and priorities

- Coordinate FGR activities and integrate them in broader national strategies ad programs (forestry, biodiversity, food security, poverty reduction, etc)
- Development and implementation of regional strategies and programs for conservation of FGR
- Develop and improve information systems on FGR for conservation and sustainable use at national, regional and global levels
- Strengthen research and training programs to produce knowledge and capacity necessary for conservation and sustainable use of FGR
- Improve germplasm movement for research and development

Chapter 5. STATUS OF KNOWLEDGE –CURRENT AND EMERGING TECHNOLOGIES

Chapter 5 describes the status of knowledge on FGR with a particular emphasis on emerging technologies currently used in research. Information is mostly drawn from country report, thematic studies committed by FAO and various publications. In addition to describing the important findings from the reports, the chapter presents the constraints to knowledge generation and research development on FGR.

5.1. CONTEXT, INFORMATION SOURCES

This is the first report of its kind; thus although rapid advances are being made and much knowledge has accumulated in the past decades, there is no comparable report as a baseline for comparison. This first report is, in essence, the baseline for future comparison. Sources of information for this chapter include National Reports prepared by countries for this first State of the World's Forest Genetic Resources Report, summaries that were prepared following regional workshops, background Thematic Studies that were prepared to supplement the information provided by countries, and additional information was synthesized from scientific articles and other published literature. Earlier chapters of this report describe the status of FGR. This chapter is limited to status of knowledge about the resources. Of necessity the treatment of knowledge of FGR, herein is a somewhat superficial overview, as volumes would be required to capture all available knowledge. Examples are used in the chapter to illustrate levels, types and applications of genetic knowledge.

According to National Reports, approximately 450 tree species are undergoing some degree of selection and improvement, globally. Assuming a total global count of at least 80,000 tree species, less than 1% of the tree species have been subject to genetic study for human use. Although additional tree species have been studied for other reasons, the percentage of the globe's tree species that have been studied remains very low. Undoubtedly many species with untapped potential await study, pending sufficient resources and interest.

[Fig. histogram that represent the number of known tree species per continent/region and the approximate percentage of tree species that has been studied by way of genetic tools.]

The tree species that have been most studied using scientific approaches (since about 1950) fall in two categories: those that have been extensively planted in commercial plantations for wood and those which are valuable in agriculture for fruit and other livelihood benefits. Commercial plantations represent about 7% of the world's forests, but are responsible for almost 50% of world's industrial round wood production (FAO 2011). Approximately 30 tree species from just 4 genera (*Acacia*, *Eucalyptus*, *Pinus* and *Populus*) account for much of the area planted globally (Carle, et al. (FAO – find full citation)). Most of these species have been studied in detail, including quantitative and molecular/genomic analyses. Some of the most studied species include: *Acacia mangium*, *A. nilotica*, *Eucalyptus grandis*, *E. camaldulensis*, *E. globulus*, *Gmelina arborea*, *Tectona grandis*, *Pinus caribaea*, *P. elliottii*, *P. patula*, *P. taeda*, *P. radiata*, *P. nigra*, *P. pinaster*, *P. massoniana*, *P. sylvestris*, *Picea sitchensis*, *P. abies*, *Pseudotsuga menzesii*, *Cunninghamia lanceolata*, *Populus trichocarpa*, *P. deltoids*, *P. nigra*, *P. tremuloides*, and *P. tremula.*

Tree species producing fruit and other food-related crops of global significance have a much longer history of domestication and accumulation of knowledge, and unlike the case for tree species that have been managed for wood production, well recognised varieties of fruit tree species have been developed over centuries. Yet unlike, herbaceous crops, the original species still exist as wild populations capable of sharing genetic material with domesticated varieties. Some of them are under threat, for example several globally significant fruit tree species that originated in Central Asia (Eastwood, et al. 2009).

Although basic genetic principles are consistent across flora and fauna taxa, forest trees differ from agricultural crops in significant ways, and the study, management and conservation of their genetic resources has had to adapt accordingly. Thus the type of knowledge and focus on particular genetic technologies also differ between forest trees and domesticated plants and animals in some regards. Even the relatively small proportion of forest tree species that are undergoing incipient domestication typically also exist as large wild, randomly mating, and unstructured populations (Neale and Kremer 2011). Most forest tree species have narrow regional adaptation so the numbers of species planted commercially are much higher than for food crops (Pautasso, 2009). Trees are keystone species in forest ecosystems, and the diversity of associated species depends on inter- and intraspecific diversity of trees (Whitham et al., 2006). Specific colonising symbiont microbial species are often essential for successful establishment of tree species (Bonfante and Anca, 2009).Tree species are long-lived and generation times are long. Many tree species encompass enormous genetic diversity (Hamrick, et al. 1992); even breeding populations in improvement programmes represent relatively large gene polls compared to agricultural crops, and tree genomes may be orders of magnitude larger than those of cultivated crops (Neale and Kremer 2011). Tree species are predominantly out-crossing and in fact, none are known to be predominantly selfing (Petit and Hampe 2006). With a few exceptions, tree breeders do not aim to develop varieties similar to those of agricultural crops. In addition to all of the aforementioned distinctions, the sheer number of tree species that have known or potential value is in the 10’s of thousands. This means that forest geneticists and genomicists face very different challenges and require different tools and techniques from those who work with agricultural crops.

5.1.1. What constitutes knowledge of Forest Genetic Resources?

Forest genetic resources refer to genetic diversity of tree species of present or potential value to humans (FAO 1989). This includes ecological value as well as direct livelihood values. For the purposes of this overview, we do not attempt to determine potential value and we assume that any species that has been studied has potential, if not present, value. Relevant knowledge encompasses quantitative, molecular and genomic information; however having knowledge of a tree species implies more than, for example, the existence of a single genetic marker study of a small number of individuals. In addition to “direct” genetic information, knowledge of species distribution and environmental variability within the species range; population size and relative degree of contiguity; and observable morphological variation (in a natural population), can all provide insight into genetic variability of a species. Traditional or indigenous knowledge predates published information emanating from relatively recent studies and it is less well-documented, but in some regions is significant.

If a tree species has high commercial value and is planted it is likely that selection, testing and breeding have been undertaken and this implies a particular type of knowledge. If such a species is vegetatively propagated, a different type of knowledge is implied. Other species that are highly valuable are harvested exclusively in the wild and very little may be known about genetic resources of such species. In some cases the genetic resource of such species may be degraded through dysgenic selection, when the best quality trees are cut leaving only badly shaped trees as contributors to next generation. In the absence of an improvement strategy and plantation this may have dramatic effects on the resource sustainability but few conclusive studies have evaluated this (Cornelius 2005).

5.1.2. Reasons for studying FGR and type of information generated

Uses, management, and priorities for research and action are all highly diverse for forest trees. Most formal genetics study has been devoted to trees of commercial value for timber, and most of these are temperate species. About 30 species have been studied intensively, tested, and bred for increased wood production, improved quality (Ref?) and/or resistance to pests and diseases (Yanchuk and

Allard 2009). A body of knowledge has also accumulated over a longer period of time and in a much more fragmented way on tree species that are important for non-timber forest products: fruit and nut-bearing trees, species with valuable medicinal properties, oil or latex producing trees, and species having shade or ornamental value. Traditional knowledge of phenotypic variation extends from informally recorded traditional knowledge to recent scientific studies. Few of these species have been thoroughly studied using modern techniques, with the exception of those having high commercial value, and in such cases, the techniques employed and aims pursued bear resemblance to those of agricultural crop genetic research.

Most tropical timber species are managed in semi-natural forests; in many cases, selectively harvested and their renewal depends on natural regeneration. In general little is known about the sustainability of the genetic resources comprised by selectively harvested tree species, especially those in the tropics (Wernsdorfer, et al. 2011). However, effective long-term management of these species requires knowledge of population genetic parameters such as gene flow dynamics, and structure of genetic variation in economically and adaptively important traits. Such knowledge is important to ensure that viable populations are maintained in harvested areas and that harvest does not have a dysgenic impact on seed trees. Genetic markers that can be used effectively for identifying species and origin of timber are important as well, to monitor legality of timber harvest.

Conservation of evolutionary potential is important for all use and management categories of trees. This requires an understanding of the extent and patterns of genetic diversity throughout a species' range. Many studies have been conducted on limited numbers of populations for many species, using various molecular markers to elucidate patterns of diversity. Often studies are limited by insufficient funds, resulting in small sample sizes and thus limited applicability of results; and the use of different markers for subsequent studies in divergent geographic locations of the same species leads to disparate results that may even be contradictory, with little potential for generating a common understanding. Little concrete action has been taken on the basis of most conservation genetic studies, in part because of a gap between the results of studies and applicable conservation knowledge (Knight 2008). The data are still largely insufficient to allow testing if congruent patterns of spatial genetic diversity exist among species (zones of genetic endemism, richness). This has important implications in terms of landscape management and conservation as forest reserves are ideally localized on the basis of genetic information across all species.

Table 1 – summarising numbers and types of studies on tropical species (from S. Cavers)
(To be included)

Tree species are much better characterised in some regions than others. In Europe, North America and Australia at least some genetic knowledge has been generated for most species. Species in Latin America have received more attention than those of Asia or Africa, in general, although there are exceptions at the country level. Even in countries where significant resources have been focused on understanding FGR, the evenness of species coverage is variable, with key species highly saturated, but many, with little or no information. At the species level, approaches vary widely, with single population studies common for tropical species, up to range-wide surveys for species of broad commercial interest. Publications describe studies using a single neutral marker, and for other species, genome-scale genetic analyses.

It is notable that there is no apparent impact of Priority Species list strategies in the peer-reviewed literature: this may well not be the case when other work (like trial establishment, or non-genetic work) is taken into account, but from a molecular genetics point of view, other factors seem to be more important.

Tree improvement

Wood production - The term tree improvement is generally assumed to refer to improvement of timber species for wood production and the earliest genetic studies on forest trees were designed to quantify variation in traits of commercial value for purposes of selection and breeding. Most of the effort has been focused on improving tree form for timber production and increasing wood volume both for timber and pulp and paper. Wood quality, including strength and density, and more recently lignose/cellulose ratio, have been of secondary importance. Breeding for resistance or tolerance to biotic and abiotic factors tends to be restricted to more specialised research programmes (Yanchuk and Allard 2009). Hence much information is available for most commercial plantation species on the complicated growth rate-related traits associated with quantity of wood production, but relatively little genetic information has been generated about other traits.

Agricultural purposes - Domestication of fruit trees and other tree species that are important for livelihoods o r have cultural or religious significance has been underway for millennia, without the benefit of scientific genetic knowledge for most of that time. The most reliable method for capturing improvements is by cloning trees having desirable properties. Unlike the case of commercial timber species, domesticated varieties of trees important for food and other non-wood amenities have been developed for many years, simultaneously, in many geographic locations.

Conservation

During the last three decades, since the development and broad use of molecular markers, many studies have been conducted applying these tools to inform conservation strategies and approaches. Neutral genetic markers are used to deduce population-level parameters that are informative about spatial patterns of genetic diversity, reproductive biology (mating system, pollen- and seed-mediated gene flow), species evolutionary history and demography (for example, existence of genetic bottlenecks, localization of refugia sites, founder populations).

Aims of conservation genetic studies are to understand genetic status, impacts of land use changes on intraspecific variation, and vulnerability of populations to threats; and to identify populations having high priority and design approaches for their conservation. A combination of neutral molecular markers and either phenotypic measurements or genomic markers for adaptive traits would be ideal for defining priority populations.

Evolutionary History

Patterns of genetic differentiation and speciation have been studied in order to understand evolutionary history of species. Petit and Hampe (200?) reviewed the evolutionary consequences of being a tree, noting that the high diversity and very high fecundity of most tree species allows for rapid evolution at the micro scale, but long generation time, large size and other characteristics result in slow macroevolution.

Chloroplast DNA is most commonly used to examine evolutionary pathways..., examples of studies, practical applications

Taxonomy & phylogeny

Taxonomic studies rely increasingly on genetic markers to complement or replace conventional morphological methods to determine taxonomic status and understand phylogenetic relationships.

Many tree genera are incompletely described at the species level, in part because of hybridization and introgression among species; Quercus spp in Mexico provide an example where number of species is 135-150 (González-Rodríguez, et al. 2004) but exact number is not known. A combination of nuclear markers and morphological traits are employed to differentiate species.

Chloroplast DNA genome of choice for phylogenetic studies because of the small size of the genome, and uniparental inheritance, allowing spatial pattern of haplotypes to be interpreted as an estimate of past gene flow. In addition, the chloroplast shows neutral differentiation among divergent populations sooner than nuclear alleles. If population divergence has occurred relatively recently, neutral cpDNA variation will be more likely to show the differentiation than nuclear polymorphisms (Hamilton, et al. 2003). Hamilton, etal. (2003) examined patterns of cpDNA haplotype variation and in particular, searched for evidence of selection acting on several insertion/deletion regions of the chloroplast genome of eight species of Lecythidaceae, which is the Brazil nut family. They found that the rate of evolution was highly variable among regions in the genome, but that the variability seemed to be lineage-related rather than region-related. They concluded that the insertion/deletion markers and nucleotide variation in the chloroplast genome were selectively neutral and thus should provide unbiased estimates of population parameters.

The Bar Code of Life project attempts to use DNA markers directly to identify species. This is further discussed below, with respect to use of DNA forensics for reducing illegal logging.

5.1.3. Trait based knowledge of tree genetic resources

Until the advent of biochemical and molecular methods, the only way to estimate genetic values or variation was by measuring phenotypes and using statistical tools to separate genetic information from environmental influences. Although efforts in field studies designed to estimate genetic parameters have declined, such studies are still essential for understanding genetic control of phenotypic traits.

Before the development of genetics as a scientific discipline, trees had been planted for food, wood, shade and religious purposes for thousands of years. Knowledge of trait variation was used in traditional farming and subsistence systems to select, save and/or cultivate valuable individual trees on the basis of phenotypic characteristics. Besides food tree species such as *Olea europaea* , *Malus domestica*, *Citrus sinensis*, other cultivated tree species of significant importance include *Cinchona lederiana* from Bolivia and transported to Europe to combat malaria, then grown in Asia; and *Hevea brasiliensis*, the rubber tree in Brazil seeds of which were transported to the UK then Asia, in the late 1800s. All of these species were subject to selection and breeding on the basis of valuable phenotypic characteristics.

Indigenous and traditional knowledge

Traditionally living societies generally maintain an intimate relationship with the natural world of their (actual and/or historical) living environments. They are (or until recently were) strongly dependent on the exploitation of natural resources for their livelihoods. Through this intimate relationship with, and dependence on, the natural world, people have developed extensive knowledge about natural resources, often built up over generations. Trees are among the most important life forms to traditional people in terms of usefulness which they owe to their more complex habit and multipurpose nature compared to herbaceous plants: apart from fulfilling human needs for food and medicine they also contribute considerably as sources of (construction) materials and fuel, and providers of a wide array of ecological services (Thomas and Van Damme 2010). The importance of species with a tree habit for traditional societies to a large extent co-varies with the nature of their living environment. For example, Clement (1999a) calculated that 68% of the 138 species under cultivation or management at the time of European arrival in Amazonia, were trees or woody perennials.

Ethnobiological research on people-plant interactions has traditionally focused mainly on the utilitarian (ethnobotanical) dimension of plant species and far less on ecological aspects. However, studies that were dedicated to investigating traditional ecological knowledge (TEK) of plants more broadly have demonstrated the deep knowledge held by people on aspects including species' habitat preference, phenology, pollination systems, seed dispersers, species associations, intraspecific variation, pests and diseases, environmental services provided, and behavior under different types of management (Assogbadjo et al 2008; Hmimsa et al 2012; Parra et al 2012; Fraser et al 2012). Most studies that investigated traditional knowledge about plants at subspecies level have focused on ethnolinguistic and ethnotaxonomic aspects, i.e. the ways traditional societies name and classify plants (Berlin 1992). Ethnotaxonomical classifications often coincide to certain extent with corresponding scientific classifications and can provide a first approximation of existing intraspecific variation in plants. Over differentiation, the splitting a scientific species or subtaxa into two or more traditional names is primarily encountered with cultivated varieties for which distinctive scientific names are often lacking, although such cultivated varieties may be genetically different (Hunn and Brown 2011), or not (e.g. Assogbadjo et al 2009).

TEK can provide very valuable information to inform scientific research on the ecology, management, intraspecific variation and conservation of tree species, considering that such information is still lacking for many tropical tree species. However, TEK about tree species is being lost more rapidly than the respective scientific knowledge is increasing, calling for the urgent need to strengthen efforts in recording remaining knowledge. Participatory tree breeding and domestication of tree species is a fairly recent approach, which combines TEK about tree use and management with scientific advances in germplasm collection, selection and propagation, and with market development, with the ultimate goal to improve people's livelihoods (Dawson et al 2013). TEK can also be a rich source of inspiration for designing biological approaches to tackling the environmental problems of our times such as the development of renewable energies and resources (Martin et al. 2010) or ecological restoration (Douterlungne and Thomas 2013).

Tree and landscape management

Traditional societies are typically positioned at the interface between the natural and cultural world. They live in close proximity to natural vegetation from which they extract livelihood goods, and at the same time engage in different types of plant management. Plant management in traditional societies covers a continuum, ranging from gathering and protecting plants in wild populations, and deliberately tolerating plants in man-made habitats (also defined as disturbance habitats), to cultivating domesticates as well as non-domesticates. Of all anthropogenic habitats, particularly home gardens are the laboratories where people have experimented with plant genetic resources; they contain a combination of strictly wild plants, camp followers (weeds; which can be trees e.g. in Amazonia – Balée 1994), spared and tolerated plants, and cultivated and domesticated plants. Through on-going processes of experimentation and innovation, wild plants with desirable traits are gradually brought into the cultural sphere (from dump heap, through cultivation to domestication) (Bennett 1992; Miller and Nair 2006; Clement 1999; Thomas and Van Damme 2010).

Useful wild tree species available in natural vegetation may also enter the cultural sphere when spared during clearing land for human use, as this increases contact intensity between people and such remaining trees in or along the margins of crop fields. Intensity of contact, salience, accessibility and availability of plant species are often correlated with their perceived usefulness by people (Adu-Tutu et al. 1979; Byg et al. 2006; Thomas et al. 2009a,b; Turner 1988). Tree management is not limited to humanized landscapes such as home gardens and swiddens, but occurs also in natural vegetation where certain species, may receive protection, e.g. by removing competing plants or pests to enhance the target plants' chances of survival. More significant, however, is landscape domestication, a process of landscape manipulation which was initiated by early humans all around the world (Chase 1989; Clement 1999; Aumeeruddy-Thomas et al 2012; Sheil et al 2012) and reaching its extremes in the highly artificial land use forms of modern society. The impacts of long-standing landscape domestication in forest environments is, for example, evidenced by enrichment in useful species

(Wiersum 1997; Shepard and Ramirez 2011), anthropogenic forests (Balée 1989), or anthrosols such as black earth soils containing charcoal and cultural waste from prehistoric burning and settlement and carrying distinctive vegetation as a consequence of high nutrient content. In Amazonia, black earth soils are generally associated with forests that are enriched with useful species such as Brazil nut trees (Clement and Junqueira, 2010; Junqueira et al 2011).

Risk management

Throughout human history, traditional societies have been positioned in the firing line of environmental and climate change. They are aware of the need to monitor environmental change, often through the use of indicator plants such as *Barbaceniopsis boliviensis*, a Bolivian Andes plant whose leaves are said to turn yellow as an early warning sign. To cope with the adverse impacts of environmental fluctuations traditional societies have developed a plethora of risk management strategies. Most of the strategies are designed to make opportunistic use of space, natural resources, social relations, and time. People tend to invest in a diverse portfolio of options because this lowers vulnerability and increases resilience and stability in the availability and supply of livelihood goods and services (Frison et al 2011). A popular strategy is to maximise the accessibility to, and use of different ecological units in the landscape in which people grow a variety of different plants and/or extract floral and faunal elements upon which they can draw for their livelihoods (Berkes and Folke, 1994; Ladio and Lozada, 2004; Thomas et al 2009a). This explains why indigenous groups are drawn to environments with high ecological variation, such as ecological edges (Turner et al 2003). Biological and ecological diversification strategies imply the need for diversified knowledge systems, not only about the ecological conditions of different environments, but also about a high number of biotic elements, their useful traits and management. Risk strategies based on optimal use of natural resources spreads risk in terms of space and resources; crop failure in one ecological zone may be offset by more stable harvest in another and reduced availability of one biotic resource may be compensated by use of (a variety of) other resources.

Biological and ecological diversification strategies of traditional societies are often complemented by equally important social risk management strategies (van Oudenhoven et al 2011). Smith et al (2012) recently suggested that resilience is a dynamic social process determined, in part, by the ability of communities to act collectively and solve common problems. Systems that spread risk and innovation in social space, simultaneously stimulate further diversification of available resources and provide individual elements of the network to fall back on others in case of unforeseen events (e.g. misharvest). For example, in rural communities it is very common to see high variation in germplasm grown in home gardens; different tree species, varieties or genotypes generally occur at low densities and frequencies and what is being cultivated is often very different between gardens, even in the same village (Padoch and De Jong 1991; Ban and Coomes 2004; Perrault-Archambault and Coomes 2008; Jarvis et al 2008; Thomas and Van Damme 2010; Wezel and Ohl 2005; Hmimsa et al 2012). A similar pattern is observed at larger scales (across the homegardens of different villages), as well as in predominantly agricultural landscapes (Dawson et al 2013). For example, Van den Eynden (2004) reported that about 60% of all edible plants were only used or known in one of the 42 villages of Southern Ecuador that she investigated. It is clear that social bonds, relations and interactions are crucial for allowing individual elements operating in the social space uniting different home gardens or villages to benefit from the diversification strengths of the overall system.

The success of the pre-Columbian Inca society was based on the same structural components as described above, and materialized in the terms *verticality*, *specialization* and *reciprocity*. Verticality is an underlying principle of traditional Andean social, political and economic organization (Murra, 1975). It implies that Andeans specialize in extracting and producing resources from multiple ecological zones along steep mountainsides and exchange their complementary resources for those produced by people inhabiting other ecological zones (social reciprocity) (Murra, 1975). These conditions are at the base of Andean people's extraordinary knowledge and use of micro-environments, an incredible range of technological and agricultural innovations, and formalized systems of reciprocity (e.g. exchange of labour or agricultural produce) (Alberti and Mayer, 1974).

From the above it is clear that traditional societies are in many cases the creators and keepers of an often remarkably diverse and untapped repository of tree germplasm in varying stages of domestication that is spread out over ecological and social space. There is a large latent potential for modern society to take advantage of traditional diversification strategies for addressing human development needs, not only in terms of tangible resources, but also in terms of social and ecological management and organization.

Traditional knowledge is highly dynamic and adaptive, depending on the context of use. Indeed practical knowledge is kept alive, at least in part, through its actual use. If the particular use of plants is no longer required, accompanying knowledge is likely to disappear eventually. Basically, this is what happens through modernization of traditional lifestyles: people tend to substitute traditional knowledge and plant use with modern knowledge and/or practices. Hence, unless efforts are made to deliberately retain knowledge of plant uses that are no longer applied by or relevant for a society, whether through written or oral transmission it will be lost and/or replaced by “new” knowledge at one time or another.

In summary, traditional societies have generated valuable FGR-related knowledge and archaeology can provide a complementary knowledge base to understand how that knowledge was used to adapt to changing needs.

- They experiment with FGR through cultivation of germplasm from the wild and consciously or unconsciously selecting for traits that are perceived useful.
- Through their intimate relationship with the environment they hold important knowledge about how to cope with changing climates, built up over generations and often kept alive through oral traditions, or in written form (eg Indian Aryuvedic texts).
- They hold germplasm of and knowledge about the management and behaviour of numerous underutilised FGR with vast potential for large scale use.

Classical tree improvement programmes [to be completed]

Tree improvement using scientific genetic principles has been underway for only a little more than a century and intensive selection and breeding, only since about 1950. Over the course of selection, testing, and breeding for improved traits, a body of quantitative genetic knowledge has accumulated for most major plantation species. Quantitative genetic data is generated from phenotypic measurements taken under uniform environmental conditions. Statistical analyses are conducted to separate genetic from environmental sources of variation in measured traits. The ratio of genetic to phenotypic (including environmental) variation provides a measure of the heritability of the trait, and thus the potential for improvement. Field trials to generate quantitative genetic data were initiated for forest trees in the early 1900’s beginning in Germany (ref?). Methods for provenance trials to identify the best seed sources and progeny trials to estimate additive genetic variation and heritability of valuable traits were adopted by mid-century in Europe, North America, Australia and New Zealand. Thousands of trials were established, leading to rapid improvement of growth rate and stem form, and associated broad scale planting of commercial tree species such as Pinus radiata, Pseudotsuga menziesii, Pinus taeda, Picea abies,... A leader in establishing trials and generating data on conifers from Central America, by the latter decades of the 20th century was CAMCORE

In spite of the great number of tree species (80,000 to 100,000) and the large international effort to generate genetic data, only a tiny fraction of available tree species were included in the studies; mainly temperate conifers. The efforts were also limited in the traits studied; mainly related to growth focused only on increasing production of wood.

For other species, such as Eucalyptus spp, and, increasingly Teak (*Tectona grandis*), many commercial plantations are clonal. Eucalyptus breeding programmes often focus on producing high value hybrid clones either between species or between highly selected lines. Most teak field trials are clonal, because of the low seed production and difficulty in conducting controlled crosses. Acacia...

Some of the most advanced tree improvement programmes are in the USA, where according to Neale and Ingvarsson (2008), more than 11.5 million trees have been tested in progeny tests for just four conifer programmes, more than 41,000 parent trees have been evaluated. Two of the programmes are in the third generation of testing and breeding.

Information generated by provenance trials

The original purpose of provenance trials was to compare performance of planting material from different seed sources to determine whether a non-local provenance might out-perform local ones and to define seed zones. Seed zones are geographic areas within which it is considered safe to plant seedlings sourced anywhere within the zone, i.e. zones of local adaptation. For a given species, a provenance trial usually includes trees grown from usually collections from 10 or more trees at each of several to many geographic locations within the species' range. The provenances are planted usually following a randomised block design at several locations to test performance under different environmental conditions. Provenance trials provide population level information intended to identify the sensitivity of seed sources to varying environmental conditions.

In Canada, extensive provenance testing has been carried out for 35 native species and some exotics; mostly conifers. The total number of provenances tested among all species is 7493, in 989 provenance trials. One of the species with the most extensive provenance testing is lodgepole pine (*Pinus contorta*) in the Canadian province of British Columbia and the Pacific Northwest of the United States. Seed was collected from throughout the range of the species, totalling 140 provenances and planted in field trials also representing the full range of the species, with 60 replicated field tests (Wang, et al. 2006). This "Cadillac" of provenance trials has yielded a great wealth of information since its establishment in the 1970s. Most provenance trials are less complete, but this example illustrates the value over decades of such practical field testing [Hamann, Ying, ...]

"Genecology studies have been used as a method of mapping genetic variation across the landscape, predominantly in the (USA) Northwest. These are short-term, common-garden studies in nursery environments. The goal of these studies is to examine the variation of adaptive traits across the landscape. Adaptive traits are those related to traits such as growth rate, phenology, form, cold and drought tolerance. These traits provide measurable quantitative benefits to a plant in its native environment. Because the seed sources are all grown in a common environment, any difference among them is due to their genetic composition (and possibly epigenetic effects). If the genetic variation is correlated with physiographic or climatic variables of the seed-source locations, it provides evidence that the trait has responded to selection pressure and may be of adaptive importance. Over the past thirty years short-term studies have become the research tool of choice for mapping provenance variation in Northwest conifers." – from US country report.

In temperate regions where forestry is economically important, many commercially valuable tree species were tested in multi-location provenance trials, often involving more than one country, during the last six decades. The same did not apply to tropical species, where many high-value timber species are still harvested from the wild and few planting efforts have been made. Infrastructure and human resources have been lacking to establish and maintain such tests outside of the developed world. Consequently much more is known about zones of adaptation and genetic tracking of environmental clines for temperate species, especially conifers, than for tropical tree species.

In recent years, provenance trial data has been mined for information relevant to adaptation to climate change.

For several important timber tree species, multi-location provenance trials have been established to determine appropriate seed sources for production in specific sites. Results of these experiments have been reported extensively (e.g. http://curis.ku.dk/portal-life/en/publications/search.html). These results can be coupled to precipitation and temperature data and time series to observe adaptive genetic variation across provenances under specific climate conditions (Sáenz-Romero et al. 2006;

Schueler et al. 2012). Such analyses are useful for assessment of climate change impact of tree species distributions and productivity in planted forests and agroforestry systems under future climate projections according to Global Climate Models (GCMs) (Sáenz-Romero et al. 2006). Collection of existing provenance trial data of tree species will help to carry out systematic analyses of climate change vulnerability of the selected species in specific geographic areas.

Provenance trial data can be used for various purposes. Provenance trial survival and height growth data of subtropical and Mediterranean pine species, for instance, have been used to validate climate change impact predictions for 2050 of natural species distributions with environmental envelop modelling (EEM) (van Zonneveld et al. 2009). Survival data have been used to calibrate EEM to make more realistic predictions (Benito Garzón et al. 2011). EEM can over-predict climate change impact on species' distributions because species can also survive and perfom well outside their existing climate niche (van Zonneveld et al. 2009). The estimations of EEM of tree species improve considerably when provenance performance data are included in the analyses (Benito Grazón et al. 2011). Trait data can be coupled with climate data to develop empirical productivity models to identify the seed sources that perform well for desired traits under expected climate change (Leibing et al. 2013).

Participatory tree domestication

People began selecting and planting trees for their own purposes thousands of years ago, as for other useful species, but more recently scientists began working with local people in what is known as participatory domestication. The objective is to bring together local knowledge and objectives with scientific theory and knowledge to speed the process of improvement of specific traits for particular uses (Tchoundjeu, et al. 2012). Principles and methods for agroforestry domestication, much of which involves local participation, have been compiled by the World Agroforestry Centre (ICRAF) (Dawson et al 2012).

Most examples of participatory domestication are in the tropics. In the past two decades the number of tree species that are discussed in the literature on agroforestry domestication has increased from about 10 to 50 (Leakey, et al, 2012). Much of the recent progress in domestication has combined local with scientific knowledge.

5.1.4. Knowledge of Population Genetics based on Molecular Markers

Application of molecular marker approaches to forest trees

Use of neutral molecular markers for many purposes – allozymes opened new avenues for understanding population genetic parameters and although other more direct molecular techniques that employ DNA markers have replaced them in most applications, isozyme analyses were instrumental in accumulating knowledge on relative amounts and patterns of genetic diversity, gene flow, inbreeding levels and mating systems for many tree species (see for example, Hamrick ...). Isozyme analyses have been carried out on at least

Ledig and others (...) published extensively on population and conservation genetics of temperate conifers in Mexico and southern USA, on the basis of isozymes. They found, for example that relict *Picea* populations in temperate Mexico were genetically depauperate as theory would predict on the basis of their isolation and small size. Hamrick and others (?) demonstrated relationships between life history traits and amount and distribution of genetic diversity helping to move application of population genetics for forest trees from pure theory to evidence-based hypotheses. Although Duminil, et al (2007) have since demonstrated that positive correlations among life history traits and genetic parameters have to be interpreted with caution when phylogenetic relationships is not taken into account, Hamrick's work is still useful, particularly in formulating hypotheses about patterns of genetic diversity.

Allozymes are considered to be neutral in population genetic analyses but they are not completely neutral in all circumstances. Mitton (1997) described situations in which variants of particular "housekeeping" enzymes resulted in selective advantages particularly for heterozygous individuals of a variety of species.   DNA markers having a more likely claim to neutrality, replaced isozymes because they are provide direct information on genetic variation, the number of markers available can be orders of magnitude greater than for isozymes, results are more repeatable, samples are more easily handled because DNA is more durable than protein. Although the use of DNA markers was expensive, prone to error and time consuming initially, during the past 25 years, their use has dominated population genetic analyses. [examples of a few key studies illustrating the type of knowledge...]

[RAPDs, RFLPs, SSRs, etc – continuously improving the capacity to measure patterns and levels of genetic diversity;

Marker-based understanding of genetic processes

Neutral molecular markers been used to explain much about population genetic processes and spatial patterns, particularly gene flow, genetic drift and mating systems.

Because of the relative ease and availability of these markers, their interpretation has often been over-extended (Holderegger, et al. 2006) beyond the capacity of neutral measures. In general they do not provide reliable information about genetic variation that is subject to selection. The need to extend their use beyond selectively neutral processes led to development of QTL approaches.

5.1.5. Genomic advances

Genomic knowledge of forest trees lags behind that of humans, agricultural crops, and livestock but the number of scientists taking on the challenge of applying the latest technologies to trees is steadily growing. Neale and Kremer (2011) reviewed the substantial recent progress of genomic research in forest trees and noted that in spite of drawbacks associated with long generation times, large genomes, lack of well-characterized mutants for reverse genetic methods, and low funding, forest biology is now well - positioned to make rapid strides.

The first forest tree species for which the entire genome has been sequenced is *Populus trichocarpa* (Tuskan, et al 2006). This provides an important reference genetic map although there is much work remaining to associate gene function to open reading frames. Other tree species for which entire genome sequencing is underway or nearly completed include other *Populus* spp, *Eucalyptus grandis* (Grattapaglia and Kirst 2008), *Malus domestica* (Velasco, et al. 2010), *Prunus persica, Citrus sinensis, Carica papaya, Amborella trichopoda, Coffea canephora, Castanea mollissima, Theobroma cacao,* (http://www.nature.com/ng/journal/v43/n2/full/ng.736.html), *Salix purpurea, Quercus robur, Azadirachta indica, Pinus taeda* (Neale and Kremer 2011), *Picea abies* , *Picea glauca, Pinus lambertiana, Pseudotsuga menziesii, Larix siberica, Pinus pinaster,* and *Pinus sylvestris.*

Knowledge of genetic basis of adaptive traits

Knowledge of genetic basis of productive traits

Grattapaglia, et al. (2009) reviewed the status of genomic knowledge about growth traits in forest trees and noted that although recent advances have increased the understanding of complex, interacting mechanisms, applying genomic tools to increase productivity and growth is not yet practical because of the number of component traits, each of which is genetically variable.

Resistance to pests and diseases

Combining molecular tools with tree improvement – marker assisted selection

Genetic fingerprinting with molecular markers used in tree improvement programmes (FAO 2011)

- measuring genetic diversity of breeding population accessions between indigenous provenances and naturalized landrace origins;
- testing paternity contributions to offspring grown in field tests;
- verifying genetic identity during vegetative propagation.

The challenge of combining biotechnology tools and traditional tree improvement

As genomic tools have become increasing accessible, both in terms of ease of application and cost, a major bottleneck in expanding knowledge of forest tree genomes has shifted to the cost and time required for sampling in the field and phenotyping. There is still a need to measure the range of phenotypic variation in traits of interest in order to link the genomic markers.

Quantitative trait loci

Quantitatively inherited traits are controlled by many genes and most phenotypic traits of interest in forest trees fall into this category. Each gene controls a relatively small amount of variance in a quantitatively inherited trait (Brown, et al. 2003) and such genes are known as quantitative trait loci (QTL). Much effort has gone into identifying linkages between various molecular markers and QTLs over the past two decades, by determining the number and location of chromosomal regions affecting variation in a trait and finding statistically associations between them and quantitative phenotypic traits in a segregating population (Brown, et al. 2003). Mapping QTLs allows elucidation of genetic structure of complex traits and is applied to marker-assisted selection in well-studied breeding populations of tree species that are undergoing genetic improvement (

Factors influencing ability to detect QTLs include sample size, genetic background, environment and interactions among quantitative gene loci. In long-lived organisms the expression of QTL is likely to change on a seasonal or yearly basis.

Much of the QTL work in North America has focused on wood quality (Brown, et al. 2003)

Echt, et al 2011 – pine genome project

Association genetics approaches

Unlike QTL mapping, searching for loci using association genetic approaches does not depend on pedigreed families. Association genetics uses linkage disequilibrium between a phenotypic traits and markers and can be applied for any large sample of a natural segregating population (Ingvarsson and Sweet 2011). Many more markers are needed than have typically been used in QTL mapping and this has been made possible because of the rapid development of sequencing. The hundreds of thousands of SNP markers needed for association mapping can be generated rapidly and relatively inexpensively from any species. The bottlenecks now are field-related, first collecting enough samples to ensure that associations are robust and second, phenotyping the sampled populations. Ideally, replicated field trials will provide the most precise phenotype information, but time and cost constitute serious impediments.

Association genetics may start with candidate genes or a genome-wide approach. The candidate gene approach

Diversity Arrays Technology - DArT methods

Some of the most rapid advances in application of genomic tools to breeding are focused on Eucalyptus species. Faria, et al. (2010) reported development of 20 microsatellite markers from ESTs, which are fully transferable across six Eucalyptus species. They predict that the usefulness of the markers will extend to all 300+ species in the sub-genus. In addition, according to the authors, the markers provide excellent resolution and potential for use in breeding. Intra-genus species transferability of markers is highly desirable and new methodology known as Diversity Arrays Technology (DArT) offers exciting prospects for very rapid genome-wide screening of thousands of polymorphisms (Petroli, et al. 2012) across related species. Because the markers are gene-based, they are useful for genomic selection and can dramatically enhanced breeding and improvement of forest trees that have been subject to intensive genomic study (Grattapaglia and Kirst 2008). Several Eucalyptus species were used to create more than 8000 DArT markers which were used for high resolution population genetic and phylogenetic studies (Steane, et al. 2011). Among uses that Steane et al (2011) noted for DArT markers, are species differentiation, identification of interspecific hybrids, and resolution of biogeographic disjunctions within species.

Resende, et al. 2012a used more than 3000 DArT markers to evaluate the efficiency and accuracy of genomic selection in two unrelated Eucalyptus breeding populations and they reported that for growth and wood quality traits they were able to match accuracies attained by conventional phenotypic selection. However they cautioned that, in spite of the potential for the approach to revolutionize tree improvement, experimental support is required and in the short term, it is likely that predictive models will population specific. Resende, et al. (2012b) applied the same approach to Pinus taeda populations across multiple ages and found high accuracies across environments within a given breeding zone, but not when models generated at early ages were used to predict phenotype at age six.

5.1.6. Genetic modification

Genetic modification of forest trees poses challenges both biologically and in terms of public acceptance. Walter and Menzies (2010) reported that activities related to genetic modification of forest trees is taking place in at least 35 countries and 16 of them have field trials which are generally small and of short duration. The first genetically modified tree, a poplar, was produced more than 25 years ago (Fillati et al 1987). The number of tree species that have been successfully transformed remains low, especially among conifers, and within the proportion of attempted genotypes from which transgenic plants have been recovered, remains low ((Meilan, *et al* 2010).

Traits targeted by transgenic experiments include pest, herbicide and abiotic stress resistance, hormone regulation, lignin and cell wall biosynthesis and growth (McDonnell 2010). Among forest tree species, *Populus* species and hybrids by far the greatest number of transgenic experiments have been conducted using compared to any other forest tree species or genus.

Except for a few hundred hectares of genetically modified Populus planted in China, no commercial planting has been reported. However genetic modification protocols have been developed and tested for many commercially important plantation tree species for traits such as stem shape, herbicide resistance, flowering characteristics, lignin content, insect and fungal resistance (FAO 2011). McDonnell, et al. (2010) summarised the progress on genetic modification of 10 species and hybrids for many of these traits (Table xx).

Transgenetic trees are likely to be planted within crossing distance of wild populations of the same species. Robledo-Arnuncio, et al. (2010) concluded that it is highly probable that transgenes from genetically modified trees would move into conventional forest because of the efficiency of dispersal systems over the long lifetime of tree species. Concerns about genetically modified forest trees dispersing pollen or seed, which will spread transgenic, selectively advantageous propagules into natural populations, has led to a strong focus on sterility mechanisms. Attaining a stable form of both male and female sterility in transgenic trees before releasing them is not a trivial problem. Researchers have encountered significant obstacles in the search for sterility, but it has led to expanded knowledge of genetic control of reproductive functions and floral genomics (reviewed by Brunner, *et al* 2010).

Although most genetic modification is done with the aim of increasing or improving wood production, it can also be a tool for conservation, for example in the case of American chestnut. Barbakat, et al. (2011) compared canker transcriptomes from American (*Castanea dentata*) and Chinese chestnut (*Castanea mollissima*) to identify candidate genes that may be involved in resistance to chestnut blight (*Cryphonectria parasitica)*. They identified several candidate genes for resistance and gained a better understanding of the resistance pathway in Chinese chestnut.

Table xx. Number of published successful transgenic experiments achieving gene expression or over-expression in transgenic cells (number of genes used in the various experiments in parentheses, where relevant), by tree species or genera and modification objective (summarised from McDonnell et al. 2010).

Species/genus	**Pest resistance**	**Herbicide resistance**	**Abiotic stress resistance**	**Hormone regulation**	**Lignin**	**Cell wall biosynthesis**	**Growth**
Populus spp and hybrids	8 (>5)	11 (9)	11 (10)	9 (7)	26(10)	6 (6)	8 (7)
Pinus taeda	1		1		1		
Pinus radiata	1	1			1		
Picea glauca	2 (2)						
Eucalyptus camaldulensis		1	1		1		
Eucalyptus grandis x urophylla			1				
Picea abies		1			1		
Larix decidua		1					
Larix leptoeuropaea			1				
Pinus strobus			1				

5.1.7. Propagation and dissemination technology and methods

Eucalyptus species and hybrids are widely planted throughout tropical and subtropical regions for a variety of purposes. Substantial gains can be made by using naturally occurring hybrids, but mass propagation by seed is not feasible. A technique for micropropagation was developed in the Republic of Congo (REF) and is now used throughout the world...

5.1.8. FGR Knowledge related to conservation and restoration

Types of knowledge and its application

Many studies have been conducted to understand mating systems and gene flow patterns of forest tree species with an initial focus on Europe, North America, and Australia. More recently, research is increasingly targeting tropical species; among many examples, the study by Fuchs and Hamrick (2011) on continuous and remnant populations of the endangered tropical tree *Guaiacum sanctum* (Zygophyllaceae). They found that isolated populations had maintained high genetic diversity because of long distance gene flow indicating that the species has potential to adapt and expand populations if suitable habitat is available. This adds to the growing body of knowledge gene flow among populations of neotropical species. There is still considerable disequilibrium among continents however; tropical American species have been more studied (Ward et al. 2005) than African and Asian one. In any case, the percentage of studied species is still very low in relation to the high levels of tree species endemism in tropical regions.

Spielman et al. (2004) conducted a meta-analysis to compare heterozygosity of threatened species and that of their nearest non-threatened relative. They found that for paired groups of 15 gymnosperm species and 6 angiosperms, heterozygosity was lower in 67 and 81% of the threatened species, respectively. Overall the difference in heterozygosity level between the threatened and non-threatened species was on average, 35% for both gymnosperms and angiosperms.

[include several examples – marginal or isolated populations maintaining/losing genetic diversity,]

Conservation actions when species are threatened by invasive insects or disease require a different type of genetic information. For example Potter, et al. (2012) studied *Tsuga canadensis*, a North American conifer that is threatened throughout much of its range by an introduced adelgid to inform a ex situ conservation strategy. Information required included range-wide population structure including distribution of genetic diversity within and among populations, occurrence of rare alleles and levels of inbreeding. They used microsatellite markers to identify locations of glacial refuges which are of interest because they typically have high genetic diversity. They confirmed a negative relationship between population isolation and diversity; and a positive relationship between diversity and population size. The information that they generated through the range wide study will be used to refine seed collection areas to ensure that the patterns of genetic diversity on the landscape are represented in the collections, and that areas with high genetic diversity and unique or rare alleles will be included.

Examples: Research by Fady, et al (2008) on the impact of natural and anthropomorphic factors on populations of *Cedrus libani*, a species of the eastern Mediterranean mountains that has long been influenced by human activities, determined that there are two genetically isolated groups in Lebanon and Turkey. Using a combination of cpDNA markers and allozymes, they identified priority populations for conservation and proposed how to identify appropriate source populations for assisted gene flow.

Azevedo, et al. (2007) reported on the population genetic structure of an Amazonian tree species, *Manilkara huberi* that is endangered due to over-exploitation for its high value wood. Based on seven microsatellite loci, they examined mating system, and patterns and structure of genetic diversity, to guide conservation and management of the species. The species has limited pollen flow and a highly structured spatial genetic pattern. The researchers reported evidence for genetic isolation of populations, indicating that further fragmentation of the species' distribution may result in loos of subpopulations and their associated genetic variability. This means that at least several large populations should be maintained to conserve evolutionary potential of the species. They were able to estimate on the basis of population genetic parameters, that in order to maintain an effective population size of 500, seed should be collected from more than 175 maternal trees, in order to keep.

Such thorough studies cannot be carried out for all species that are at risk as a result of land pressures and over-exploitation, but lessons learned can be applied more broadly. [example...]

Combining spatial analysis with genetic markers to prioritize conservation

The formulation of effective *in situ* conservation strategies can be maximized by an understanding of spatial patterns of tree species genetic diversity (Petit et al. 1998). Areas of high genetic diversity should be targets for *in situ* conservation as they are considered more likely to contain interesting materials for use and genetic improvement. The recent development of new powerful molecular tools that reveal many genome-wide polymorphisms has created novel opportunities for assessing genetic diversity. This is especially the case when these markers can be linked to key adaptive traits and are employed in combination with new geospatial methods of geographic and environmental analysis (e.g. Escudero et al. 2003; Manel et al. 2003; Holderegger et al. 2010; Chan et al. 2011). New methods to prioritize populations and geographic areas for *in situ* conservation, and to enable monitoring of genetic diversity over time and space, are now available and can and should be exploited to improve *in situ* conservation.

Geospatial analysis of genetic diversity has been undertaken for a wide range of tree species because the maintenance of genetic resources of most of these species depends largely on *in situ* conservation. Among recent examples, a geographic grid-based gap analysis for Norway spruce (*Picea abies* (L.) H.Karst) in Austria was used to identify new conservation units that complement the coverage of mitochondrial and nuclear molecular marker variation, and adaptive genetic diversity by the current species´ conservation unit network (Schueler et al. 2012). Another recent case study is the prioritization of *Prunus africana* populations at continental scale on the basis of nuclear and chloroplast microsatellites, combined with climate clustering as a proxy for adaptive variation (Vinceti et al. 2013).

One effective method to describe genetic diversity in geographic space is to use circular neighbourhood-type analyses. This approach is especially effective when working with georeferenced individuals rather than with populations (van Zonneveld et al. 2012a). Such an approach has been used to identify genetic diversity hotspots for the *in situ* conservation of a number of important tree species, including a high-value timber species *Cedrela balansae* C.DC. in northern Argentina (Soldati et al. 2013), cacao (*Theobroma cacao* L) in its Latin-American centres of origin and domestication (Thomas et al. 2012), in the fruit tree cherimoya (*Annona cherimola* Mill.) in the Andes (van Zonneveld et al. 2012a), and in the bush mango (*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. and *I. tenuinucleata* Tiegh in Central Africa (Lowe et al. 2000).

In addition to these large scale studies to map genetic diversity, there are many other studies that have assessed geographic patterns of genetic diversity at a smaller scale than those mentioned above. Most of these studies have been carried out in temperate and boreal zones and more studies are required in the biodiversity-rich tropical regions (Pautasso 2009). However the number of molecular studies is increasing, including in the tropics. The results can be used in meta-analysis to detect overall geographic patterns of genetic diversity for species with similar life history traits or other analogies. The results from such studies can be extrapolated to provide conservation recommendations for other tree species as well for which no genetic studies have been carried out but which share common ecological features with those species that have been subjected to molecular studies in a part of their observed distribution.

One approach to extrapolate patterns observed from these analyses and prioritize areas to maximize capture of tree genetic resources is to identify Pleistocene refugia and converging post-glacial migration routes. These areas harbour high inter-specific and intra-specific diversity (Petit et al. 2003). Georeferenced observation points of such species from herbaria and genebanks can be used to predict Pleistocene species distributions on the basis of past climate data (Waltari et al. 2007). Such data are freely available from the PMIP2 website (http://www.pmip2.cnrs-gif.fr) although it still needs to be down-scaled. Georeferenced plant data and climate models are increasingly available through online platforms such as the Global Biodiversity Information Facility (www.gbif.org) and WorldClim (www.worldclim.org), respectively. These data, where available and when they are of reasonable quality, can be fed into Environmental Envelope Modelling (EEM) to predict past species distributions and reconstruct potential Pleistocene refugia (Waltari et al. 2007; Thomas et al. 2012).

Climate change and FGR

Much research has been galvanised by predictions of impacts of climate change on forest populations and species. The impact of specific climatic changes on tree species will vary with biological, genetic and distributional properties of the species and populations within the species. When confronted with significant climatic changes, there are three possible outcomes for populations of native tree species (Aitken 2008). They may be extirpated resulting in loss of unique genes or gene combinations; they may survive in place, as a result of phenotypic plasticity or adaptation, or a combination of the two; or they may migrate following the changing climate to establish in new locations having climatic conditions for which they are adapted. However migration by seed is likely to be too slow for many tree species if climate change is rapid. Trees, given their long generation time are of particular concern.

Interestingly, past climate-driven demographic events have left some signatures in the genomes of species. Such signatures can be traced back using molecular markers. Phylogeographic methods have thus allow retracing the impact of past-climate changes on the evolutionary demographic history of plants (Hewitt, 2004; Heuertz et al., 2006; Lowe, Harris, Dormontt, & Dawson, 2010; Petit, Brewer, et al., 2002). Modelling the impact of past climate changes on species diversity provides useful information to predict the future evolution of species.

Spatial modelling using GIS mapping tools to examine vulnerability of genetic resources to impacts of climate change is used increasingly. Van Zonneveld, et al. (2012) demonstrated that the highest diversity in populations of *Annona cherimola*, a species of the Andean foothills in Latin America, fall in areas with highest expected climate-related impacts to forest ecosystems based on predictions of global climate models. Vinceti, et al. (2013) carried out a similar analysis with Prunus africana, a widely distributed, but ecologically restricted species found in all of the Afromontane regions. On the basis of climate models, they predicted that the number of populations will be reduced by about half in the area having highest genetic diversity.

The major challenge facing conservation genetics is to link traits that are important for adaptation to changing climates with molecular markers. Technologies that are being developed for breeding and improvement have relevance but must be applied in a different way because of the lack of pedigrees for most species of conservation concern.

Examples of impacts of already changing climate on tree species and their genetic resources are adding up, but still not readily available in the published literature. Based on available data and deduction, climate change is likely to have impacts on FGR through several processes which may include: loss of populations and their unique genetic variation as a result of extreme climatic events and regeneration failure, especially at the receding end of distributions; more severe pest and disease attack in some areas; altered fecundity of some tree species; pollination failure because of asynchronicity between flowers and pollinators or loss of pollinators; decline or loss of fire-sensitive species because of increased fire frequency; changes in competitive relationships resulting in new species invasions and potential hybridization (Loo, et al. 2011).

Changes in fecundity are expected because of sensitivity to spring temperatures (e.g. as observed in the southeastern United States of America; Clark *et al*., 2011) and other factors (Restoux, 2009). For example, in central Spain, a decline in cone production in *Pinus pinea* over the last 40 years has been correlated with warming, especially with hotter summers (Mutke *et al*., 2005).

Genetic technologies for tracking timber

Lowe and Cross (2011) reviewed progress toward use of DNA as a forensic tool for identifying species and origin of wood. Barcoding, using the two official sequences intended to be common for all plants, will distinguish approximately 70% of species. However, "local" barcodes may be used to increase resolution and certainty of correct identification. If spatial structuring of genetic diversity is strong, the geographic origin of a log may be determined with a high degree of precision. Finally individual logs can be tracked by fingerprinting a percentage of standing trees prior to harvest.

Table xx presents numbers of tree species, by genus for which barcodes have been developed, in each continent.
(to be added)

Effectiveness of in situ protection

Large expanses of many countries have been designated "protected" with legal protection but in fact, very low enforcement. In many cases, if inventory of tree species and populations was carried out at all, it was at least a decade or more in the past and the protected areas have been subject to a variety of human activities. Consequently it is unknown whether the species are still found within the protected areas.

In Europe, EUFORGEN has encouraged and provided expertise to facilitate the development of gene conservation reserves in many countries. A set of standards have been developed and accepted for effective in situ conservation, which includes periodic monitoring of the FGR contained within the reserves. The information collected through monitoring will be extremely useful for understanding factors which influence the effectiveness of conservation.

In cases of well protected areas with effective conservation enforcement there may be a need for management actions for conservation of genetic resources that are often not allowed by PA legislation.

Technologies for ex situ conservation (Outline from Hugh Pritchard)

Innovations in *ex situ* conservation of forest species (mainly trees)

1. Recent developments in *ex situ* plant conservation
    a. Selected collecting programmes to bring threatened trees into living collections, especially botanic gardens.
2. Screening seeds for storage behaviour
    a. Historical – IPGRI seed storage protocol (1000s of seeds)
    b. Recent – 100 seed test for desiccation tolerance, particularly for threatened species and any seed lot of few seeds.
3. Recent developments in *ex situ* seed conservation
    a. Predictions of tree seed behaviour based on botanical information
        i. Literature and database searches - resources
        ii. Literature and database searches – example based on c. 50 tress in the threatened trees campaign (IUCN, etc)
    b. Predictions of tree seed behaviour based on multi-criteria keys and ecological correlates

i. Historically – Tompsett (Araucariaceae, Dipterocarpaceae), Ellis et al (e.g. Meliaceae and trees of Vietnam), Dickie and Pritchard (global synthesis) using moisture content at shedding, seed shape, seed mass.
ii. Recently – ecological correlates, beyond moisture content at shedding.
    1. Pritchard et al – African trees, seed mass, germination rate, precipitation in the month of seed shedding
    2. Daws et al - Panama trees, seed mass and seed coat ratio
    3. Hamilton – Australian forest species, seed coat ratio, seed mass, etc
iii. Examples of lifespan in stored tree seeds

4. The matter of seed quality
    a. Environmental conditions impacting on tree seed quality at harvest, based on developmental (maturity) heat sum, and explaining differences in assignment of seed storage category between laboratories across the world
    b. The matter of vigour – the difference between tree seed germination post-storage as radicle emergence and normal germination in relation to stress tolerance.

5. Storage innovations – cryopreservation of embryos
    a. Historical - Vitrification of embryos and other tissues of trees – key points on methods, tissues and species successes from the review by Sakai and Engelmann
    b. Recent – summarise key points from 2012 FAO in vitro and cryo review
    c. Current - Vacuum infiltration vitrification (VIV)-cryopreservation – Nadarajan and Pritchard for tropical oilseeds (in press)

6. Future research needs
    a. Screening of tropical tree germplasm for seed quality and storage characteristics to account for the different floras of the world, taxonomic and phylogenetic coverage. Particularly wet flora of Africa and India.
    b. Reproductive biology of threatened trees.
    c. Relatively few trees have viability constants for storability, or rigorous. determinations of storage capability under trade conditions for forestry.
    d. For the sustainable use of stored forest seeds, a compendium of germination conditions (online tool, handbook, etc).
    e. A method for the cryopreservation and recovery growth of the most recalcitrant of tree / forest species.
    f. Integration of forest species conservation using *ex situ* conservation of pollen, storage of seed and the production of seed through the use of stored pollen through artificial pollination. Particularly important for dioecious species, e.g. long-lived cycads – the most highly threatened plant family in the world.

Morphological characterization of tree species field collections

Ex situ field genebanks maintain sources of variation of functional traits for direct use in production through propagation and breeding programs. Morphological and biochemical characterization of conserved accessions provide a wealth of trait-based knowledge. Such collections are established for tree species that are considered important for agroforestry or arboriculture production and include many fruit tree species. Most of these collections are field genebanks because in some cases, the species are recalcitrant, meaning that seeds cannot be stored using conventional methods. More generally, field genebanks enables characterization. However, field genebanks are also costly to maintain (Dawson et al. 2013). Their existence can only be justified when genebank material can be accessed by users and meets their needs. The National Genetic Resources Program of the United States Department of Agriculture, for example, holds collections of a list of tree species that are characterized (http://www.ars-grin.gov/cgi-bin/npgs/html/croplist.pl). They include many temperate fruit tree species, but also tropical ones such as peach palm (*Bactris gasipaes* kunth), the pili-nut (*Canarium ovatum* Engl.) and carambola (*Averrhoa carambola* L.). Data on traits can be consulted freely online and germplasm can be requested accordingly.

There is no centralised information system for tree species collections, thus characterization information, if collected, is generally not accessible, especially not of those in developing countries. Germplasm maintained in those collections that have been characterized, are often not accessible for potential users, and in this way genebanks lose their connection with users and their needs. An exercise with national research agricultural institutions from the Amazon, on the status of *ex situ* conservation, characterization and evaluation demonstrated a high number of collections and promising advances in morphological characterization of prioritized local fruit tree species including acai (Euterpe *spp.*), peach palm, Cupuaçu (*Theobroma grandiflorum*), camu camu (*Myrciaria dubia*), bacuri (*Platonia insignis*), Buriti (*Mauritia flexuosa*), and abiu (*Pouteria caimito*) (Scheldeman et al. 2006).

Thus even though for only a limited number of tree species field *ex situ* collections exist, still a considerable number of these collections is already morphologically characterized. Unfortunately, many of these collections are not known by a general public, and existing characterization data is difficult to access or not available for general public. To enhance the use of genebank characterization, such information should be systemized and be made accessible at a central point.

Application of Genetic principles in forest ecosystem restoration

Appropriate sources of forest reproductive material: Bozzano *et al* (2013) conducted a survey and analysis of the degree to which genetic considerations are recognized and applied in restoration projects, globally. They found that geographical origin of planting material is often considered, but there is little awareness of other genetic considerations. Even when guidelines exist they are often inadequate, advocating collection from at least five trees, for example.

Examples of knowledge gaps include: a quantification of the risks associated with genetic mismatching of source of planting material to site conditions or narrow genetic base, particularly considering climate change; thresholds for optimum level genetic diversity in restoration material; and genotype by environment interactions. It would also be valuable to understand the potential for combining species rescue with ecosystem restoration, i.e. the potential of individual restoration projects to contribute to species conservation and serve as future seed sources, especially for rare, endemic and endangered tree species.

Species selection and availability: Exotic species or seed sources are very commonly used for restoration and in some cases it is clearly justified. In other cases however, this can not only result in wasted efforts, but can threaten native species if the exotic ones become invasive (FAO 2008? Report on invasiveness of introduced tree species). Often the reason for using exotic species is simply availability and knowledge about nursery production. There is a need to expand knowledge of native tree species to understand their potential to achieve diverse restoration objectives in different states of site degradation and ecological and socio-economic contexts including understanding the ecological and socio-economic trade-offs related to the use of exotic versus native species, and the factors that currently constrain wider use of native species.

Regional Overviews

Europe (needs to be completed): Europe has the longest history of testing, selection and tree improvement for wood products. Although, compared to tropical countries, the species diversity of Europe’s forests is low, many of the species are relatively well studied. Improvement for timber production is limited to … EUFORGEN; EUFGIS (European Forest Genetic Resources Information System) includes information on genetic conservation units for 125 tree taxa (mostly species, but a few subspecies level taxa are also recognised). EVOLTREE – a European project to evaluate climate change impacts on forest ecosystems from an evolutionary perspective

North America: Tree improvement activities; combating invasive pests and diseases; some degree of quantitative analysis of at least 70 species; molecular studies on more; genomic – one species completely sequenced, at least two more underway; North American Forest Genetic Resources Working Group, New Genetic Resources Centre in Mexico, CONFORGEN (other initiatives). Canada and the United States have a history of seed source testing and tree improvement, dating back to the beginning of the 20th century. In Mexico, tree improvement efforts have not been supported to the same extent as in the northern countries and earlier studies were often conducted with the aim of sourcing useful material for planting elsewhere, rather than establishing breeding and improvement programmes in Mexico (Ref?), for example, knowledge has been generated by CAMCORE . Intensive tree improvement is still in the beginning stages there (Saenz-Romero, Niensteadt and Vargas-Hernandez 1994; CONAFOR 2012).

In Canada, exploration and testing of various exotic species began in the western prairie region for use in shelterbelts and for horticultural purposes between 1900 and 1910 (Fowler 1974). The Canadian Forest Service Petawawa National Forestry Institute in Ontario played a lead role in forest genetics research in Canada during much of the century (Place 2002) with genetics test plantations established at Petawawa Research Forest beginning in 1922. Some of the earliest tests used non-indigenous species: *Picea abies* in 1924, European *Larix* species in 1930, and exotic *Pinus* spp. in 1936. Many non-indigenous species from other parts of Canada and the USA, Europe, and Asia were tested but very few non-local seed sources were found to perform better than the local ones. Exceptions were some *Populus* spp and hybrids, and a few seed sources of *Picea abies*.

The earliest provenance trials for local sources of native species were established with *Picea* spp. in the 1930s and 40s, and for *Pinus banksiana* and *P. resinosa* in the 1950s (Anon. 1996). In the 1950s, Mark Holst initiated an ambitious program with *Pinus resinosa*, sending seed to other parts of North America and Europe for testing, in addition to establishing many experiments in Ontario. The program was abandoned when it became apparent that genetic variation was lower than for most other conifers (Steill 1994). In Eastern Canada the primary focus for early exploration and testing was *Picea* species with rangewide provenance trials established for *P. mariana*, *rubens* and *glauca*. Provenance trials including native and exotic *Larix* species were also established in eastern Canada.

Exploration, testing and breeding of *Pseudotsuga menziesii* began in the 1950s in British Columbia (Orr-Ewing 1962). Beginning in 1958, an arboretum was established with 216 *Pseudotsuga menziesii* sources from throughout its range in Canada, the US and Mexico. The objective was to provide as wide a gene pool as possible for a breeding program (Orr-Ewing 1973). Samples of the other five *Pseudotsuga* species were established in the arboretum as well. Subsequent testing and tree improvement projects in British Columbia included *Picea* spp, *Tsuga heterophylla*, *Thuja plicata*, *Larix occidentalis*, *Pinus contorta,* and *P. ponderosa*.

As in Canada, early efforts in the northwestern states of the USA were also focused on *Pseudotsuga menziesii* with the earliest work initiated by Hoffman in 1912 in Wind River Experimental Forest in southern Oregon (Duffield 1959). He set up the first seed source studies, but tree improvement programmes began in the 1960s. Because of the topography and associated high environmental variation over short geographic distances, many small breeding programmes were initiated. By the 1980s there were 125 separate breeding programmes for *Pseudotsuga menziesii* in Oregon, Washington and British Columbia (Johnson 2000). Other species have received much less attention in the Pacific Northwest but exploration, assessment and improvement programmes have been undertaken to varying degrees for species such as *Tsuga heterophylla*, *Pinus monticola*, *Pinus lambertiana*, *Picea sitchensis*, *Chamaecyparis lawsoniana*, and *Pinus contorta*.

Elsewhere in the US, the foundation for tree improvement was laid in the 1920s and 30s. The Placerville Institute of Forest Genetics in California was initiated in 1925 by James Eddy, as a private research centre dedicated to improving forest growth through breeding. The Institute was first focused on pines and 49 *Pinus* species from many regions were planted in 1926. The most complete pine arboretum in the world was established there in 1931. In 1935, the Institute was donated to the US Forest Service and it has been central in forest genetics research since that time (USDA Forest Service; accessed 03\02\09).

Phil Wakeley established a test in the southern USA in 1926 that included four provenances of *Pinus taeda* (Rogers and Ledig 1996). He also initiated a large study of geographic variation of four southern pine species (*Pinus taeda*, *elliottii*, *palustris*, *echinata*), which were planted in 66 test plantations across the southeastern USA in 1951 (Wakeley, 1954). This set the stage for most of the later genetics work with these species (Zobel 2005). In the early 1950's Bruce Zobel initiated a tree improvement programme in east Texas, focusing on drought resistance and wood properties (Zobel 2005). Tree improvement co-operatives were established in Texas in 1952, Florida in 1954 and North Carolina in 1956 and programmes developed rapidly during the rest of the century. Before 1960, there was no genetically improved seed available and all seedlings for planting were produced from woods-run seed, with little control over quality (Dorman 1974). By the mid-1970s, much of the seed used for tree planting in the southern USA was from genetically improved seed orchards.

Mexican forests encompass very high levels of biodiversity with high numbers of species and high variability at the sub-species level. Small tree improvement programmes are underway for nine native species: *Pinus patula*, *P. Douglasiana*, *P. leiophylla maximinoi*, *P. greggii*, *P. oocarpa*, *P. pseudostrobus, Taxus globosa*, *Cedrela odorata*, and *Swetenia macrophylla* (CONAFOR 2012). In addition, improvement programmes are underway for several non-indigenous species, including *Eucalyptus urophylla*, *Gmelina arborea* and *Tectona grandis*.

At least 25 North American tree species are used for forestry purposes and have been extensively tested in other countries (Rogers and Ledig 1996). An example of one such species is *Pinus radiata* which occurs only as five small populations in its natural range and has never been used for forestry in North America, however it is a very important timber species in other countries (Ref?). It was first introduced into Australia for ornamental plantings around 1857 (Wu, *et al* 2007) and its rapid growth led to its use in plantation forestry beginning in the 1920s.

Improving the understanding of intraspecific variation is recognized as important for the sustainable management of forest genetic resources. It is recognized that monitoring changes below the species level provides necessary information for ensuring that the species' adaptive potential is maintained so that species can evolve in response to changing environmental conditions. Ensuring that species can respond to environmental change is a priority for much of the forest genetic resources research conducted within Canada.]

Presently there are at least 150 "public" or cooperative breeding programs, representing over 70 species in the U.S. (Table 10). Many of these programs are part of the USDA Forest Service or are based at universities. The university-based programs tend to be cooperative breeding programs that are supported by government and industry partners, these include:

- NCSU Cooperative Tree Improvement Program (http://www.treeimprovement.org/)
- Western Gulf Forest Tree Improvement Program (http://txforestservice.tamu.edu/main/article.aspx?id=1687)
- Cooperative Forest Genetics Research Program (http://www.sfrc.ufl.edu/cfgrp/overview.shtml)
- Northwest Tree Improvement Cooperative (http://www.fsl.orst.edu/nwtic/)
- Inland Empire Tree Improvement Cooperative (http://www.cnr.uidaho.edu/ietic/)
- Minnesota Tree Improvement Cooperative (http://mtic.cfans.umn.edu/)
- University of Tennessee Tree Improvement Program (http://treeimprovement.utk.edu/home.htm)
- Hardwood Tree Improvement and Regeneration Center (http://www.htirc.org/)

There are also private companies that have forest tree breeding programs, including:

- Arborgen (http://www.arborgen.com/) primarily breeds *Pinus taeda, P. elliottii, Populus deltoids, Populus* hybrids, *Liquidambar styraciflua,* and *Eucalyptus.*
- GreenWood Resources (http://www.greenwoodresources.com/) breeds *Populus*
- Weyerhaeuser – (http://www.weyerhaeuser.com/) breeds *Pinus taeda, Pinus elliottii,* and *Psuedotsuga menziesii.*

Many of the companies involved with the university cooperatives have, in the past, run separate testing programs to step up gains from the cooperatives. This activity has declined with the advent of the vertically integrated companies spinning off their land holdings into Timber Investment Management Organizations (TIMOs) or Real Estate Investment Trusts (REITs) for tax reasons.

Practically all these breeding programs recognize the need to delineate breeding zones and typically have breeding populations for each zone or combination of zones. Effective population sizes of the cooperative breeding programs tend to be in the hundreds (Johnson et al. 2001), thus insuring that most of genetic variation is maintained; although rare low-frequency alleles could be lost. The numbers of clones used in seed orchards tend to be of sufficient size to maintain levels of genetic variation similar to native populations (Johnson & Lipow 2002).

The university-industry cooperatives all strive to increase growth rates and also look at health, disease resistance and wood quality. The federal programs stress adapted populations. For species that are under severe pressure from disease; disease resistance is the primary trait (e.g. chestnut, elm, and ash)."

From Mexico's country report: "Mexico has no national policy to study or develop an inventory of genetic variation in tree and scrub species, and mechanisms for monitoring the genetic loss and vulnerability of the species have not been established. However, through institutions such as the National Council of Science and Technology (CONACYT) and the National Commission

for Knowledge and Use of Biodiversity (CONABIO), which are federal agencies, some projects to determine the genetic diversity of forest species have been supported. These projects have been developed by educational and research institutions in the country. For example, CONABIO has funded 47 projects related to research studies on floristic inventories, analysis of species with economic potential, and useful species for reforestation (CONABIO, 2012). Existing pieces of work are mainly on forest species, which are categorised as at risk, and those with a restricted distribution. Genetic diversity of a few species of economic importance and wide distribution has been quantified, such as *religious Abies, Pinus patula, Pinus oocarpa, Pinus greggii, Pinus pinceana, leiophylla Pinus, Pseudotsuga menziesii* and *Cedrela odorata"*

South and Central America: Significant strides have been made in the past decade with respect to increasing level of knowledge of FGR in Latin America. In comparison with North America, Latin America lags in many respects, particularly for native tree species. However, participants at a regional FAO workshop in fall, 2012, indicated that knowledge of tree species introduced for commercial plantation forestry is sufficient and species level information is collected by means of national forest inventories.

A range of specialised knowledge exists, from the traditional use and management of FGR by indigenous and traditional communities to advances in molecular techniques and biotechnology for a number of species.

Many tree species that are important for timber and pulp are introduced in South America. In Chile, for example, the species used in tree improvement programmes are presented in Table xx. Tree improvement began more than 40 years ago with *Pinus radiata* but improvement for native species was not initiated until the 1990s.

Species	**Native or introduced**	**Purpose**	**Stage**
Pinus radiata	Introduced	Timber and pulp	3rd
Pinus ponderosa	Introduced	Timber	2nd
Pseudotsuga menzesii	Introduced	Timber	2nd
Eucalyptus nitens	Introduced	Timber	2nd
Eucalyptus globulus	Introduced	Timber and pulp	2nd
Populus spp.	Introduced	Timber	2nd
Nothofagus alpine	Native	Timber	1st
Nothofagus oblique	Native	Timber	1st
Nothofagus dombeye	Native	Timber	1st
Nothofagus pumilio	Native	Timber	1st
Laurelia sempervirens	Native	Timber	1st

Constraints with respect to knowledge of FGR in Latin America include:

- Insufficient number of professionals working on FGR themes
- Scientific studies about FGR are not focused on production or conservation needs for the countries or for society; also no clear link between studies and conservation actions.
- Forest companies are reticent to share information on technological advances
- The national inventories do not include indicators or parameters to evaluate FGR.
- The understanding of FGR of native species is generally insufficient.

Priorities for action include:

- Include priority and threatened species in reforestation plans and in education, communication and public awareness.
- Establish and or strengthen local networks around species of common interest to implement actions. Bring together scientific and traditional knowledge through projects that involve local communities in conservation of forest resources
- Generate projects and research initiatives with adequate funding that permit a connection between genetic studies and in situ and ex situ conservation activities in each country.
- Strengthen the public-private cooperation, considering involving society in general.
- Implement actions and develop indicators and common parameters or standards that are simple to apply, to evaluate FGR for use in national inventories.

Asia :A high degree of variation exists among countries in Asia with respect to capacity, education, species diversity, climate and other factors influencing what is known about FGR and what influences them. To illustrate, India has a programme in which genetic variability has been evaluated for 104 species. In contrast, in Nepal, genetic variability has been partially evaluated for 7 tree species. Species distributions are generally recorded through national inventories, and lists of threatened and priority species have been developed in a number of countries. On a project basis, some species have been studied thoroughly, including quantitative, molecular genetic and genomic analyses. In East Asia information genetic knowledge exists about the main planted species.

Constraints identified for South Asia –

- Inadequate knowledge on species distribution, biology, FGR
- (no baseline information)
- Inadequate capacity (training) to undertake genetic level research
- Insufficient infrastructure to carry out research and studies
- Narrow focus on a few selected species

- Lack of capacity and funds to carry out conservation and management
- Difficulty to access information
- Unavailability of FGR information in vernacular language
- Ethnic groups are usually conservative beyond the community
- Knowledge generation is weak

Priority actions:

- Carry out baseline studies and create species information database for distribution, habitat, biology, genetic variation
- Establish nodal action points for species to collate information and coordinate action
- Make species information available for different stakeholders at different levels, including in local languages
- Increase awareness of policy makers on the importance of FGR
- Exclusive outreach programmes on FGR needed
- Strengthen technical capacity of scientists by organizing research workshops on recent technologies and advancements and exposure visits
- Incentives, recognition, awards for scientists and foresters working in the area
- International organizations to support research coordination and integration of FGR into development framework
- Develop training materials for FGR
- Budget allocation

SE Asia

Constraints:

- Lack of information on species, distribution and genetic variation
- Still narrow focus on a few (country specific) valuable species
- Research is still localized and not extensive enough within countries and between countries.
- Land accessibility to complete trials and collect data.
- Lack of systematic monitoring
- Lack of government investment in knowledge of FGR program development
- No structure for FGR by country to share information, knowledge and ideas
- Knowledge of actions of forestry companies and groups in the country
- Cost of books and information on FGR (PROSEA) and access to resources.
- Knowledge lacking on the importance of FGR in adaption and climate change.

Priorities for action:

- Monitoring and evaluation of genetic erosion
- Set up a FGR committee (within country) across agencies to share FGR knowledge including policy and research activities and develop strategy.
- Generate knowledge on soci-economic, cultural and ecological value of FGR.
- Genetic variation in important species
- More tree improvement emphasis on valuable species (teak, eucalypts, pine)
- Training and education in FGR (including youth)
- Information management systems including websites
- Budget allocation

East Asia

Constraints:

- Information on genetic diversity/variation of many species still unavailable;
- Insufficient studies on FGR conserved in situ;
- Insufficient participation/involvement by local people in FGR activities
- Lack of storage and propagation methods
- Too many species to work on, need prioritization;
- Limited available information on biology of less-known species

Priorities for action:

- Strengthen national coordination of activities in FGR, e.g. information, researches, uses, etc
- Assessment/monitoring of genetic diversity of identified species with important and potential economic values;
- Awareness raising of government, public

Central Asia

Constraints:

- Lack of basic information on tree species, their FGR and the value of FGR
- Poor knowledge of current approaches, methods of research of FGR.
- Forest inventory lacking or does not have information about FGR.
- Lack of qualified experts and scientists
- Outdated or no equipment
- Funds
- Weak system of monitoring of FGR conservation.
- No list of priority species for gene conservation.
- Lack of information sharing among CA countries

Priorities for action:

- Training: university courses, modern methods in FGR conservation including post-graduate education
- Increase information about FGR of main forest tree species.
- Joint regional data base on FGR conservation.
- Seed zoning development.
- Allocation of budget funds.
- Include FGR in forest policy and improve legislation.
- (Training on) monitoring of FGR.

Overall, in Asia, there remain serious constraints to improving the level of knowledge of tree genetic resources. As in other areas, work has been primarily focused on a few, mainly commercial species, and basic biological, ecological and genetic information on most species is still lacking. Reasons identified by participants at a regional workshop organised by FAO in fall 2012 include:

- Lack of long-term funding
- Lack of coordination and information sharing between people and institutions working on the same species
- No systematic monitoring
- Research remains site-specific, localized, not comprehensive for a species
- Little knowledge about genetic conservation value of protected areas
- Limited knowledge about managing FGR for climate change adaptation and mitigation

- Inadequate technical and institutional capacity, including lack of trained staff to handle FGR
- Poor networking at national level among scientists to develop science on FGR
- Inadequate use of novel research methodologies in characterization
- Lack of infrastructure on research, storage facilities (specifically ex situ)
- No education programs to cover FGR in the forestry sector
- Training materials are outdated
- Lack of information available in local languages

Africa An enormous wealth of tree diversity exists in Africa. Trees are found in very different ecosystems ranging from dry parklands to dense tropical rainforests. As a demonstration of this heterogeneity, White (1983) recognized 10 regional centres of endemism in Africa (eight in continental Africa, two in Madagascar). The highest levels of tree diversity are found in tropical forests; for example, ca 500 tree species in a 50ha plot in Cameroonian evergreen forest (http://www.ctfs.si.edu/data/pdf/CTFSbook_PDF/KorupChapt.pdf) and ca 450 tree species in a 4 x 10 Ha plot in Congolese semi-deciduous forest (http://www.ctfs.si.edu/data/pdf/CTFSbook_PDF/IturiChapt.pdf). Millions of people depend on the forest for basic necessities including, most importantly, fuel, food, medicine, fodder and shade for livestock, and many other products, including timber. According to the regions (regional centres of endemism) and their respective characteristics (climate, tree species abundance, etc;) there are sharp differences in the use of forest resources by people. For example, there is generally high pressure on species used for fire wood in dry forests and high pressure on a limited number of timber tree species in tropical forest. Despite the central role of trees for human populations, African tree species biology is largely unknown. In general, much more has been known about exotic tree species planted in Africa than the native species, although this is beginning to change with multiple studies on species such as *Prunus africana*, *Allanblackia floribunda*, *Parkia biglobosa*, *Vitellaria paradoxa*, *Erythrophleum ivorense*, *E. suaveolens*, *Baillonella toxisperma*, *Milicia excelsa*, *Distemonanthus benthamianus*, *Greenwayodendron suaveolens*, *Aucoumea klaineana*, *Santiria trimera*, *Pentadesma butyracea* and a few others.

African countries are facing numerous constraints for the management of their FGR. In national reports, lack of information on FGR was frequently cited as a problem and consequently as a constraint to the development of programmes for their conservation. Currently the sustainable management of FGR urgently needs scientific studies on, for example, regeneration capacity, reproductive biology, and adaptability to changing environments. The absence of knowledge can have dramatic consequences on species sustainability. For example, in the case of timber tree species of the Guineo-Congolian forest, ministries responsible for forest management provide information on species density that can be logged. Though these measures might actually provide a general framework for the conservation of forest genetic resources it is not based on scientifically-relevant information. In this context there is a common pattern shared by all African countries: a clear lack of capacity in terms of trained people, and insufficient facilities and financial to develop scientifically-based management of forest genetic resources. In general, these capacity gaps demonstrate insufficient investments by local governments. Moreover, the market value of FGR is often unknown. This is particularly true for non-wood forest products.

The number of species for which molecular genetic studies have been conducted is steadily increasing in many countries, for example, in the Guineo-Congolian region, about 10 native species have been the subject of genetic marker development (*Erythrophleum ivorense, E. suaveolens, Baillonella toxisperma, Milicia excelsa, Distemonanthus benthamianus, Greenwayodendron suaveolens, Aucoumea klaineana, Santiria trimera, Pentadesma butyracea, Pericopsis elata, Lophira alata, Entandrophragma cylindricum, Coffea canephora)*. Most of these are economically-important timber species and marker availability will allow characterizing the spatial distribution of their genetic diversity (which his important to establish conservation plans) as well as their reproductive biology (which provide necessary information to determine the minimum viable density of population). In this context, some forest logging companies have understood the importance of their contribution to scientific knowledge of logged species. They greatly favour scientific work by providing access to the field and access to inventory data. In turn, thanks to their help, scientists will be able to provide useful tools in order to improve the sustainable management of genetic resources. Logging companies have much to win from such collaborative framework as it is clearly an engagement for transparency and the obtaining of wood certification. But most of these recent developments were done in collaboration with North Hemisphere countries and the private sector generally without substantially developing African country capacities. For example, despite the importance of establishing molecular laboratories to study for example the genetic diversity of the species or to develop protocols of wood traceability there is not at present, a molecular laboratory available to work on tree species in Cameroon or DRC. This underlines the clear and urgent need for policies and economic investment in science in these countries.

The following tables present the main constraints and priorities for action in each African region. Interestingly, these constraints and priorities for action are very similar among regions.

Table 1. Constraints to generating knowledge by region in Africa identified at regional workshops in fall 2012.

Southern Africa	Eastern Africa	Central Africa	West Africa	North Africa and Near East
Information on FGR is inadequate, Scattered and not shared and non compatible formats	Inadequate knowledge on FGR Inadequate baseline data	absence of sub-regional database; Companies do not communicate genetic results to local communities; Insufficient (knowledge?) of traditional values of FGR	Information inadequate on biology and ecology of important forest trees and shrubs	Insufficient knowledge of FGR; no database; Lack of information on threatened species and urban or peri-urban species Lack of information of provenances
Inadequate capacity to assess genetic diversity and erosion at institutional and community level	Brain drain; Inadequately trained personnel	Absence of qualified human resources Vast extent of territory	Research and tree improvement capacity weak	Insufficient national expertise Limited or no research
Inadequate knowledge and effective enforcement on sustainable utilization of FGR including resource valuation, value addition etc	Insufficient legislation on FGR Inadequate knowledge on FGR /Information Gap Insufficient knowledge about the market value of FGR	Absence of statistical data and studies to evaluate the contribution of FGR to GDP Inventories are very old (dating from the 70s) and low coverage; Lack of political will		Forest inventories incomplete and old or absent.
(Lack of) Research institutions /Centre of Excellence with adequate facilities to undertake research coordinated both at national and regional levels		Absence of platform to exchange information		Insufficient exchange and capitalization of knowledge and information
Adoption of new emerging technology / techniques / tools for Research in FGR				
Low institutional capacity human, equipment and infrastructure relevant to FGR	Funding; Lack of Infrastructure & latest equipments; Inadequate qualified trainers on FGR	Fianancial and technical means are insufficient; Seed centres not autonomous and equipment is not sufficient; Botanical gardens and arboreta are not maintained		Limited Resources Lack of coordination between institutions

Table 2. Priorities for action to improve FGR knowledge by region in Africa identified at regional workshops in fall 2012.

Southern Africa	**Eastern Africa**	**Central Africa**	**West Africa**	**North Africa and Near East**
Needs assessment and gap identification (for species?)	Genetic Studies on Endemic /Native species including Red List	Study the contribution of FGR to GDP; Integrate the needs and priorities for improved understanding of FGR in "EDF" published by COMIFAC		Improve access to information Review/revise the list of threatened and endangered species
Promote inventory/monitoring and surveys using standardised methods	Survey/Inventory including Maps for FGR	Promote forest inventories that take into account FGR Develop indicators specific to species and ecosystems of Central Africa for sustainable management of FGR Map FGR		Carry out and/or update forest inventories
Systematic and compatible documentation system	Invasive Alien Species map to study and determine alien species invasion.	Develop a database for FGR in Central Africa	Improve availability and access to information on FGR by developing a regional database on ecology, botanic and ethno-botanic information on forest trees and shrubs of the region.	Put in place a system to coordinate at the national level Establish a coordination unit and capitalise on knowledge
Promote networking and collaboration		Elaborate a sub-regional report on the state of FGR	Support development of networks and regional data base as a tool to support education, research and improve the knowledge on forest species	Develop a platform for information sharing
Trained personnel at all levels	Capacity Building			
Better equipment and tools			Strengthen the herbarium capacity	
Increase awareness at community level		Share and popularise information on value of FGR		
Establish national and regional centres of excellence and	Research	Encourage forest research activities; Improve understanding of inter and		Develop research on genetic diversity and FGR

Southern Africa	**Eastern Africa**	**Central Africa**	**West Africa**	**North Africa and Near East**
strengthen existing research institutions		intraspecific diversity		
Identify and promote new and emerging technologies/tools for research in FGR				
Establish and strengthen existing training institutions with FGR relevant curricula				Teach and recruit specialists in FGR
		Document local knowledge on use and management of FGR in relation to NTFPs	Make assessment of traditional knowledge on use and management of FGR to improve the knowledge base on forest trees and shrub species and taking into consideration the ethnobotany dimension;	

Pacific and Oceania: In Australia there are approximately 2500 tree species and about 200 of them are of current commercial significance, either in Australia or overseas. Australian FGR has global use; trees of several Australian genera (*Eucalyptus*, *Acacia*, *Grevillea*, *Casuarina*, *Melaleuca*, *Macadamia*) are grown extensively overseas for a variety of commercial wood products, fuel, food and soil conservation uses. The Australian Tree Seed Centre (ATSC) has supplied more than 200,000 certified

seedlots from over 1000 tree or shrub species to researchers in over 100 countries since the early 1960s. This implies a basic knowledge of all of these species.

In the Pacific Islands, tree planting is mostly carried out using non-native tree species. Priority species have been identified for their cultural and commercial significance. Lack of understanding of FGR, lack of expertise to fill the training gap, and a lack of training in biology and ecology of endangered species were cited as constraints to conservation and management of FGR. Identified needs specific training for forestry officers on tree breeding and improvement and promotion of awareness of the importance of genetic resources especially at the community level.

Conclusions and recommendations

All countries reported an inadequate public awareness of FGR – thus an impediment to generating new knowledge to alleviate the woeful information gaps, is lack of general understanding of its importance.

1. Knowledge of FGR is reported to be inadequate for well-informed policy or management, in most countries.
2. Among the 80 – 100,000 tree species, a small proportion has been studied to describe genetic parameters (less than 1%) although both the number of studies and the number of species studied has increased significantly in the last decade.
3. Most studies conducted during the past two decades are at the molecular level, either using DNA markers or genomic technologies to characterise genetic resources; the quantity of information at the molecular level is accumulating much faster than whole-organism information, with the consequence that little of the accumulating knowledge has direct application in management, improvement or conservation.
4. A few species are very well studied and genetically characterised, based on both molecular and quantitative studies. These are mainly temperate conifers, Eucalyptus, several Acacias, teak, and a few other broadly adapted, widely planted and rapidly growing species.
5. Quantitative genetic knowledge has led to significant productivity gains in a small number of tree species that have high value as plantation timber.
6. Genomic knowledge of forest trees lags behind that of model herbaceous species, including the important agricultural crops, but the entire genome of several tree species has been or is in the process of being sequenced and novel approaches have been developed to link markers to important traits. Genomic or marker assisted selection is close to being realised but phenotyping and data management are the biggest bottlenecks.
7. Progeny and provenance trials established for many species in many countries were abandoned as funding and interest switched to molecular approaches. Existing but dispersed data should be assembled, maintained and evaluated for potential to inform seed zone delineation, plans for assisting gene flow in response to climate change, identification of propagation material for restoration and conservation efforts for high-value populations.
8. Many of the species identified as priorities, especially for local use, have received little or no research attention, indicating a need for associating funding to priority setting

exercises. This should be a starting point for expanding knowledge, particularly about genetic control of and variation in valuable traits.

Chapter 6. Needs, challenges and required responses for the future

Introduction

The country reports on the State of Forest Genetic Resources Forest covers about 31 percent of the world's total land area with 93 percent being natural forest and only 7 percent planted. Estimates of the number of tree species vary from 80 000 to 100 000. Forest ecosystems remain essential refuges for biodiversity, and 12 percent of the world forest land is designated primarily for the conservation of biological diversity. Approximately 14 million people worldwide are formally employed in the forestry sector. Many more depend directly on forest and forest products for their livelihoods. In developing countries, wood-based fuels are the dominant source of energy for more than 2 billion poor people. In Africa, over 90 percent of harvested wood is used for energy. Wood is not the only resource taken from forests, about 80 percent of people, in developing countries, use non-wood forest products to meet their health and nutrition needs and for income.

The contribution of forests and trees to meeting the present and future challenges of food security, poverty alleviation and environmental sustainability depends on the availability of rich diversity between and within tree species. Genetic diversity is needed to ensure that forest trees can survive, adapt and evolve under changing environmental conditions. It also maintains the vitality of forest and provides resilience to stresses such as pest and diseases. Furthermore, genetic diversity is needed for artificial selection, breeding and domestication programmes for the development of adapted varieties or to strengthen useful traits. In many countries, the prospects for sustainable development in rural areas will be greatly influenced by the state of diversity in forest ecosystems and species.

Efforts to sustainably manage FGR at international as well as at national levels need to rely on solid and coherent baseline information. The country reports on State of Forest Genetic Resources as developed following the FAO guidelines are the main source of comparable information. They constitute the basis for the identification of the priority areas for actions on FGR at national regional and international levels. Four priority areas for actions have been identified to cover the major concerns raised in country reports and further stressed during the regional consultations on the State of Forest Genetic Resources organised for Central Asia countries in Dushanbe (Tajikistan), for South East Asia countries in Kuala Lumpur (Malaysia), for Near East and North Africa countries in Tabarka (Tunisia) , for Latin America countries in Santiago (Chile), for the Pacific countries in Nadi (Fiji), for West Africa countries in Ouagadougou (Burkina Faso), for East and Southern Africa countries in Nairobi (Kenya). The identified four priority areas are stated as follow:

- Improving the availability of, and access to, information on FGR
- In situ and ex situ conservation of FGR
- Sustainable use, development and management of FGR
- Policies, institutions and capacity building
- The common needs and priorities for actions found in the country reports, were discussed and recommended during the regional consultations and further amended by the Intergovernmental Technical Working Group of the CGRFA. These Strategic Priorities are presented in the section developing the four Priority Areas

Specific features justifying the Strategic priorities

- Most forest tree species are wild, managed in natural ecosystems, or are at a very primitive stage of selection or domestication as compared to agricultural crops
- Forest tree species are typically long-lived, highly heterozygous organisms, which have developed natural mechanisms to maintain high level of intraspecific variation, such as a high rate of out crossing, and dispersal of pollen and seeds over a wide areas. These mechanisms, combined with native environments that are often variable in both time and space, have contributed to the evolution of forest tree species into some of the most

genetically variable organism on earth22. In situ conservation allowing dynamic maintenance of the genetic diversity and processes is the preferred approach for forest species, while ex situ conservation most commonly used for domesticated plant species.

- Trees have multiple functions by providing numerous products and services about 80 percent of people in the developing world make use of non-timber forest products for health, nutrition and income purposes.
- Quantifying the value of the benefit derived from FGR is difficult for several reasons. Apart from timber, most forest products are harvested for local consumption or commercialized without proper national monitoring and documentation. This is particularly the case in developing countries.
- In term of their present or potential contribution to food security and environmental sustainability, FGR are underutilized and undervalued.
- Knowledge of FGR is usually scattered and detained by different institutions in unpublished reports, with limited access in most countries. Baseline information, such as country species checklists, species distribution maps and forest reproductive material catalogues, are lacking.
- The number of known forest tree species exceeds 80 000, but current efforts in member countries to test and improve forest species focus on approximately 450 species.

6.1. IMPROVING THE AVAILABILITY OF, AND ACCESS TO, INFORMATION ON FGR

It is recognized that reliable data on forest status and trends are of great importance to the efficient management of FGR. However, available forest-related information largely relates to forest resources in general rather than to forest diversity and variation within tree species. Availability of specific information on the status and trends in FGR is today inadequate, although some progress has been made at national and subregional levels during the last decade.

Availability of, and access to, quality and updated information on FGR is reported to be poor in many countries. Most Country Reports highlight the need to promote awareness among decision-makers and the general public, of the importance of FGR and their roles in meeting present and future development needs. Lack of information limits the capacity of countries and the international community to integrate FGR management into cross-cutting policies.

Gaps in information related to FGR reported in the country reports include the following:

- lack of an updated species check list;
- lack of an accurate global picture of the status and trends of FGR;
- lack of a comprehensive assessment of national and international capacities to manage FGR;
- lack of an accepted methodology for directly linking general information on changes in forests to their impacts on biological diversity, species, (provenances), populations and genetic variation.

- lack of knowledge on reproductive and development characteristics of forests species, allowing for ex situ conservation, effective production of seedlings, planting and development of such species outside their original habitats.
- loss of traditional knowledge and beliefs leading to decrease in valuing genetic resources of indigenous species.

These deficiencies complicate global monitoring of the status and trends of FGR and limit capacity for effective decision- making and action at national and international levels.

In many countries, there is an important relationship between the use and management of FGR and traditional knowledge. This valuable knowledge supports the livelihoods of indigenous and local communities in many countries, while representing a tremendous asset for industrial and trade development in sectors such as cosmetics, pharmacy, food technology and bio-pesticides etc. Further more traditional knowledge can make a significant contribution to sustainable development through practices such as local conservation and sustainable use of plants and can contribute to efforts to solve serious global problems such as climate change, desertification and land and water degradation. Policies on FGR information management should therefore take these important roles into consideration. Traditional knowledge is under threat as a consequence of FGR degradation and changes in land use and socio-cultural practices.

Establish and strengthen national FGR assessment, characterization and monitoring system: Information on FGR is inadequate or barely available in many countries. National forest inventories do not usually include the relevant concerns for the planning and sustainable management of FGR. In many countries the lack of updated forest species list and species distribution maps represents a serious constraint to the development of proper FGR management plans and activities. The capacity of many developing countries to conduct botanical inventories, manage national herbaria and genebanks are rather weak due to the limited number of plant taxonomists, forest geneticists and lack of adequate technical infrastructure. Objectives of forest inventories should include updating species list and developing species distribution maps as these are information necessary for developing sustainable forest genetic resources management plans.

Genetic resources including forest is regarded by scientists and the international community as one of the major opportunity for mankind to coop with important challenges such as the increasing demand in food, energy, wood products, and environment services etc. Baseline information on the status, trends and characteristics of FGR is needed in order to identify priorities for actions to achieve sustainable use and conservation, as well as the **development of tree domestication** and improvement programmes.

Traditional knowledge related to use and management of forest resources should be regarded as an integral part of the resources and adequately reflected in technical programmes and policy documents.

Traditional farming and natural resources uses and management, including forest genetic resources are based on long established knowledge and practices that help to ensure food and agricultural diversity, valuable ecosystems, livelihoods and food security. However, traditional livelihoods and indigenous plant varieties, landraces are now increasingly endangered by large-scale commercialization of agriculture, population dynamics, land-use/cover changes and the impacts of climate change.

The importance of **Traditional knowledge** lies in its contribution to the welfare of indigenous and local populations in many developing countries. These facts are increasingly acknowledged in various reports and publications which highlight the use of forest and wild plants to meet the basic needs (food, medicine, shelter, etc.) of the rural communities. It contributes to sustainable development through practices such as local conservation and sustainable use of plants. It can also contribute to solving serious global problems such as climate change, desertification and land and water degradation. There is therefore a need to preserve traditional knowledge of FGR by developing national assessments and improving documentation.

The State of the World's Forest Genetic Resources provides the first global overview of the diversity, status and trends of FGR and of national regional and global capacity to manage these resources. Many Country Reports indicate that there are important gaps in knowledge of FGR and that information at country level is scattered and difficult to access. There is therefore an urgent need to improve access to information on FGR for all stakeholders by promoting the establishment and reinforcement of FGR information systems including databases to store and share available scientific information and traditional knowledge on uses, distribution, habitats, biology and genetic variation of species and species populations**.** The use of common protocols for FGR inventories, characterization and monitoring should be promoted to ensure that data collected from different countries are comparable.

6.2. IN SITU AND EX SITU CONSERVATION OF FGR

The development of a worldwide conservation strategy for FGR is based on the need to maintain the adaptive and neutral genetic diversity of forest trees and shrubs. This goal can be met by applying *in situ* conservation methods based on individual tree species distribution ranges.

Regional collaboration through species or thematic networks should play an important role in implementing in situ conservation strategies for forest genetic resources and monitoring the progress made. This collaboration should aim at addressing the issue of in situ FGR conservation while taking into consideration the use of ecosystem approach as well as different forest and tree management types and the different levels of genetic conservation.

In situ conservation often comprises ecosystem functions and species interactions, rather than individual tree species. In addition forest have a number of native trees and shrubs that may be of minor interest to forest managers, but may be highly valuable in terms of genetic resources and future use. It is therefore important that the above described forest and trees management types includes specific products and indicators related to sustainable forest genetic resources management in their regular monitoring protocols.

In the current context of increasing pressure on forest land and forest resources, primary forests and protected areas remain refuges for threatened FGR. An important proportion of wild and/or endemic plants occur only in primary forests and protected forest areas. Genetic structure of species natural populations is best conserved in those forests. Natural processes involved in the dynamics of FGR resources are better assessed and understood in protected natural forests, which remain the best laboratories for studying species ecology and biology.

Among the constraints identified by countries, the following should be highlighted:

- 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 and market demand for timber
- Lack of or insufficient integration of FGR issues into current wider national policies and laws, impacting on FGR.
- Climate change reducing regeneration of conserved species; causing range shifts of species and vegetation communities due to shift in climatic zones.
- Lack of knowledge on genetic resource and processes, and gene-ecological zones, including of those assets already in conserved *in situ*
- Concentration on charismatic, priority species at expense of conservation of other indigenous and traditional species
- Lack of knowledge of relevant policies, laws and regulations on the part of stakeholders, including those charged with law enforcement

Protected areas are suitable for the conservation of viable forest tree populations of diverse species and of representative ecosystem samples, as well as for maintaining vital ecosystem services. They have a primary objective of ecosystems and biodiversity conservation and serve as a refuge for forest species which are unable to survive in intensely managed landscapes. The surface of protected areas have been increasing over the last decades as a result of national and international efforts to preserve biodiversity. This protection is implemented under many management types and categories including strict nature reserves, national parks, habitat/species management area, protected landscape, Protected area with sustainable use of natural resources (Dudley, 2008). National programmes for the sustainable use and management of FGR should therefore take the important roles of protected areas into account, although most of them may have been initially design for purposes such as wildlife protection, recreation and various ecosystem services.

Marginal and/or range limits tree species populations may be key in providing adaptation to the novel environmental extremes that are expected to occur as a result of rapid climatic change. It is necessary to understand the dynamics of marginal forest species populations through adequate examination of adaptive genetic variation in quantitative traits. Furthermore conservation in the current climate change context requires accurate estimates of the positions of future extreme environmental conditions (range limits). Modeling of species distribution dynamics needs to account for changes in species' distribution areas and in those of their associated environment correlates (e.g. pollinators) and also the possible influences of interactions with other plant or animal species.

Adequate *in situ* conservation measures are needed to preserve the natural growing conditions of the tree species in order to study and better understand their evolutionary process and adaptation to changes. Information from *in situ* conservation activities for marginal and/or range limits populations will be essential in providing options for adaptation to climate change.

On-farm management of FGR, including agroforestry systems, is identified as one of the important land use types that contribute substantially to *in situ* conservation of FGR, particularly domesticated or semi-domesticated species (e.g. the agroforestry parkland system in West Africa). Many priority species identified in Country Reports from semi arid zones are trees growing on farmlands, including agroforestry systems. Most of them are indigenous species that have been traditionally managed by farmers for centuries. Tree diversity in farmland varies from a few species in some countries to more than 100 in some others. Some of these species are semi-domesticated species that occur only in agroforestry systems (eg. *Acacia Senegal*, *Vitellaria paradoxa*,). Sustainable management of the agroforestry systems is therefore needed in order to conserve the genetic resources of the species.

It appears from the country reports on the state of forest genetic resources that the number of species mentioned as country **priority species** varies from nearly 300 (e.g. 287 for Brazil) to less than 10 (eg. 2 for Norway). Given the high number of tree species recorded as priority worldwide as mentioned, about 2500 recorded from 80 country reports, it is clear that prioritization among the many alternative species should be encouraged for more efficient action at national regional or international levels. Priority setting is complicated greatly by the lack of basic information on the variation, variation patterns and potentialities of many tree species. Understanding and developing FGR using a species approach is regarded as adequate and useful option. Updated information on forest species of the country, their uses and level of threats are good bases for sound identification of country priority species for actions. Priority species can be identified at the national, sub-national levels and shared in existing regional and international fora so as to provide better focus and more efficient resource use.

The general aim of priority setting is to compare the consequences and trade-offs of a range of actions. It implies that some areas, species or genetic resources will be given lower priority than others. When different stakeholders have similar priorities, concerted action on the part of these stakeholders is possible. When their priorities are dissimilar, independent but harmonized action is more likely to succeed. It is likely that among governmental, non-governmental and international organizations active in forest biological diversity and genetic conservation, substantial differences will exist in terms of priorities, as well as in terms of their capabilities to implement various management techniques. Where such differences exist, it will be necessary to form coalitions for action, operating under coherent frameworks and at appropriate levels.

Commitment at national and local levels to specified objectives and priorities is a prerequisite for the implementation of sustainable conservation programmes. Governments have worked towards ensuring a wide ownership of their Country Reports by organizing stakeholder workshops to review and validate the reports. During regional consultations in the Near East and North Africa, West Africa, Central Asia, Asia, Pacific, Central Africa, East and Southern Africa and Latin America, regional priorities for action were identified. In many cases regional priority species were discussed. However, the process needs to be continued in order to define the detailed actions for each species and to allocate responsibilities among actors and partners at national, regional and international levels.

Ex situ Conservation. In a growing number of situations in situ conservation of FGR is no longer possible in particular due to climate change effects. As a consequence, conservation strategies should include the creation of in situ and of ex situ conservation units. However countries are often lacking adequate policies and programmes addressing the needs for in situ and ex situ conservation of FGR. Given the large number of stakeholders involved in many ways, in the use, development and management of FGR at national levels, it is useful that national strategies and programmes are developed to provide an appropriate framework of action.

The ecosystem approach is a way to manage entire ecosystems in a holistic manner without excluding other management and conservation approaches such as area-based management tools and single-species conservation practices. Ideally all these approaches should be integrated, through regional networks when appropriate.

Regional strategies for conservation of forest genetic resources, including regional networks of *in situ* genetic conservation units and corridors of priority species are needed to ensure the dynamic conservation of key forest genetic resources and their evolutionary ability for the future. Definition and implementation of regional conservation strategies provide a good justification for coordination and collaboration at regional level. Investment in joint activities regional level may often be more efficient and cost-effective than the multiplication and duplication of activities at national level.

6.3. SUSTAINABLE USE, DEVELOPMENT AND MANAGEMENT OF FGR

The challenge of achieving food security for all and environment sustainability in the context of the combined effects of climate change and the increasing human pressure on forests is greater now than it has ever been. More efficient use and management of available forest resources is therefore needed, especially in tropical and less-developed countries, in order to meet the growing demand for forest goods and services.

To ensure sustainable management of forests, the genetic resources of forest trees must be conserved and developed, whether they exist as trees in planted forest, in natural forest or protected conservation stands, or as seeds or tissue cultures in storage. Managing FGR involves developing overall strategies, applying specific methodologies, developing and applying new technologies, and coordinating local, national, regional and global efforts.

Monitoring forest biological diversity and managing FGR requires reliable information on the status and trends of these resources. There are no common standard methods for measuring changes in the status of FGR in relation to sustainable forest management as undertaken in most countries. Parameters commonly included in national and global forest resources assessments, such as forest area, species occurrence and richness and forest fragmentation, are not on their own able to provide information on FGR. Adequate and commonly agreed **indicators** are needed and should be integrated into the national forest assessment policies and monitoring tools.

Countries reported that large plantations areas are being established to serve many purposes, including the production of timber biofuel and fibres and the provision of various environmental services such as reclamation of degraded land and soil and water management. However many countries lack adequate forest **seed supply systems** and therefore face difficulties in getting the quantities and quality of forest reproductive material needed to implement their plantation programmes. This jeopardizes the success and performance of plantation programmes in these countries. Collaboration between tree seed centres should be enhanced, to encourage development and use of common quality seed standards**,** to facilitate forest reproductive material exchange within regions and support national afforestation programmes.

The current growing concern about climate change and its effects on ecosystems and on performance of forest-related production systems, challenges stakeholders in FGR management to better understand forest species mechanisms for adaptation to current and future climate changes. Genetic diversity is needed in order to ensure that species can adapt, as well as to allow for artificial selection and breeding to improve productivity. Thus genetic diversity, including diversity among species, is the key to the resilience of forest ecosystems and the adaptation of forest species to climate change. Countries should therefore develop adequate effort to **Support climate change adaptation and mitigation through proper management and use of FGR.**

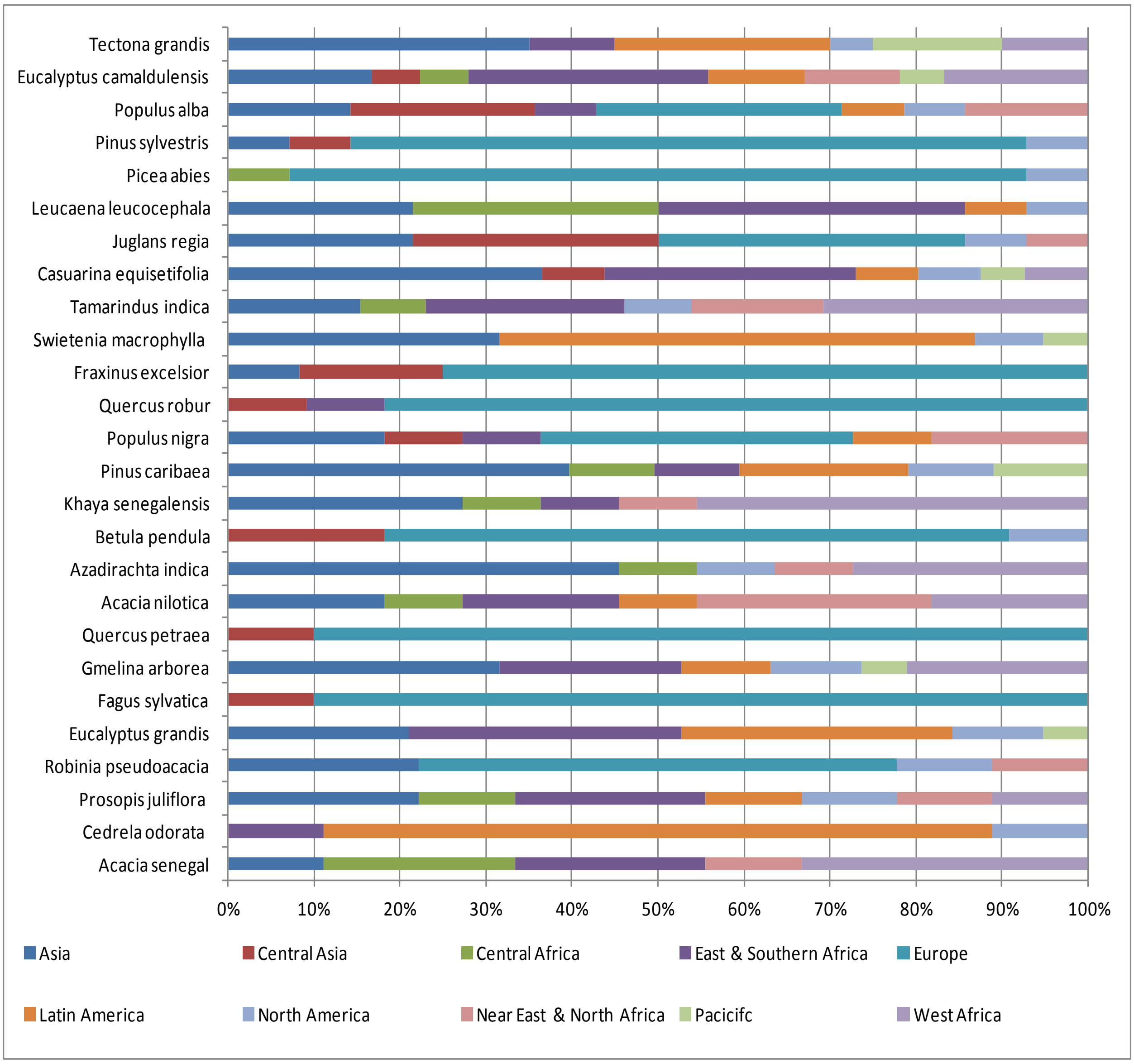

Figure 9: Most common priority species mentioned in country reports

Along with climate change, invasive alien species are increasingly being reported as major threats to FGR. These threats come from plant species, which have the capacity to invade natural and/or slightly disturbed forest associations and become predominant, often displacing whole ecosystems and species. Pest and diseases affecting forest and trees are predicted to become an increasing threat as the effects of climate change become more prominent and the movement of plant material across countries and continents accelerates.

Tree improvement activities remain limited to a few economically important tree species, not only because of the financial constraints but also because of the time necessary to obtained tangible results, due to the fact that trees are long lived perennial species, with long regeneration cycles and late sexual maturity. Because of these characteristics, improvement and breeding research in tree species require more time than is required for the equivalent activities in other crops. New technologies, such as genomics and micro-propagation, can help accelerate the selection process and unlock the huge potential of forest trees species. The **use of these new technologies** has proved to be useful for understanding forest ecosystem dynamics, including species genetic processes. They can provide options on practical measures for sustainable conservation, management, restoration and rehabilitation".

These new technologies have proved to be useful for understanding forest ecosystem dynamics, including genetic processes. They can orientate appropriate practical measures for sustainable conservation, management, restoration and rehabilitation".

Adequate **effort on domestication and bioprospection**, by taking advantage of the large potential of FGR can substantially contribute to sustainable development through diversification in food and other economically valuable commodities. In addition to timber, forests provide many other commodities that are important to local communities and to national economies. The importance of medicinal plants, fodder and food plants is increasingly recognized and strongly reflected in many Country Reports. In many developing countries, a large portion of the population makes use of medicinal plants for their health care. Free grazing is still a common practice in many developing countries, and forests are often an essential source of fodder. These various resources are still harvested from wild plants in forest lands and in some cases are under threat due to over-exploitation.

Domestication of such plants will improve the supply of the targeted products while reducing the vulnerability of their genetic resources. Many countries particularly from the tropics underlined the need to develop domestication programmes with the objective to improve the supply of various forest products including non wood forest products. Among the top twenty five most common species identified as priority for actions by the country are *Acacia senegal, Juglans regia* and *Tamarindus indica* which are managed for their non wood forest products. Figure 9 below shows the species coming on top as the most commonly identified priority species in the country reports.

6.4. POLICIES, INSTITUTIONS AND CAPACITY BUILDING

In many cases, national policies and regulatory frameworks for FGR are partial, ineffective or inexistent given the fact that FGR is not commonly well understood and properly dealt with in many countries. The concerns on sustainable forest genetic management such as in situ conservation of species and species populations are usually lacking or inadequately addressed by most country. Awareness building at all levels will be a key prerequisite action towards mobilizing popular support and international collaboration for the implementation of the Strategic priorities for Action. Appropriate advocacy tools need to be developed to ensure effective communication and information sharing related sustainable FGR management and uses.

There is an increasing demand for forest products including round wood, fire wood and non wood forest products (NWFP) in many countries. Country data reported in the Global Forest Assessment 2010 showed that the value of NWFP is some times higher than round wood and firewood when information in available. Sound social and economic policies are needed at national and global levels to ensure integration of FGR in wider national forest policy frameworks and global initiative such as FRA for sustainable management of FGR.

Technical and scientific capacities on FGR were reported by many countries as weak. University training curricula on issues such as FGR conservation, tree breeding and management of NTFP are rarely available in many countries. Research and education needs strengthening in all areas of management of FGR in most countries in particular in developing countries and countries in economic transition. Establishing, strengthening and maintaining research and education institutions is key to building national capacities to plan and implement priority activities for sustainable use, development and conservation of FGR.

Transfer and exchange of Forest Genetic Material are regulated under international agreements, which, in some cases, can limit access to proper quality material and subsequently prevent research programmes from delivering results that are likely to have a real impact. It is also regarded by development actors as a constraint to accessing quality genetic material even for countries sharing the same ecological conditions. It was therefore recommended during most of the regional consultations to promote and apply mechanisms that will facilitate access of material for scientific work within regions as well as to encourage regional networking for exchange of FGR material, in compliance with national legislation and international regulations.

Institutional strengthening, training and support to research, are needed for countries to be able to respond to pressing and increasingly varied needs in conservation and FGR management. This includes promotion of training and research at national and international level in aspects related to recent development on Forest Genetic Resource Management. The role of National Research Systems and programmes including Tree Seed Centers and their support by the CGIAR system is crucial in this context.

Many developing countries have a decentralized country administration or are undergoing decentralization process. Natural resources, including FGR, management should therefore be considered in this perspective for these countries. In some cases regulations measures are decided at province or state level. There is therefore a need to provide appropriate technical support to decentralized administrations in the countries to review or develop policy tools that ensure sustainable use and management of FGR, including protecting, preserving and sustainably using FGR for maintaining customary use by indigenous and local communities.

In the context of scarce resources and a great risk a duplicating the same activities at national or regional levels, efforts should be made to promote collaboration, partnership and coordination at national, regional and international levels when appropriate and to mobilise the funding required to ensure that the strategic priorities on FGR are successfully translated in to actions by the stakeholders. Collaboration at national level should particularly aim at creating synergy between FGR related international progmmes and conventions (CBD, UNCCD, Climate change, ABS, FRA, NFPs), coordinated by different national authorities, to enable efficient information sharing and resource use and for a better support of the national priorities identified on FGR. Furthermore most country reports and participants during the regional consultation highlighted the need to promote thematic networking to facilitate linkage between stakeholders, and enhance institutional development and capacity-building.

In summary the following needs should be addressed to adequately support countries policy, institutions and capacity:

- Update and Integration of FGR conservation and management needs into wider national policies and programmes frameworks of action at national, regional and global levels
- Develop collaboration and promote coordination of national institutions and programmes related to FGR
- Establish and strengthen educational and research capacities on FGR to ensure adequate technical support to related development programmes
- Promote participation of indigenous and local communities in FGR management in the context of decentralization.

- Promote and apply mechanisms for germplasm exchange at regional level to support research and development activities, in agreement with international conventions
- Reinforce regional and international cooperation to support education, knowledge dissemination, research, conservation and sustainable management of FGR
- Encourage the establishment of networks activities and support development and reinforcement of international networking and information sharing on FGR research, management and conservation
- Promote public and international awareness of the roles and values of FGR
- Strengthen efforts to mobilize the necessary resources, including financing for the conservation and sustainable use and development of FGR

REFERENCES *(to be completed)*

ABBREVIATIONS AND ACRONYMS *(to be completed)*

GLOSSARY *(to be completed)*

BOXES *(to be completed)*

TABLES*(to be completed)*

FIGURES*(to be completed)*

ANNEXES (ON CD-ROM) *(to be completed)*

1: Country Reports

2: List of priority species mentioned in country Reports and related conservation and management activities

2: Regional synthesis

3. Thematic studies

4. List of authors reviewers and affiliations