

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 adaptation. 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 using the scarce, available resources. 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 needed for adaptation to climatic regimes different to those in which they 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.

This State of World Report on Forest Genetic Resources FGR (SoW – FGR) addresses the conservation, management and sustainable use of forest tree and shrub genetic resources of actual and potential value for human wellbeing in the broad range of management systems (see Table 1-Main types of forest and tree resources management)/ The definition of forest used in FIO's global forest resource assessment 2010 is *land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10% or trees able to reach these thresholds in situ*. Palms and bamboo forests are included if these criteria are met, as tree-like monocotyledons such as palms, including climbing rattans, and bamboos, have generally been considered as FGR, and the responsibility of forestry agencies. Whilst the main focus of this SoW-FGR 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.

1.1 Attributes of FGR

1.1.1 Definitions of FGR, FGR conservation and related terms

Forest Genetic Resources (FGR) refers to the actual or potential economic, environmental, scientific and

5 societal value of the heritable materials maintained within and among tree and other woody plant 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 1451 cases of species used in plantations whose origin was identified, 1240 or 85% were used as exotic and only 211 or 15% were use as native, demonstrating the paramount importance of a small number of exotic, widely-planted, 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.

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: <ul style="list-style-type: none"> • 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

15 **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). PGRFA 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 agroecosystems (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.

In 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 DN! is always inherited biparentally from the male and

female parent, organellar DNA may have different modes of inheritance. Chloroplast DNA is 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
5 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.*
10 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-
5 populations, coexisting 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
10 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, 2001ab; FAO, FLD, IPGRI 2004; Heywood and Dulloo 2005). **In situ conservation** refers to the conservation of ecosystems and natural habitats and the maintenance and recovery of viable
15 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
20 (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**
25 **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 2004).

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
30 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 CO₂ levels, habitat fragmentation, increases in and new pests and diseases, competition with invasive exotic
35 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
40 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.

5 **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
10 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

15 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
20 (e.g. Whitham *et al.* 2006 and references contained therein).

Differences between trees and other organisms

Chromosomes and DNA

25 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
30 *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
35 *et al.* 2007; Parchma *et al.* 2010). Whilst polyploidization or whole genome duplication is rare in animals and conifers¹, 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

¹ Polyploids in conifers include *Sequoia sempervirens* (hexaploid) and *Fitzroya cupressoides* (tetraploid) – see for a review of polyploidy in gymnosperms see Ahuja (2005)

lineages including families with important FGR such as the legumes (Fabaceae) and provided a major diversifying force in angiosperms (Soltis *et al.*, 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 (Conside *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 poplar², 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 (*Lagarostrobos 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*); >

² *Populus trichocarpa* has been determined to have 41,335 loci containing protein-coding transcripts (<http://www.phytozome.net/poplar>; accessed 9 March 2013).

2000 years – western juniper (*Juniperus occidentalis*), Huon pine (*Lagarostrobos franklinii*), Rocky Mountain bristlecone pine (*Pinus aristata*), foxtail pine (*P. balfouriana*), coast redwood (*Sequoia sempervirens*); and > 1000 years – Nootka cypress (*Chamaecyparis nootkatensis*), sugi (*Cryptomeria japonica*), Rocky Mountain juniper (*Juniperus scopulorum*), alpine larch (*Larix lyalli*), whitebark pine (5 *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 10 1994 of the Wollemi pine (*Wollemia nobilis*), in a valley near Sydney, eastern Australia and presumed to be the last remnant³ 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*).

15 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 20 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.

25 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 30 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 35 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

³ 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.

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 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 rates⁴ 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'onnell, 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).

40 1.1.3 Types and complementarities of FGR conservation

⁴ 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 _awa 1987- Olng'otie 1991-Sebbenn 2000-Stacey *et al.* 1996; Ward *et al.* 2005.

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 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 wellresourced 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 (SP 11).* 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 situ* 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 many species in 36 European countries has been undertaken through _iversity's European Information System on Forest Genetic Resources (EUFGIS), including through creation of a network of a national network of FGR inventories and development of minimum requirements for dynamic conservation units of forest trees.

2. *Large scale, long term ex-situ conservation in seed banks for tree species with orthodox seed storage behaviour* (SP 7). 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/ _SIRO's Australian Tree Seed _entre/ ! 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/ !n 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).

1 *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.

2 *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.

5

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 FGR⁵, are as follows:

10 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
15 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

20 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
25 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
30 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. In some cases the forest cover estimates have varied from FR! 2005
35 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/

⁵ 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.

5 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, 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 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.

10

15 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.

20

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

25 *“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).*

30

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 famine⁶. 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 increase⁷, especially in tropical developing regions and

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⁶ 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.

⁷ 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.

placing additional pressures on forests. There are estimated to be around 400 million people dependent or highly reliant on forests for their livelihoods⁸. Whilst there is a marked trend towards increasing urbanization of human populations⁹ 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-forests¹⁰.

FGR in sustainably managed multiple-use production forests

10 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).

25 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.

30 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

⁸ 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.

⁹ 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.

¹⁰ 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.

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 *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 °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 °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).

10 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
15 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*;
20 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
30 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-seedprosper/millennium-seed-bank/seed-research-problem-solving/index.htm>).
35

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
40 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
45 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 Agroforestry database, which provides storage information for a total of 670 agroforestry tree species.

***In vitro* conservation**

- 5 More than 70% of commercially valuable tropical tree species are estimated to have recalcitrant or intermediate seeds (Ouedraogo *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.
- 10 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
- 15 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
- 20 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 excelsa*), agarwood (*Aquilaria 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
- 25 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.
- 30 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
- 35 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)
- 40 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
- 45 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°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 (Ryyanen 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°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.

5

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

10 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).

15 The contribution of FGR &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
20 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 Islands¹¹.

25 Contribution to exports was substantial for many countries: in Canada the forest sector is the third largest contributor to balance of trade, while in Ghana the sector ranked fourth in contribution to export earnings. For the Solomon Islands the export of round logs (1.4 M m³ in 2008) provided over 70% of export earnings and 18% of total Government revenue: and is the mainstay of the economy. In Swaziland the contribution of the forest sector to national revenue was 26%. For countries that
30 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. Degradation of forest resources can have significant economic impacts, for example, Ethiopia noted a decline of over 50%

¹¹ 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.

in contribution of forest sector to GDP between 2002 and 2011, with deforestation and degradation key causes of the fall.

5 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; 2.8% of the workforce in Finland and 1.2 M people in Germany are employed in forest-based industries. The forest sector is a major provider of rural employment in Africa, e.g. In Swaziland 16-18% of the workforce, Gabon 20-30%, Burkina Faso and Ethiopia. Forestry is also the primary source of employment in rural areas of the Solomon Islands (p4).
10 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.

15 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-Saharan Africa.

20 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 have found that 80% of rural communities are living below the poverty line and have a strong
25 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. 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
30 forests and common lands as men. 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 in Canada.

35 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 noted that 'the use of non-timber forest products in agriculture technologies is such that in their absence most farming activities would be
40 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 'nearly 39% of cattle depend on forests for their fodder either partially or fully'-in Niger 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

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-in Zimbabwe '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.

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, wood products and food, 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. 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, 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. 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. 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

5 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. 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.

10 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.

15 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

20 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 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.

30 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).
35 Temperate forests and forest tree species support and provide habitat for myriad other life forms. For example, two thirds of Canada’s 140,000 species, two thirds occur in forest ecosystems/ In the UK, 285 different species of phytophagous 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
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recognition of the number of mammals and birds that utilise its 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).

5 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
10 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 CO₂. Vigorously growing tree plantations sequester vast amounts of carbon, e.g. maximally around 80 tonnes of CO₂ 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
15 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
25 97 cases or 3% of priority species nominations (Judith table 4a1). 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
30 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.

35 The tabulated results show biodiversity conservation as the most commonly nominated environmental use accounting for 27% of listings, 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.

40 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.

5 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. 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. 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 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 and Seychelles. Medicinal uses of trees were also noted as important throughout Asia including China with nearly 1000 medicinal plants, mainly woody species; India, Nepal and Indonesia with 2039 medicinal plants. The search for medicinal compounds, or bioprospecting, 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 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.

5 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),
10 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 trichopoda*), 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
15 which are characteristic of 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.

20 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, India, Zimbabwe, and Ghana. Cultural, aesthetic and religious values accounted for the largest
25 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
30 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

35 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 CO₂, 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
40 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°C.

45 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 nutraceuticals, such as sources of antioxidants, antiinflammatories 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).

15 In summing up it is evident that well-characterized¹², 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

¹² 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.

(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 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 ochlopecies whose complex variation patterns cannot be satisfactorily accounted for by conventional taxonomic categories (Whitmore 1976).

Based on literature reviewed in preparing Annex XXX it is conservatively estimated that there are more than 34,000 tree species¹³ 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 total 7941 species and subspecies were mentioned in Country Reports (Figure 1) and 2363 species and 2363 subspecies were mentioned as being actively managed in various systems (Figure 2).

Figure 1: Number of species and subspecies mentioned in Country Reports, total number and by region

¹³ 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

Total number of species and subspecies reported

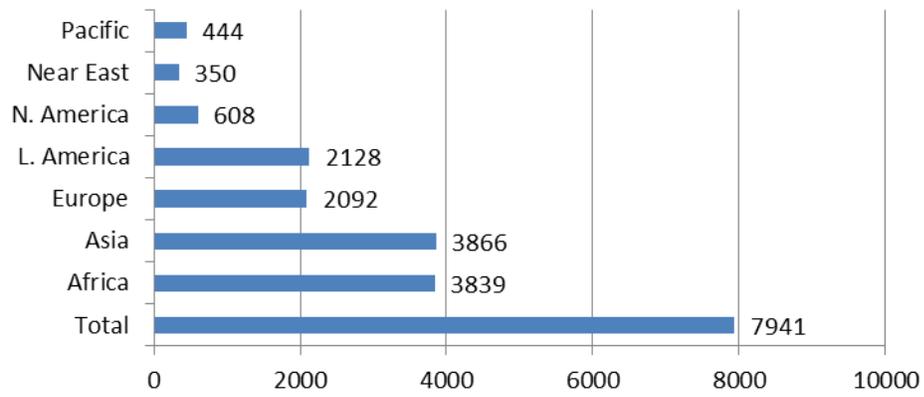
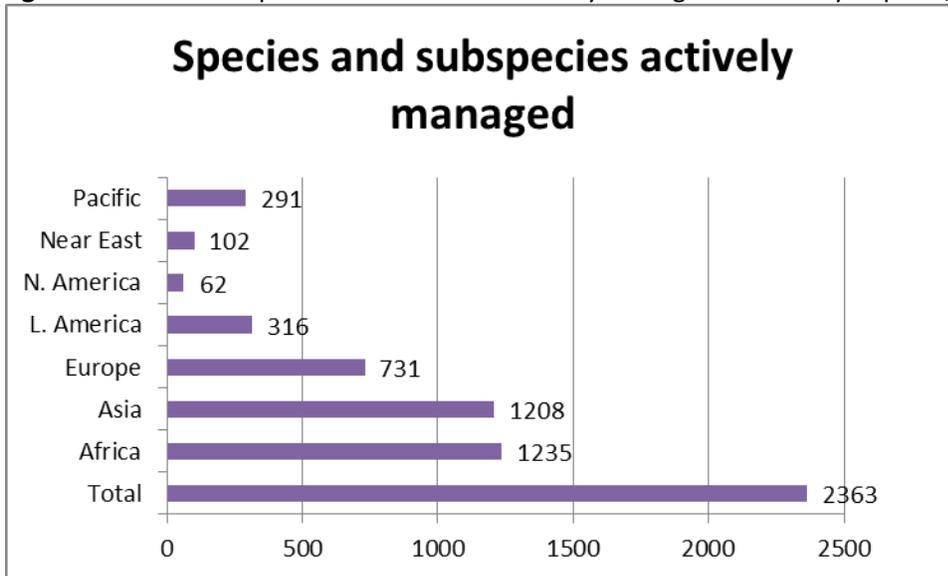


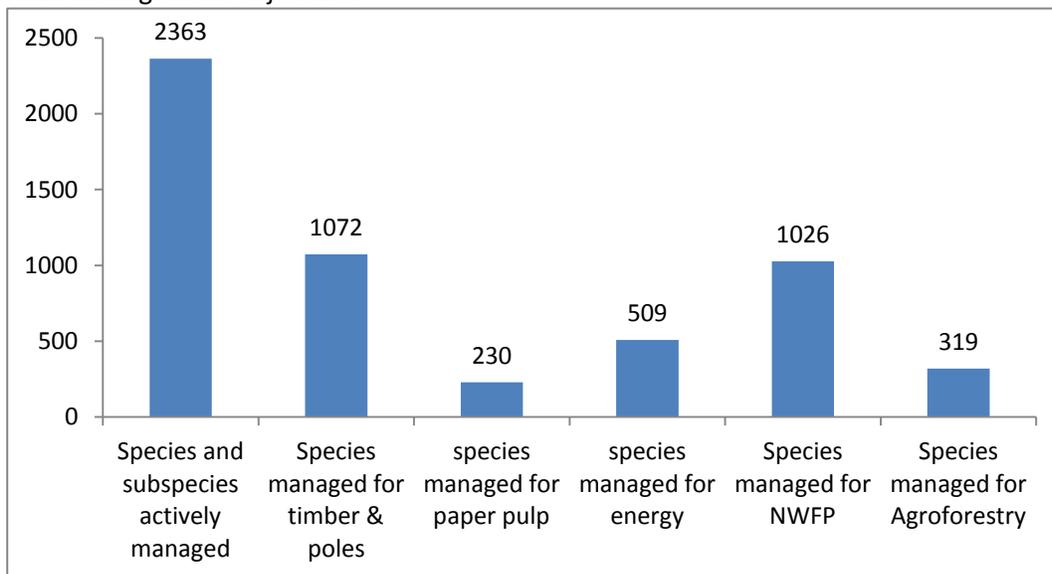
Figure 2: Number of species mentioned as actively managed in Country Reports, by region



5 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 illustrated by Figure 3. 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).

10

Figure 3: Number of species mentioned as actively managed in Country Reports: total number and by main management objectives



Conservation of FGR, including a vast diversity at the tree species level, is seriously hampered by a lack of taxonomic skills, 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.

5 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 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.

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; Eriksson *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*; Pinyopusarek *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. 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. 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.

5 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.
10 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 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
15 (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. In Burkina Faso, shea (*Vitellaria paradoxa* subsp. *paradoxa*), néré (*Parkia biglobosa*), tamarind (*Tamarindus indica*), palmyra (*Borassus aethiopicum*) baobab (*Adansonia digitata*), Senegal gum acacia (*Acacia senegal*) and marula (*Sclerocarya birrea*), have been studied with
20 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
25 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.

30 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/ Other examples in the published literature include:

- Red calliandra (*Calliandra calothyrsus*) in Mexico and Central America indicating need to
35 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
40 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. the 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
45 diversity, e.g. for broad-leaved trees such as oaks (*Quercus* spp.) in Europe (Iberian Peninsula, Appenine

Peninsula and the Balkans) (Potyralaska 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
5 unique diversity and specific adaptations that warrants special attention for evaluation and conservation.

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
10 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
15 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
20 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
25 focus on those priority species whose distributions overlap the national boundaries and have wider socioeconomic 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
30 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
35 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 Cunninghamioideae, 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
40 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.

5 The most primitive angiosperm or flowering plant is considered to be *Amborella trichopoda*: 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
10 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*,
15 *Koordersiodendron*, *Kostermansia*, *Krugiodendron*, *Laguncularia*, *Limonia*, *Litchi*, *Maesopsis*, *Muntingia*, *Neobalanocarpus*, *Noltea*, *Ochroma*, *Olneya*, *Oroxylum*, *Platycarya*, *Pleiogynium*, *Rhoiptelea*, *Spathodea*, *Ticodendron*, *Triplochiton*, *Umbellularia*, *Umtiza*, *Veillonina*, *Vitellaria*, *Xanthoceras*, *Veillonina* 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
20 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,
25 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
30 Somalia is classified as vulnerable (IUCN) while the monotypic *Canacomyrca 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.

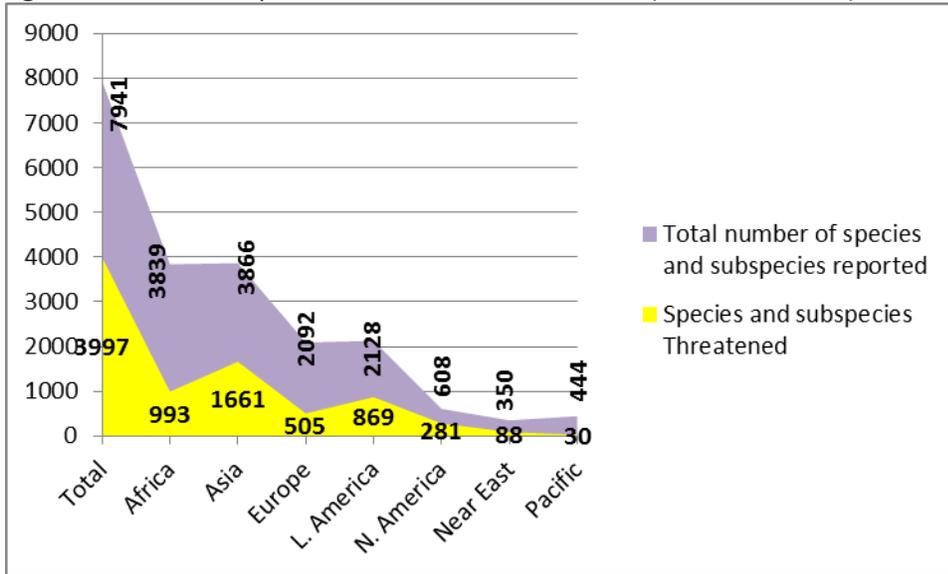
35 1.4 Threats

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;
40 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 acidification, 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.

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Figure 4: Number of species mentioned as threatened (at various levels) in Country Reports, by region



1.4.1 Causes of genetic erosion, threats and risk status

1.4.1.1 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
5 reduction, forest degradation and fragmentation. This will almost certainly continue to be the case while the world's population continues to rise. India 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
10 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). 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
15 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.

In sub-Saharan Africa various human activities were noted as threats to FGR. Mining may cause the loss of entire local tree populations and Burundi noted mining and quarrying as threats to
20 FGR. Tanzania noted cutting of firewood and charcoal production as contributing to deforestation. 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). 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
25 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
30 smaller residual base of native forest, are concentrated in more biodiverse rich forests, and leading to greater fragmentation with long-term impacts on associated animal species and gene flow and viability of more fragmented species and populations.

1.4.1.2 Atmospheric pollution, rising CO₂ levels and climate change

Since the Industrial Revolution atmospheric pollution has caused damage to Europe's forests, but is a
35 diminishing direct threatening factor to FGR, with most damage likely to result from stressed trees being more susceptible to insect pests and diseases. Of greater global concern for FGR are the increasing and accelerating CO₂ levels. These result from human activities (burning of fossil fuels, forest destruction etc) over the past half-century and are already, as predicted by IPCC, contributing to more extreme climatic events. Worsening and changed climate, including prolonged drought is mentioned as a threat
40 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).

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15 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

20 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.

25 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)

30 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

35 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).

40 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°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).
- 10 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).
- 15
- 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)
- 20
- 25 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 CO₂. 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)
- 30
- 35
- 40

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 detrimental 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.

1.4.1.3 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.

5 Countries reporting forest fires as a threat to FGR included Algeria, Burundi and Ethiopia.

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
10 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
15 (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
20 the need to conserve and make use of genetic diversity in multipurpose tree species.

1.4.1.3 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
25 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
30 species and totally modifying and displacing entire ecosystems, with the loss of many of the existing tree and other species. In East Africa 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).

35 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
40 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 Southwestern 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) – chalarra 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 (Snieszko 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 podocarp*i 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

5 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
10 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
15 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
20 their further spread.

1.4.1.4 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. However, for narrowly distributed
25 and naturally rare species, overharvesting can directly lead to or threaten extinction. In China, 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. Overharvesting usually involves highly valuable species such as ebonies, sandalwoods, agarwoods and frankincense, but in areas with high population
30 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
35 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. 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.

1.4.1.5 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/ FIO'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 F₁ 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

1.4.2.1 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), 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 ecosystems and alter the FGR contained in them.

1.4.2.2 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 List¹⁴ 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 and is a contributory threat factor for some species.

Through the Global Trees campaign and under the auspices of IU_N'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 Magnoliaceae, 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 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

¹⁴ 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

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 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.

1.4.2.3 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 tropical 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).
- 5
- 10 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. $\leq 5\%$, 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.
- 15
- 20 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).
- 25
- 30 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.
- 35
- 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).
- 40
- 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.

5 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).

10 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 afro-montane 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
15 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
20 loss of genetic diversity (MacLachlan and Gasson 2010; India p 63).

Swietenia mahogany (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
25 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.

30 *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.

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