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SITUATIONAL ANALYSIS OF TREE BREEDING AND TREE GERMPLASM SUPPLY IN AFRICA: UNDERPINNING SUSTAINABLE FOREST MANAGEMENT

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Front cover photos:
Left: Four-month old seedlings of P. oocarpa, Katuugo Nursery, Uganda. (Photo by Heriel Msanga, 2014)
Middle: A demonstration of safe tree climbing during seed harvesting, TTSA, Morogoro, Tanzania. (Photo by Heriel Msanga, 2014)
Right: Seed germination tests in a germination room, TTSA, Morogoro, Tanzania (Photo by Heriel Msanga, 2014)

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Left: Eucalyptus plantation in Congo near Pointe-Noire Diosso. (Photo by jbdodane, 2014); Right: Teak plantation. (Photo by Amber Karnes, 2008)

Situational analysis of tree breeding and tree germplasm supply in Africa: underpinning sustainable forest management

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Acronyms

AGM	Annual General Meeting
AFF	African Forest Forum
ATSC	Australian Tree Seed Centre
AFORNET	African Forest Research Network
BSO	Breeding Seedling Orchard
CA	Central Africa
CAMCORE	Central American Coniferous Resources
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	Clonal Seed Orchard
DRC	Democratic Republic of Congo
DANIDA	Danish International Development Agency
EA	Eastern Africa
EFC	Eucalyptus Fibre du Congo
FAO	Food and Agriculture Organisation
FGR	Forest Genetic Resources
FRA	Forest Resource Assessment
GxC	Grandis x Camaldulensis hybrid
GxT	Grandis x Tereticornis hybrid
GxU	Grandis x Urophylla hybrid
GCF	Gatsby Charitable Foundation
GTZ	German Agency for Technical Co-operation
ICFR	Institute for Commercial Forestry Research
ICRAF	International Centre for Research in Agroforestry
ICS	Indigenous Commercial Species
IFT	Indigenous Fruit Trees
ISTA	International Seed Testing Association
KEFRI	Kenya Forestry Research Institute
NGO	Non-Governmental Organisation
NTFP	Non Timber Forest Products
NTSC	National Tree Seed Centre
NORAD	Norwegian Agency for Development Cooperation
OECD	Organisation for Economic Cooperation
PROTA	Plant Resources of Tropical Africa
SA	Southern Africa
SAIF	Southern Africa Institute of Forestry
SFM	Sustainable Forest Management
Sida	Swedish International Development Agency
SODEFOR	Society for the Development of Forests
SSO	Seedling Seed Orchard
TPF	Timber Producers Federation
WA	Western Africa
WAC	World Agroforestry Centre (ICRAF)
ZAR	Zuid Afrika Rand

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This pan-African report is a summary of regional reports and information on tree breeding and tree germplasm collection and deployment in Central, Eastern, Southern and Western, Africa. In the course of these assignments, we visited many countries and institutions, interviewed a number of professionals working in forest departments, academic institutions, Non-Governmental Organisations (NGOs) and international organisations. The names are too many to mention, but have all been listed and cited as personal communications in the regional reports. We also want to thank all the participants of the regional workshop on sharing knowledge and experiences to strengthen collaboration among stakeholders in African forestry held in Lomé, Togo from the 26th to the 30th of September 2016. The questions and discussions were informative and helped us in learning and articulating the situation throughout Africa. While we acknowledge with thanks all those who availed information during the conduct of this study, we however remain solely responsible for any omission and errors of interpretation.

Executive summary

Forests and planted trees provide sustenance to many millions of people in Africa, particularly the vulnerable, women and children. Balancing utilisation of forest resources and growth of forests and trees forms the basis of sustainable forest management (SFM). Africa's natural and planted forests are not sustainably supplying wood and other products to meet the needs of the growing population as well as the demand of national, regional and international markets. Serious shortages of wood are forecast in many countries for the near future and this has negative socio-economic implications. The African Forest Forum (AFF) recognised the need to improve SFM in Africa through planting trees using genetically improved planting stock for establishment of industrial plantations, community tree woodlots and agro-forests. This report is based on situational analyses of tree breeding and tree germplasm supply conducted in West and Central Africa (Avana-Tientcheu, 2016), Eastern Africa (Msanga, 2016) and Southern Africa (Marunda, 2016).

To understand trends in the choice of species and estimate seed demand, the studies looked at forest statistics in selected African countries and reviewed the history of tree planting (introduction of species and provenances), afforestation, reforestation statistics and conservation needs. Plantation development has been generally successful in countries where the private sector has been encouraged and supported to invest in tree planting (e.g. South Africa, Tanzania and Congo), research (Congo, Ghana, South Africa, Tanzania and Zimbabwe) and tree germplasm development (Burkina Faso). Community tree planting for agroforestry, whilst still in the nascent stages of development, has been encouraged and supported by international donors. Distribution of seed is mainly through informal farmer networks supported by local and international organisations, national tree seed centres (e.g. Burkina Faso) and the private sector (e.g. in South Africa). The users of tree germplasm in African countries have become diverse - from large plantation corporations, community-based organisations and city councils, to small-scale tree growers, including farmers groups and individual farmers including women keen to plant indigenous fruit trees to improve their livelihoods. This diversity brings with it challenges and opportunities. Challenges may include how to supply a variety of high quality tree seed from a range of species whilst the diversity offers opportunities for the rural communities to be involved in the supply chain of tree germplasm.

The studies showed that Africa, like most parts of the world, has imported, tested, shared, exchanged, sold and improved genetic resources for tree species. Use of genetically improved planting stock was reported in all countries in Africa although the levels of use vary from country to country, with countries such as South Africa having the most sophisticated tree germplasm development and deployment systems. Some countries, e.g. South Africa and Zimbabwe, acknowledged the presence of species and provenance trials which revealed the best performing species and provenances, seed sources and provided the material for tree improvement and for subsequent deployment to operational plantings. Other countries, especially in West and Central Africa (except Ghana), reported that most provenance trials were abandoned and illegally exploited and most data and information has been lost.

A new wave of establishment of commercial plantations is sweeping through many parts of Africa, for example in Congo (Eucalyptus Fibres du Congo), Ghana (Africa Plantations for Sustainable Development, Siricec, Miro Forestry), Mozambique (New Forests Green Resources, Florestas Do Planalto, Chikweti Forests, Florestas de Niassa), Rwanda (New Forests), South Africa (International Finance Corporation, Hans Merensky), South Sudan

(Maris Capita), Tanzania (Green Resources, New Forests, Kilombero Valley Teak Company), Zambia (Green Forest Development) and Uganda (Sawlog Production Grant Scheme). This new wave of plantation development has seen an increase in the demand of tree germplasm and new species for planting in marginal areas that are available for afforestation.

In 2016, the Forests for the Future – New Forests for Africa initiative was launched in Ghana with the aim to stimulate and drive large scale reforestation in Africa. The set target is to plant 100 million hectares of new forests. The Great Green Wall Initiative was launched in 2011 and involves 12 countries of which 8 are from West Africa. The goal is to plant trees as a means to try to stop, or even to reverse, the desertification process, which is the main ecological problem of many countries with arid climates (e.g., Niger, Chad, Mali, Nigeria, Burkina Faso, Mauritania and Senegal). The need and call to plant more trees (e.g., Billion Trees Campaign and Green Belt Movement) will increase the demand for seed and new species, and national tree seed centres will need to be prepared for the increased seed demand and identify priority tree species.

The reviews of tree breeding and tree germplasm supply and demand in Africa showed a decreasing trend in research and development investments and widening gaps in the supply of good quality germplasm. Given the forecasted increase in tree planting and the recorded threats of pest and diseases to forest genetic resources in Africa (Bosu, 2016; Gichora, 2016; Kojwang, 2016;), tree planting programmes in Africa might not reach the optimum productivity levels if germplasm supply and pest and disease threats are not addressed. Forestry development in Africa will have to address these issues as part of a wider programme to achieve SFM.

It is clear that most African countries recognise that SFM is achieved by combining strategies that conserve and encourage regeneration of native tree (e.g. *Ngitili* in Tanzania; *Zai* in Burkina Faso; landscape restoration in Maradi and Zinder (Niger), coppice management in the miombo woodlands of Southern Africa) and the promotion of tree planting at large plantation scales and at the farmer level. The choice of species for commercial plantations has been decided based on decades of research on species trials and collaborative research for agroforestry species. For newer species for agroforestry, research is still fairly new and a number of candidate species are still being tested and promoted.

The commonly planted species in Africa are *Eucalyptus, Pinus, Acacia, Hevea* species *Tectona grandis* and *Gmelina arborea* for the primary supply of industrial wood, rubber, gums and fuelwood. The first two genera have formed the backbone for commercial tree planting and have undergone several cycles of selections and in some cases mating to create new clones or varieties. The genera are attractive because of the shorter economic and reproductive rotations that are possible. Recently, agroforestry species for intercropping, alley cropping, fodder provision and indigenous fruit trees have been tested for growth and productivity in many African countries. Indigenous tropical hardwoods such as *Khaya senegalensis*, *Khaya anthotheca* and *Milicia excelsa* have been domesticated as plantation species in tropical countries. *Acacia senegal* and *Acacia seyal* have been planted in plantations for gum Arabic production (hashab and talha from the two species respectively). *Faidherbia albida* is commonly planted throughout the continent for soil amelioration, provision of fodder for livestock and firewood.

A number of indigenous commercial hardwoods are harvested from natural forests in all the regions but more so in West Africa. Priced hardwoods such as *Milicia excelsa, Entandrophragma* spp., *Triplochiton scleroxylon, Terminalia* spp., *Nauclea diderrichii*, *Khaya* spp., *Pericopsis elata* and many others are harvested by concessionaires. Although most of the countries developed sound forest policies oriented toward sustainable forest management, there are low levels of incentives to conserve or apply sound silvicultural practices to ensure regeneration of most species. Germplasm of good phenotypes is therefore lost during harvesting, as seed is not collected for replanting. Physiological characteristics of seeds for most tropical hardwood species are either recalcitrant or unknown (i.e., do not store for long periods under low temperature and moisture conditions), thus making it difficult to store the seed for future use.

The review of tree germplasm production in Africa showed that Africa's forest sectors, both commercial and community forestry, need quality seeds, but the continent's capacity to supply good tree planting stock varies from good to poor depending on the country. Countries often lack the institutional capacity to support the growth of tree seed markets (an issue that cuts across boundaries), tree breeding research, seed production, seed storage and testing, and regulation. Expertise in tree breeding, tree germplasm management and investment could help build the capacity to produce good quality tree seeds and improve on other aspects of the tree seed sector, including management, logistics, deployment and the integration of new species and technologies.

Since many tree species used in plantations or agroforestry were found to be the same across the continent, indicating a wider ecological and economic range than individual countries, it is prudent to have regional research programmes on tree breeding and improvement, germplasm management, and share information on silvicultural aspects, environmental benefits, impacts on soils and biodiversity, pest/disease prevention, wood utilisation and economics.

1. Background

1.1. Objectives of the study

The Africa-wide synthesis is part of a project that the African Forest Forum (AFF) is implementing under the project entitled “Strengthening Sustainable Forest Management in Africa” that seeks to generate and share knowledge and information through partnership in ways that provide inputs into policy options and capacity building in the forest sector. The ultimate goal is to better address poverty eradication and environmental protection in Africa through improved forest management (AFF, 2014). The project is funded by the Swedish International Development Agency (Sida). This synthesis report reviews tree breeding and tree germplasm deployment for priority species for plantation and community tree planting projects, identifies challenges and opportunities for collaborative strategies to enhance the development and deployment of good tree germplasm amongst regions and countries.

This synthesis report builds on the regional studies in WCA, EA and SA. It provides a deducted analysis on the following issues;

a) the current situation in Africa of tree germplasm improvement, production, supply and demand;
b) list of priority species for industrial plantations, community woodlots and agroforestry for each region (WCA, EA and SA);
c) inventories of seed sources and tree improvement research on the 10-15 most important plantation species;
d) institutional, personnel, technical and infrastructure and other facilities;
e) recommendations on the development and deployment pathways of tree germplasm production and supply of improved tree germplasm; and,
f) recommendations on regional and continental strategies on enhancing the utility of collaborative forestry research, seed production systems, and exchanges of research information to support SFM in Africa.

1.2. Approach to the review

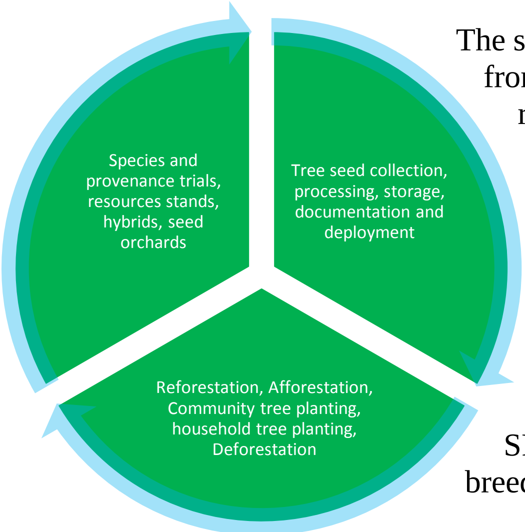

Figure 1. Interrelations amongst tree planting activities, tree breeding and seed systems

The study approach is based on the premise that the transition from deforestation (unsustainable forest management) to reforestation will create a strong demand for tree germplasm. Afforestation activities drive the demand for seed and good seed is a product of concerted and sustained efforts in tree improvement and breeding (Figure 1).

The report is structured to give a brief review of SFM and how tree planting activities (plantation statistics and community tree growing activities) contribute to SFM goals. This is followed by a discussion on tree breeding of the key species and seed supply situation for commercial, indigenous fruit trees, agroforestry species and those species threatened by over exploitation. The report gives a set of recommendations on simple and cost-effectives strategies that can be employed by the individual countries and regional collaborative frameworks.

1.3. Contextualising SFM in Africa

To put the pan-African synthesis into context, it is important to understand that forest resources in Africa, both natural and planted, are the main sources of wood, energy and non-timber forests products. Planted trees, both as plantations and community woodlots, are an important source of wood and other forest products. The growing of trees in plantations and in community tree planting projects has been viewed as one way of contributing towards achieving SFM and most African countries have recognised this as a long term objective and it is included as part of the national and regional development plans and strategies (Kowero, 2009). Modern day forest plantations in many countries were developed on the foundation of science and technology supported by decades of forest research and science (Nambiar, 2013). Recently, similar efforts are being applied on new species such as indigenous fruit trees and agroforestry species (Akinnifesi *et al*., 2006). The development and deployment of tree germplasm of good genetic and physiological quality underpinned the successful establishment of trees. Over the years, investment in forestry research and development in most African countries has declined resulting in gaps in the supply of good tree germplasm. This, coupled with a call to promote SFM through increased rates of afforestation and reforestation, and regeneration of natural forests, has given the continent an impetus to re-look at the role of tree breeding and tree germplasm deployment (AFF, 2014).

1.4. Forests in Africa

The total land area under forests in Africa is 624 million ha (Table 1). There are 125 million ha of primary forests, 165 million ha of production forests, 16 million ha of planted forests, 133 million ha of multiple use forests and the rest is set aside for biodiversity conservation, habitat for wildlife and provision for environmental services (FAO, 2015). About 140 million ha are under some form of forest management plan. The endowment value of forests and woodlands in Africa is enormous, and can be used to promote a wide range of livelihood opportunities, including increased income and enhanced livelihood security (Sebukera *et al.*, 2006). Table 1 also shows vital forest statistics and data which are crucial to support decision-making for investment and policy making in sustainable forest development. For this synthesis, the data on afforestation and reforestation indicates the scope for or need for ramping up tree planting on the African continent.

1.4.1. Natural forests in Africa

Africa's forests and woodlands can be classified into nine general categories, including *tropical* rain forests, moist forests, dry forests, shrubs and mountain forest, and *subtropical* humid forests, dry forests, mountain forests, and plantations (FAO, 2003). The forest sector in Africa plays an important role in the livelihoods of many communities and in the economic development of many countries. Africa has a high per capita forest cover at 0.8 ha per person compared to 0.6 ha globally (FAO, 2002; FAO, 2015).

The distribution of forests and woodlands varies from one sub-region to the other, with Northern Africa dominated by the Sahara Desert and having the least forest cover while Central Africa is dominated by the Congo basin forest ecosystem, which is the second largest forest in the world. Eastern Africa forests and woodlands are widespread and include high altitude forests, medium altitude moist evergreen forest and semi-deciduous forests. Southern Africa is dominated by forests and woodland types which include large tracts of tropical rain forests found in parts of Angola and the Congo basin, afromontane forests; Zambezi teak forests, Miombo woodlands found north of the Limpopo River, Mopane woodlands; and the Cape Floristic Centre forests found along the south-western coastline of Africa (see Sebukera *et al.*, 2006).

1.4.2. Planted forests in Africa

As natural forests declined, the establishments of plantations became necessary to meet the increasing demand for forests products (Evans and Turnbull, 2004). Planted forests are now an important component of the forest landscape in Africa. The successful establishment of commercial plantations in Africa have generally been driven by the private sector encouraged and supported by governments and international finance and sign-posts the way to the future expansion of plantations in Africa (Jacovelli, 2014).

Table 1. Forest statistics for countries in Africa (adapted from FAO, 2015)

Country	Forest cover (1000 ha)	Cover (%)	2010 Deforestation (ha/y)	2010 Afforestation (ha/y)	2010 Reforestation (ha/y)	2015 Plantations (1000 ha)	2015 Net change %
Central Africa							
CAR	22 170	35.6		400		2	-1.0
Cameroon	18 816	39.8				260	-1.0
Congo	22 334	65.4			100	71	-1.0
DRC	152 578	67.3		300		60	-0.2
Eq. Guinea	1 560	55.9				58.5	-0.7
Gabon	23 000	89.3				30	0.2
Tchad	4 875	3.9					
West Africa							
Benin	4 311	39.0			14 600	23	-1.2
Burkina Faso	5 350	19.6		15 000	14 000	239	-1.0
Côte d'Ivoire	1 040	32.7				427	0.1
Gambia	488	78.8				1	0.4
Ghana	9 337	41.0		0	20 000	325	0.3
Guinee	6 364	25.9		2 100	0	104	-0.5
Guinee Bissau	1 972	70.1				1	-0.5
Liberia	4 179	43.4	200	0.0	300	8	-0.7
Mali	4 715	3.9	146 000	0.0	67 000	135	-1.4
Niger	1 143	0.9				150	-2.1
Nigeria	6 993	7.7			214 000	420	-3.5
Senegal	8 273	43.0			19000	561	-0.5
Sierra Lone	3 044	42.5		700	300	16	-0.1
Togo	188	3.5		0.0	1000	46	-5.0
Eastern Africa							
Burundi	276	10.7			400	120	-0.2
Djibouti	6	0.2				0	0
Eritrea	1 510	15.0				39	-0.3
Ethiopia	12 499	11.4				972	-0.8
Kenya	4 413	7.8			5 400	220	-0.3

Country	Forest cover (1000 ha)	Cover (%)	2010 Deforestation (ha/y)	2010 Afforestation (ha/y)	2010 Reforestation (ha/y)	2015 Plantations (1000 ha)	2015 Net change %
Somalia	6 363	10.1				0	-1.0
South Sudan	7 157	11.3				188*	
Sudan	10 210	10.3	174 000			6 121	-0.8
Tanzania	46 060	52.0	372 000	10 000	27 000	290	-0.8
Uganda	3 077	10.4			10 000	60	-3.3
Rwanda	480	19.5				418	1.7
Southern Africa							
Angola	57 856	46.4		0		125	-0.1
Botswana	10 840	19.1		0			-0.9
Lesotho	49	1.6		200		17 000	0.8
Madagascar	12 473	21.4	57 000	11 400	28 000	312	-0.4
Malawi	3 147	33.4	17 900	18 000	3 000	419	-0.9
Mauritius	39	19.2		0	100	18	-0.3
Mozambique	37 940	48.2	219 000	12 000	0	75	-0.5
Namibia	6 919	8.4		0			-0.9
South Africa	9 241	7.9		2 200	50 600	1 763	0
Swaziland	586	34.1		0		135	0.9
Zambia	48 635	65.4	287 000	0	1 500	87	-0.3
Zimbabwe	14 062	36.4	309 000	0	6 000	6	-1.8

Blank denotes very small number rounded off to zero
Source: FAO (2015)
*Figure for South Sudan sourced from Gafaar (2011)

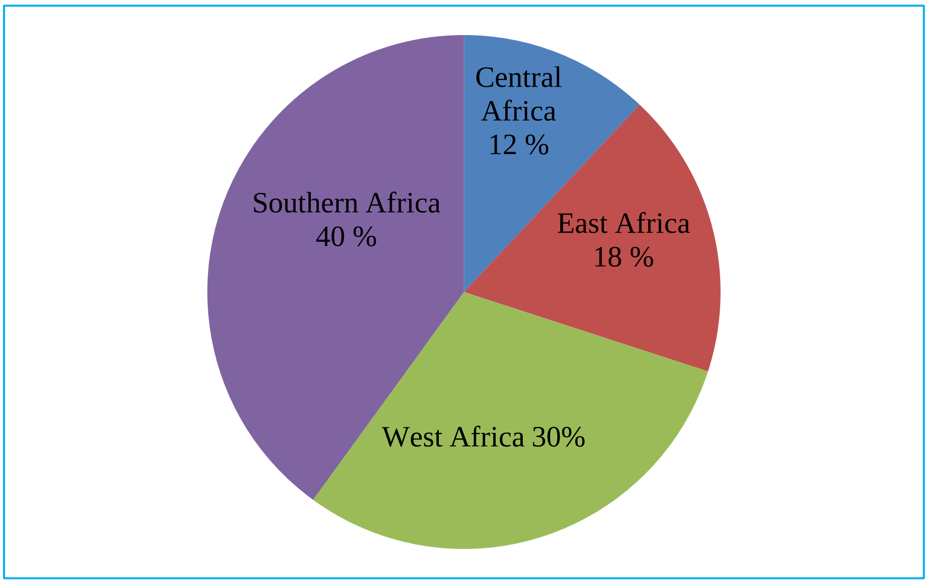

Figure 2. Proportion of Forest plantation areas in sub-Sahara Africa (AFORNET, 2015)

The total plantation area in Africa is just over 8 million ha, representing 4.3% of the global plantation area with an annual rate of planting estimated in 2005 to be 194 000 ha or 4.4% of the world total. *Eucalyptus* is the most widely planted genus on the continent covering 22.4% of all planted area, followed by *Pinus* (20.5%), *Hevea* (7.1%), *Acacia* (4.3%), *Tectona* (2.6%), other broadleaved (11.2%), other conifers (7.2%) and unspecified (24.7%) (AFORNET, 2015).

Eastern and Southern Africa is home to expansive plantations of exotic coniferous, eucalypt and acacia species which provide a mixture of products ranging from sawn-wood, pulp-wood, poles, charcoal and firewood (see main reports by Msanga, 2016 and Marunda, 2016). In West and Central Africa, plantations of *Eucalyptus* spp., *Tectona grandis, Gmelina arborea*, *Hevea brasilensis* and indigenous species have been established and provide a range of products (Avana, 2016). Figure 2 shows the proportion of plantation area in each of the four regions of sub-Sahara Africa.

The growing of trees requires deep and extensive knowledge of choice of species, site-species matching, development and deployment of good tree germplasm to stakeholders. More often than not, many tree planting projects have used ordinary run-of-the-mill seed resulting in poor tree survival and growth. As tree growing has expanded from commercial plantations to community and small-holder tree plantings, the demand for new species has increased and new deployment strategies are needed to guarantee success.

1.5. Forest decline in Africa

Forest and woodland resources are declining, primarily as a result of unsustainable forest management practices evinced by increased woodfuel collection, clearing of forests for agriculture, illegal and poorly regulated timber extraction, conflicts and increasing urbanization. Low levels of investments in afforestation and reforestation by many countries further exacerbates the decline in forest resources.

The high level of dependence on forests by a large percentage of the population in Africa has resulted in a net negative change in forest area. Between 2010 and 2015, FAO (2015) recorded a net annual change of -2.8 million ha. In WA, Nigeria and Togo had the highest percent change in forest area in 2015. In Central Africa, Equatorial Guinea had the largest decline in forest area whilst in Eastern Africa, Uganda had the fastest rate of forest decline mainly attributed to increasing demand for construction timber and demand for timber for export to neighbouring countries (Jacovelli, 2010). In Rwanda, the positive net forest change was due to replanting efforts promoted through the National Forest Policy of 2010. The main objectives of forest plantations established during this period were protection of vulnerable soils against erosion, reduction of pressure over the remaining natural forests and protected areas and fuelwood supply to an ever growing population. In Southern Africa, Zimbabwe recorded the highest decline in forest area fuelled by the demand for wood energy to cure tobacco and for cooking and heating due to erratic electricity supply. Zambia continues to experience high rates of deforestation due to the demand of charcoal which leads to localised deforestation in the charcoal producing areas (Gumbo *et al*., 2013)

However, as noted by FAO (2015), the rate of change has declined from 2010 to 2015. The change in area is a process of gain (forest expansion) and loss (deforestation). Understanding this process helps shape forest policies especially when developing SFM. Table 1 shows the forest statistics of most African countries. It could be observed that most countries have negative net changes in forest areas, implying a need to invest in SFM practices. Tree plantations have long been seen as a way to combat such impacts by producing wood products in a cost-effective way. The current level of tree planting in Africa is well below the level required to meet the predicted demand from consumers and industry.

1.6. Reversing the trend – pointing to the need for more tree germplasm

The decline of forest areas in Africa suggest a need for countries to invest in SFM. One strategy will be to increase the rate of tree planting. In 2016, the "Forests for the Future – New Forests for Africa" initiative was launched with the aim to stimulate and drive large-scale reforestation in Africa with a target to plant 100 million hectares of new forests. To realize this, African leaders saw the need for forestry projects based on a long-term approach and multi-stakeholder benefits with intensified cooperation with the private sector as they have the resources, innovation and the ability to deliver (http://newforestsforafrica.org).

Many countries have developed afforestation strategies and have set tree planting targets to increase forested areas. For example, in Congo, the Green Economy Policy was launched in 2010 as an innovative reforestation programme to plant "one billion trees in savannas and degraded forest landscapes from 2010 to 2020" (Matondo, 2013). Ghana has developed a Forest Plantation Strategy – 2015 to 2040, which details plans by the government and private sector to reforest degraded forest lands by developing commercial forest plantations of recommended exotic and indigenous tree species at an annual rate of 20 000 ha (10 000 ha: public/public-private partnerships; 10 000 ha: private sector) over the next 25 years. The strategy targets are for the maintenance and rehabilitation of an estimated 235 000 ha of existing forest plantations as well as enrichment planting of 100 000 ha of under-stocked forest reserves with high value indigenous timber species over the same period (FC, 2013). Similarly, Mozambique developed a National Afforestation Strategy that has zoned close to 7 million ha as potential area of plantation development, and is targeting to plant 3 million ha in the next 20 years using fast growing plantation species and creating 100 000 jobs (Cotzee and Alves, 2005). In Zimbabwe, there is a call for a process of engaging the private sector, the government and other stakeholders to urgently halt the decline of forest areas and increase tree planting activities (Katerere, 2016, presentation at the TPF AGM 2016). The programmes would require finance, availability of land, education and enabling policies. Successful tree planting would be guaranteed by growing improved genetic stock.

1.7. Sustainable forest management in Africa

SFM entails the management of forests to maintain their full range of environmental, social and economic values. The concept of SFM has a long and evolving history in Africa. As our knowledge of forest ecology has increased and community attitudes have changed, management practices have also changed to meet sustainable timber yields, non-timber products and maintain and protect other forest values such as biodiversity conservation, protection of water systems and climate change mitigation. SFM is primarily a systematic approach to sustaining all the components of the forest ecosystem and the interaction amongst them. SFM has been defined by FAO (2005), as "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems". Policy, legal, institutional, technical and economic constraints have undermined wider adoption of SFM as well as limited opportunities for development (Chamshama *et al*., 2009)

Within the context of Africa, SFM can be viewed from three platforms:

- management of natural/multipurpose forests by communities;
- management of production forests by timber concessionaires in partnership with government agencies;
- planting trees for the establishment of plantations, agroforests and community woodlots.

The first two are not part of this synthesis but it suffices to mention that management of natural forests and woodlands (e.g. encouraging natural regeneration) are an integral part of achieving SFM. Maisharou *et al.* (2015) reviewed and listed common sustainable land use management practices that have been successfully used and up-scaled to restore degraded areas in the Sahel. Examples of such approaches in Africa include; *Ngitili* in Tanzania (Kamwenda, 1999; Ghazi *et al*., 2005); the *Zai* pit system in Burkina Faso (Sawadogo *et al*., 2011), restoration of landscapes in Maradi and Zinder regions of Niger by allowing trees such as *F. albida* to regenerate on agricultural lands, the root systems and falling leaves fertilizing the surrounding soils (Sendzimir *et al*., 2011; Gabou and Maisharou, 2014); the miombo natural regeneration in Zambia (Luoga *et al.*, 2004; Chidumayo, 1997). Restoration could be achieved through a number of practices, which include community-based natural regeneration where communities allow indigenous trees and shrubs to re-grow on degraded forest land from live stumps, underground roots and soil seed-banks and pruning mainly to manage densities and meet local needs for firewood. Livestock densities are also carefully managed and entire forest patches are fenced off from both humans and animals to allow natural forest to regenerate. By supporting natural re-growth, communities are not only able to restore trees to the landscape, but also produce and sell firewood, berries, fruits and nuts.

Tree planting using fast growing species, with clearly defined end-products and tried and tested tree culture technologies is well recognized as a strategy to increase forest resources and achieve SFM. However, tree planting needs a high level of investment and planning. Choosing the right species for the right site to produce the required product is critical, thus development and deployment of tree germplasm is a critical success factor for any tree planting operation. A timely supply of genetically improved planting stock is also critical and can be achieved through a clear understanding of the tree planting objectives, seed demand based on levels of afforestation and reforestation or community tree planting needs (Denning, 2001).

Unfortunately, most countries in Africa have reduced investments in forests research and development resulting in inferior tree germplasm being used in planting operations. Situational analyses in Central and Western Africa (Avana-Tientcheu, 2016), East Africa (Msanga, 2016) and Southern Africa (Marunda, 2016) have all pointed to reduced forest research and development in tree breeding and deployment of tree germplasm. This lack of investments in the development and deployment of tree germplasm to support successful tree planting outcomes has been identified as one of the many barriers to achieving SFM in Africa (AFF, 2014).

1.8. Tree breeding and seed production –cornerstone for SFM in Africa

In Africa, tree breeding has been conducted on key species such as pines and eucalypts, and some significant improvements have been obtained in adaptability to wide environments and productivity.

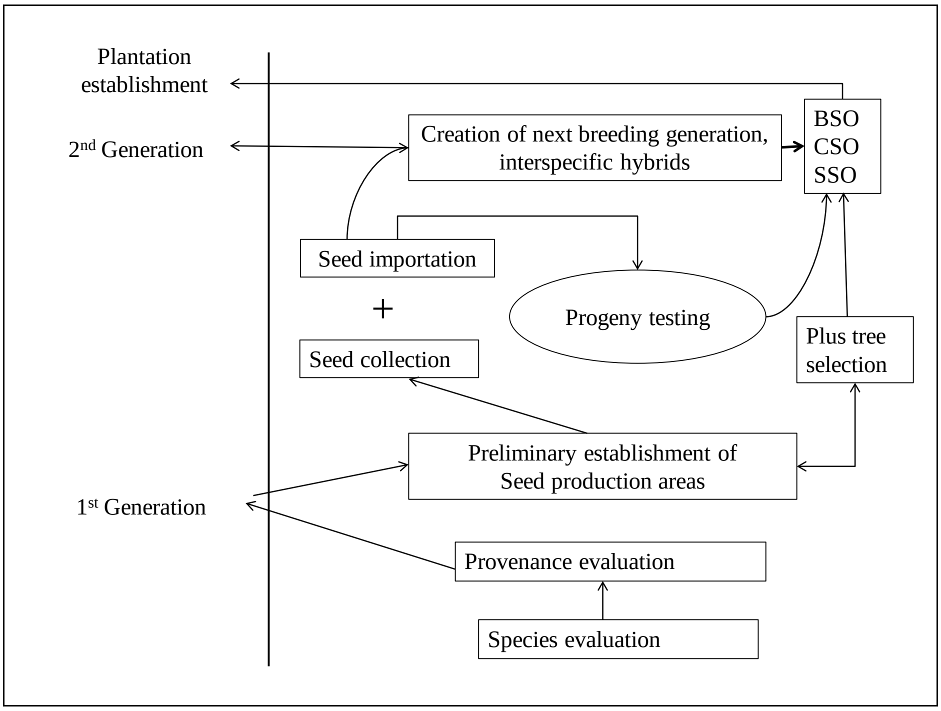

Figure 3. Processes involved in conventional tree breeding programme (adapted from Pottinger, 2003)

The reviews of the history of exotic species in four regions of Africa (Avana-Tientcheu, 2016; Marunda, 2016; Msanga, 2016) have shown that most countries followed the traditional way of identifying candidate species, establishing small trials to identify "best bet' provenances, followed by more extensive provenance trials involving large numbers of seed sources, establishing seed production areas, seed orchards and inter-specific hybridisation of related species (e.g. Harwood, 2011).

Figure 3 above shows the various stages involved in breeding and tree improvement of most commercial species. In countries with sophisticated breeding programmes, a current issue is the development of strategies that allow rapid exploitation of existing genetic variability, while at the same time providing continuing genetic gains, maintaining flexibility for future changes of site or market, and minimising the risks of monoculture, genetic uniformity and loss of variability.

Today, most countries with forests plantations based on exotic species and commercially important indigenous species have invested in provenance trials. However, due to the long term nature of the breeding cycles and seed production phases, some countries did not successfully complete the breeding and seed production phases. Thus, there are countries that can supply seed (e.g. Tanzania and South Africa), countries that have lost the capacity to produce seed (e.g. Malawi and Zimbabwe) and some countries are resorting to importing seed from other countries (e.g. Mozambique).

For indigenous species and agroforestry species, initial activities started a few decades ago focused on identifying priority species by local communities through participatory approaches in all stages of their domestication, product development and commercialization (e.g. Akinnifesi *et al.*, 2006). This was followed by domestication and development of vegetative propagation. Rather than focusing on provenance selection, the domestication programme also explored how best to deploy the material to the farmer either as seed, seedlings, cuttings or vegetative cloned material. For example, in Mali, genetically improved planting stock of *Z. mauritiana* is now available as rooted cuttings or grafted material (Kalinganire and Koné, 2010; Kalinganire *et al.*, 2012).

The introduction of agroforestry species and domestication of promising indigenous species has brought with it challenges and opportunities. Financing such activities has been the domain of many local and international NGOs, resulting in national agencies not undertaking the funding responsibility and programmes not being widely adopted by national systems (Tembani *et al*., 2014). Because of the dependency of the programmes on short-term donor funding and subsidisation of the cost of planting stock through "free seed" hand-outs, it is difficult to put the programmes on a sustainable pathway.

Despite this, agroforestry and domestication of indigenous species still provides a huge potential for many millions of rural people through participation in community projects (hence build-up of social capital and knowledge), seed collection, and access to more products from forests.

The new wave of plantation development occurring in Africa and the participation of rural communities in agroforestry and domestication of indigenous species, as well as restoration activities on degraded landscapes puts Africa on a SFM path. What is needed now is to augment this impetus with a supply of superior planting stock through sustained investments in research and tree germplasm deployment.

2. Defining the forest genetic resources in Africa – candidate species for planting

Tree-planting has a long history in Africa. Large scale establishment of industrial forest plantations started at different times during the early 1900s, e.g. in East and North Eastern Africa (Chamshama, 2011), West and Central Africa (Harris, 1993) and in South Africa, the first commercial plantation of Eucalypts was established in 1876 (Nordin, 1984, in Zobel *et al.*, 1987 cited in Chamshama and Nwonwu, 2004). The first extensive plantings of industrial tree crops in Africa occurred during the period 1900-1945, mostly in countries with little utilisable natural forest and where there had been an early influx of European settlers (Evans, 1992). In 1938, for example, South Africa had 520 000 ha of plantations of which 370 000 ha were privately owned (SAIF, 2000). Plantation development was motivated by the realisation that the indigenous forests with very slow growth and difficulty in propagation would not meet future wood needs. Most species planted for plantations were exotics, mainly Eucalypts (hardwoods), Pines (softwoods), Hevea (rubber), Acacias (gum Arabic and fuelwood), Tectona (hardwood) and a few others (Table 2).

Table 2. Commonly planted species in Africa by percentage and area planted

Species	Area (%) (Chamshama and Nwonwu, 2004)	Area (ha) (Pandey, 1992)
Eucalypts	22.4	790 000
Pines	20.5	610 000
Hevea	7.1	-
Acacia	4.3	250 000
Tectona	2.6	140 000
Others	-	1 200 00

The choice of species for planting depended on expected end-products, survival and growth of the species. Growth and survival are fundamental to successful plantations, regardless of the production objective (Teulières *et al*., 2007). To identify a list of species, basic research on species and provenance adaptability was conducted in many African countries. The species elimination testing phase was generally followed by the traditional more extensive provenance trials of one or more of the most promising species using larger plot sizes and extending the testing period to at least half of the planned rotation. This was followed by the importation of broad-based populations of the best provenance of the species finally selected for planting, so as to support a breeding program leading to production of improved planting stock. This has been the approach in most African countries and list of research trials are provided for key species (Avana-Tientcheu, 2016; Msanga, 2016; Marunda, 2016). Complex tree breeding programs followed aiming to improve the profitability and competitiveness of forest growers/processors through the genetic improvement of economically important traits.

The value of the tree improvement programme is only realised when the genetically improved material is deployed operationally to tree planting programmes and deployment strategies need to be out in place. Thus, many countries in Africa have invested in tree seed centres which are linked to the tree breeding programmes or government agencies promoting community tree planting. Genetically improved planting stock remains the most effective means of improving forest productivity. This is best achieved if tree breeding is combined with good silvicultural management practices (Chamshama *et al*., 2009)

2.1. Eucalypt species for planting in Africa

The most widely planted species in Africa falls under the *Eucalyptus* genus, which are also the most widely planted hardwood species in the world (Doughty, 2000). Most of the species fall in the sub-genus *Symphyomyrtus* with the following species as the mostly planted: *Eucalyptus camaldulensis, E. dunnii, E. globulus, E. grandis, E. nitens, E. pellita, E. saligna, E. tereticornis* and *E. urophylla* (Harwood, 2011). Most of these species have been tested and deployed for operational tree plantings in many parts of Africa. They are planted mainly for pulp-wood, transmission poles, fencing post, construction timber and firewood.

Eucalypts and their hybrids dominate plantation forestry worldwide, and huge investments have been made in the evaluation and development of their genetic resources in recent decades (Harwood, 2011). Countries in Southern Africa (Mozambique, South Africa and Zimbabwe) have a long history of introducing eucalypts. In East Africa, eucalypts were introduced in Kenya as early as 1902. About 100 species have since been introduced and 83 have been planted at various times at the Kenya Forest Research Institute (KEFRI) Arboretum in Muguga (Gottneid and Thogo, 1975). Out of the 83 species planted in the arboretum, only 71 have survived (Oballa *et al*., 2010). Initial introductions of the species were informal and unscientific, and undocumented and the diversity of the introductions were narrow - if known at all.

Figure 4. 5 year old E. grandis in Lichinga, Mozambique (Photo by C. Marunda, 2014).

Whilst these early introductions were useful in proving that the species can grow, they did not present the wide genetic base on which to build tree breeding programmes. Subsequent importations of seed were sourced from a wide range of sources in Australia and exchanged between countries (Koskela *et al.*, 2010). Testing of the species followed the traditional breeding strategy as outlined by Harwood (2011) and this involves testing a few species in simple replicate trials and identifying the potential species followed by more extensive and large provenance trials.

With assistance from the ATSC, aid programmes and private arrangements, Africa has managed over the years to assemble a range of species and provenances of the most commonly planted *Eucalyptus* species. Table 3 lists some of the common species planted in Africa. Other Eucalypts species tested in Africa include *E. pilularis, E. microtheca, E. citriodora, E. maculata* and *E. decaisneanai* in West Africa. In South Africa, new temperate eucalypt species are being tried in cold and frost-prone areas, including: *E. bagjensis, E. bethami, E. macurthii* and *E. henryii* (Mondi Forest and SAPPI, 2014 Annual reports).

Table 3. List of the commonly planted eucalypt species in Africa.

Species	Regions/countries introduced	Selected countries
E. camaldulensis	CA, EA, SA, WA	All
E. citriodora	SA	South Africa, Zimbabwe
E. cloeziana	SA	Zimbabwe
E. grandis	EA, SA, WA	All countries
E. globulus	SA	Malawi, Ethiopia, South Africa
E. dunni	SA	South Africa, Zimbabwe
E. microtheca	SA	Zimbabwe
E. nitens	SA	South Africa, Zimbabwe
E. pellita	SA	Mozambique, South Africa
E. saligna	SA	Malawi, South Africa, Zimbabwe
E. robusta	SA	Madagascar, Mozambique
E. tereticornis	SA, EA, WA	Mozambique, Zimbabwe,
E. urophylla	SA, EA	Mozambique, South Africa, Zimbabwe

2.1.1 Clonal eucalypt forestry

Clonal propagation has evolved from its inception in the 1970s when the French in the Congo and the Australians first began trialling root cuttings as a method for clonal propagation of eucalypt species. In the Republic of Congo, 42 000 ha of clonal eucalypts plantation were established in the coastal plain of Kouilou, owned by a private industrial company, Eucalyptus-Fibre du Congo (EFC). The country is now well known for the development of a high performing *Eucalyptus* hybrids used in forestry plantations (Marien and Peltier, 2010). Interspecific hybrids of *Eucalyptus* spp. have been developed and the germplasm (clonal material) deployed to commercial companies, e.g. in Angola, Kenya, Mozambique, Rwanda, South Africa and Uganda. In countries with a tropical to sub-tropical climate (e.g. Uganda, Kenya, Congo, DRC, Mozambique and Angola), *grandis* x *urophylla* hybrids have been introduced for growing on warm moist sites. In countries such as South Africa, investments to develop hybrid germplasm to extend the planting of eucalypts into colder environments is ongoing, whilst in other countries *grandis* x *camaldulensis* hybrids have been introduced for drier areas (e.g. Zimbabwe and Zambia) with limited success. In East Africa, clones of Eucalypts (GxU, GxT, GxC,) have been developed with support from Mondi, Gatsby Charitable Foundation and Tree BioTechnology Projects in Tanzania and Kenya (Msanga, 2016; Ngamau *et al.*, 2004). Hybrids have been created using controlled pollination and the hybrids are adapted to intermediate climatic and environmental conditions that are in-between the pure species and the new hybrids. Another objective of hybrid breeding is to combine favourable and complementary traits such as volume, stem form and drought tolerance. Examples of inter-specific hybrids are given in Table 4.

Whilst clonal forestry has increased productivity and resistance to pests and diseases in countries (e.g. South Africa) which have invested heavily in the technology, some countries with low level of investment might find clonal forestry expensive, as costs per plant might be higher than seedlings. Also clones might be susceptible to diseases and whole blocks of plantations might be wiped out (e.g. in Zimbabwe and Zambia, *grandis x camaldulensis* clones succumbed to pests and clonal plantings failed). Inter-specific hybrids tend to be more vulnerable than the pure parental species to pests and diseases (e.g. Harwood, 2011).

Table 4. Common inter-specific hybrids of eucalypt species planted in Africa.

Hybrids	Target environment	Examples	References
grandis x nitens	Frost prone sites	South Africa	ICFR, 2015;
grandis x urophylla	Tropical and sub-tropical humid areas	Mozambique, Angola, Uganda, Kenya	Kilimo Trust, 2011
grandis x camaldulensis	Drought prone areas	Zimbabwe, Zambia, Nigeria	Madhibha *et al.*, 2013 McComb and Jackson, 1969
grandis x tereticornis	Drought prone areas	Zimbabwe, Mozambique	Madhibha *et al.*, 2013

The adoption of clonal forestry has increased productivity and uniformity of pulp plantations in countries that have made large investments in capital and technologies, but there are dangers of narrowing the genetic diversity and pre-disposing the plantations to diseases and pests. Countries with well-established clonal forestry programmes need to continuously test the performance of hybrids in different conditions to make sure they are adaptable and resistant to pests and diseases. In East Africa, eucalypt clonal forestry has been promoted (e.g. through the Sawlog Production Grant Scheme in Uganda, Tree Biotechnology programmes in Kenya and Tanzania) and there are increasing concerns that small-scale tree growers are collecting seed from clonal trees for raising seedlings. This is resulting in poorly performing plantations and woodlots (Cheibowo, personal communication, 2016). There is need to raise awareness and regulate seed collection and distribution to ensure use of good seed. It should be noted that the "monoclonal blocks are impressive if they work, but are equally impressive if they don't" (Henson, 2011).

2.1.2. Eucalypt seed production

From the regional reports, it appears that seed of Eucalypts species is readily available. However, localised shortages may be experienced, e.g. the seed centre in Zimbabwe is failing to supply seed of certain eucalypt species due to increased demand for planting for providing energy for curing tobacco. Other species such as *E. nitens* are shy seed producers. Inconsistent flower and seed production is a major hindrance to the genetic improvement and commercial seed production of the species in South Africa (Swain and Gardner, 2003). The selection of sites for the establishment of orchards for commercial seed production and breeding of this species still presents a major challenge.

Seeds of most of the species are available, but concerns for genetic and physiological quality were reported in some countries. Systems for germplasm development and deployment for most eucalypt species are well advanced, although some countries indicated the need to re-invigorate their tree improvement programmes through enriching genetic diversity of species to improve productivity and expand afforestation into new eco-zones (e.g. frost prone and cold environments), to increase resistance to new pests and diseases (e.g. Blue gum chalcid, red gum lerp and bronze bug on *Eucalyptus* spp. in Southern Africa), and mitigate the potential impacts of climate change by importing provenances from the extreme ends of natural distribution of some species.

Most species planted in Africa are managed on coppice rotation (5-20 years), and it is only when the old moribund stumps are removed that new seed sources are planted. This cycle, if not managed carefully, might lead to the planting of inferior planting stock or in the case of trials, losing or depleting the original genetic diversity. The need for enrichment collection was mentioned in many countries and it is recommended that countries should engage with the Australian Tree Seed Centre (ATSC) – a unit under the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to acquire more seed from a diverse range of provenances.

The critical questions for eucalypt genetic resources in Africa are;

- whether the genetic pool held in Africa is broad and resilient enough to face the new challenges of climate change, new diseases and pests (e.g., Psyllid, chalcid and bronze bugs in many parts of Africa);
- are the *Eucalyptus* genetic resources robust enough to be further improved for yield since national economies are growing and the demand of wood is projected to increase;
- do African countries need to re-invigorate their *Eucalyptus* gene pool through new importation from Australia or other original sources;
- do countries need to engage in inter-specific hybridization to create new clones adaptable to new climatic conditions, resistant to pest and diseases and superior in performance to pure species and how costs effective is vegetative clonal forestry compared to seedlings?

2.2. Pine species for planting in Africa

Tropical pine species from Mexico and Central America are being used in plantations all over the world (Dvorak, 2000). In Africa, *Pinus* species are the second most widely planted species in environments ranging from cool-high rainfall high altitude areas to low-lying high-rainfall areas. *P. patula* was the first species to be introduced in South Africa from collections made in Mexico in the early 1900s (Butterfield, 1990).

Figure 5. 10 year old Pinus patula tree in Stapleford, Zimbabwe (Photo by C. Marunda, 2014)

The early plantings served as a source of genetic material for other countries in southern Africa for many years (Butterfield, 1990; Poynton 1977). Several species, mostly originating from the American or Asian tropics and subtropics, are now widely cultivated and planted, including *P. caribaea*, *P. elliottii* *P. greggii*, *P. kesiya*, *P. maximinoi*, *P. patula*, *P*, *oocarpa*, *P.radiata* and *P. tecunumanii*. *P. kesiya* is a tropical pine species from Asia, widely planted in Madagascar and Zambia. In West Africa, Nigeria established trials of the following species *P. caribaea*, *P. oocarpa*, *P. khasya (kesiya)* and *P. merkusii* as part of a series of species introduction trials in the 1960s.

Pines are popular because there is a wide range of species suitable for varying growing conditions; they flourish in dry, poor soil and degraded sites; the volume production of some of the species can be very high; they are robust pioneer species well suited for reforestation and for simple silviculture (monocultures and clear-felling) and for their wood qualities and uniform coniferous wood valued for production of lumber, chemical pulp, paper, particleboard, etc. (Lamprecht, 1990).

Table 5 shows that *P. caribaea* and *P. oocarpa* are widely planted in Africa, but do not necessarily occupy the largest plantation areas. These species grow well along low-lying coastal areas. Unconfirmed reports appear to suggest that there is a local shortage of seed of these species. For example, in Mozambique, private companies establishing plantations of the species in the northern part of the country are importing untested seed for plantation expansion. P. *maximinoi* and *P. tecunumanii* were recently introduced in Southern Africa and are slowly replacing *P. patula* as preferred species. Recently, countries such as Kenya, Mozambique, Tanzania, Uganda, South Africa and Zimbabwe have partnered with Central American Coniferous Resources (CAMCORE) to import new genetic material of selected *Pinus* spp. for enriching genetic diversity of existing species.

Table 5. List of commonly planted pine species in Africa.

Species	Regions introduced	Countries with records of species trials or plantations
P. caribaea	WA, CA, EA, SA	Burundi, Cameroon, Congo, DRC, Gambia, Ghana, Guinea, Kenya, Nigeria, Madagascar, Malawi, Mauritius, Mozambique, Liberia, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Rwanda, Zambia, Zimbabwe
P. elliottii	SA, EA	Burundi, Madagascar, Mauritius, S. Africa, Tanzania, Rëunion, Zimbabwe
P. greggii	SA	S. Africa, Zimbabwe
P. kesiya	SA	Nigeria, Madagascar, S. Africa, Zambia, Zimbabwe
P. maximinoi	SA	Mozambique, Tanzania, S. Africa, Zimbabwe
P. merkusii	WA	Nigeria
P. oocarpa	CA, WA, EA, SA	W/CA: all countries on the coast from Sierra Leone to Angola; EA: Ethiopia, Kenya, Tanzania, Uganda; SA: Malawi, S. Africa, Mozambique, Zambia, Zimbabwe
P. patula	SA, EA	Ethiopia, Kenya, Malawi, Mozambique, S. Africa, Swaziland, Tanzania, Rwanda, Zimbabwe
P. taeda	SA	S. Africa, Zimbabwe
P. tecunumanii	SA. EA	S. Africa, Malawi, Mozambique, Tanzania, Zimbabwe
P. radiata		S. Africa,

Main data source: http://www.cabi.org/isc/datasheet

2.2.1. Clonal forestry for pines

South Africa leads investment in pine clonal forestry. A number of hybrids are being tested in cooperation with CAMCORE (Table 6). One of the popular hybrids is *P. elliottii* x *P. caribaea* which consistently has shown good growth and form and field evaluation trials are showing that the *P. patula* x *P. tecunumanii* is showing a lot of promise (Camcore, 2013). The hybrids were created to improve resistance to diseases such as the pitch canker in *P. patula*, and to increase productivity (fiber gain). The development of clonal forestry for pines has been developed in cooperation with CAMCORE.

Table 6. Some of the hybrids planted or being evaluated in South Africa

Species	*P. patula*	*P. elliottii*	*P. radiata*	*P. tecunumanii*	*P. greggii*	*P. caribaea*
Crossed with	*P. pringlei* *P. greggii* *P. tecunumanii* *P. oocarpa* *P. elliottii*	*P. tecunumanii* *P. caribaea* *P. maximinoi* *P. taeda* *P. greggii*	*P. patula*	*P. oocarpa*	*P. maximinoi*	*P. tecunumanii*

Source: CAMCORE, 2013

2.2.2. Pine seed production

Demand of seed for *P. maximinoi* and *P. tecunumanii* outstrips supply in Southern Africa (e.g. Mozambique and Zimbabwe) (Nyoka and Tongoona, 1998; Gapare *et al.*, 2001), and even world-wide (Koskela *et al.*, 2014). The two species have been planted in a number of countries in Southern Africa and it is helpful to observe existing plantations and trials to follow flowering patterns and seed production levels and determine the landscapes most suitable for establishing seed orchards or seed production areas. The other species whose seeds are difficult to acquire in Mozambique are *P. caribaea* and *P. oocarpa* (Kachale, pers communication). The shortages are due to the fact that the species are shy seed-producers under certain climatic and ecological conditions and more research on flowering fecundity needs to be done to identify suitable conditions for good seed production. Other pine species were distributed by CAMCORE to its member organizations (mainly private companies) as part of a series of international provenance and progeny trials and developments of *ex-situ* conservation stands (Dvorak *et al.*, 1996).

Countries with a history of planting pines on a large scale (e.g. South Africa) reported sufficient supply of most pine species. This has been made possible because the private sector has invested in tree germplasm to meet own demand and sell excess seed. Zimbabwe used to be self-sufficient in pine seed supply and used to be the largest exporter of pine seeds. However, over the past years local shortages are common as investments in tree breeding and seed supply have gone down in the country. Some of the clonal seed orchards are too old and have lost vigour resulting in decreased yields (e.g. for *P. elliottii* and *P. taeda* in Zimbabwe). The same situation applies to countries like Malawi and Zambia where seed production areas have been neglected for a long time.

2.3. Tectona grandis planting in Africa

Teak (*Tectona grandis*) plantations account for 2.6 % of the plantation forests in Africa (AFORNET, 2005). Teak was introduced from Asia more than one hundred years ago, with reports of successful introductions to Nigeria and Cameron 1968 (Egenti, 1978, cited in Koskela *et al.*, 2010). Subsequent introductions were made into Tanzania, Togo (Chollet, 1956, cited in Koskela *et al.*, 2010) Ghana and Cote d'Ivoire (Tariel, 1966, cited in Koskela *et al.*, 2010) and Sudan (Hall and Williams, 1956). The species is grown in countries with a tropical moist and warm climate and it contributes significantly to production of high-quality tropical hardwood.

Figure 6 Tectona grandis trees (source: http://www.fincaleola.com/teak.htm)

The documentation of the origin (seed sources) of the plantings in Africa is poor and most of the collections are now referred to as local land races. Vehaegen *et al.* (2010) showed that nearly 95% of teak landraces in Benin, Cameroon, Côte d'Ivoire, Tanzania, Togo and Senegal came from North India, and 96% of Ghanaian teak appeared to be very closely linked to Central Laos. The study showed that trees from North India had very bad stem forms compared to Laotian and Thai provenances, which generally had good stem forms but low vigour. This genetic knowledge is essential for programmes to develop varieties and to improve the quality of plantations, particularly in Africa (Vehaegen *et al.,* 2010).

2.3.1. Seed production for Tectona grandis

In Africa, where teak is grown as an introduced species, seed supply is a major limiting factor in planting efforts and is reducing the quality of the plantations, especially in countries where seed is sometimes sourced from old trials or pilot plantations. In Nigeria, for example, availability of quality seeds is a major constraint as the current stands are generally of poor form especially the bole height, and fruiting appears very early (age 3) resulting in reduced height growth and more branching (Kwame Asomoah Adams, personal communication, 2016).Tanzania provided large amounts of seeds for plantations in EA, and later in WA Africa from seed sources in Kihuhwi, Bigwa and Mtibwa (Msanga, personal communication, 2016). It is well known that teak seed germination is poor and sporadic as a result of its dormancy behaviour. Under nursery conditions the germination of untreated seed is about 30-50% over a germination period of 50 days. Vegetative propagation is also used to propagate the species, for example, in Côte d'Ivoire, the Society for the Development of Forests (SODEFOR) and CIRAD developed a mass micro-propagation technique for the production of millions of vitro-plants from the improved clones of teak (Bouvet, 2011).

The trials established in WA in the 1970s continue to provide information on the species performance, produce seed for plantation development and material for vegetative propagation. Seed is collected from local land-races that are in most circumstances undocumented meaning that the genetic status is not known. The implication of this on productivity is difficult to quantify. The seed of the species is short-lived and is difficult to germinate and most countries reported on the adoption of vegetative propagation for planting stock. Seed supply is one of the most critical factors limiting the teak planting programmes. The germplasm shortage results from a scarcity of accessible, good quality sources as well as difficulties in delivering any available seeds or planting stock from source to end-user. This is especially so in Africa, where teak is grown as an exotic species, and seed used is mainly from old provenance trials or pilot plantations. Problems of seed supply, including the amount and quality of the annual seed requirement, are considered critical for successful plantation establishment.

It has been estimated that by using improved seed, the growth and/or volume production gain of the plantation is increased (from base populations) by 5-25%, depending on types of seed source and planting site (Wellendorf and Kaosa-ard, 1988). Thus, use of improved seed (i.e., from seed production areas, seed orchards and plus trees) is most essential in the improvement of growth, stem quality and other characters.

2.4. Gmelina arborea planting in Africa

G. arborea was first introduced in Nigeria in 1888 as an ornamental for planting along streets (Oduwaiye, 1983; Akachuku, 1984). Other countries participated in an international breeding trial with seed samples coming from Ghana (Forest Products Research Institute), Tanzania (Forest Research Institute), Malawi (Forest Research Institute) and Cote d'Ivoire (*Centre Technique Forestier Tropical*) (Lauridsen and Kjaer, 2002). In Africa, there are about 130 000 ha (1990 records) with the largest plantations found in Nigeria, Kenya, Ethiopia, Sierra Leone, Ghana, Ivory Coast and Cameroon grown for pulp-wood and fuelwood. It is also grown in countries such as Malawi, Tanzania and Zambia in small woodlots to provide energy (e.g. for curing tobacco in Malawi).

The early planting of the species are not well documented throughout its domesticated range in Africa. The species is easy and cheap to establish and has early rapid growth. Trials showed that progenies from landraces perform well, indicating that *Gmelina* responds strongly to domestication through plantation silviculture. However, there are reports that the species has problem with rapid reduction in increment after the seventh year of growth, a tendency of trees to die at a young age, problems with uneven and slow drying of wood, general poor stem and branching characteristics (Lauridsen and Kjaer, 2002).

2.4.1 Seed production for G. arborea

Figure 7. Figure 8. Plantation of G. arborea (http://vikaspedia.in/agriculture/crop-production/package-of-practices/tree-crops/gmelina-arborea)

Seed is currently being collected from local landraces although in most cases the origin of the seed is unknown and may be based on a very narrow genetic base. There is a risk of future pest and disease problems and loss of production due to inbreeding depression. Seeds are recalcitrant and are prone to fungal infection and are difficult to store as they quickly lose germination capacity. Most seed centres reported on the need to improve the storage of the species. A solution to the problem of recalcitrant seed is to raise seedlings for distribution, but that would mean extra costs to the seed centres.

2.5. Acacia species for planting in Africa

Acacia species are the third mostly planted genus in Africa. Plantations of *Acacia mearnsii* were established in Kenya, Morocco, South Africa, Swaziland and Zimbabwe for tannin bark, poles, firewood and charcoal production with a total estimated net area of about 325 000 ha. Acacias are also widely planted for the production of gum Arabic, energy and fodder. The main species planted for gum production are *A. senegal* and *A. seyal*. Gum Arabic is one of the oldest articles of trade from North Africa and contributes significantly to the economies of the countries with natural stands and artificial plantings of the species.

Natural stands of *A. senegal* are managed for gum Arabic production, and a number of plantations have been established. Sudan has the largest area with 223 000 ha. The species has attracted a lot of research on provenance growth and productivity in a number of Sahelian countries and genetic resources have been assembled. Extensive plantations of A. *senegal* are found in Cameroon (Harmand *et al.*, 2012), Ethiopia (Alema *et al.*, 2013), Kenya (Wekesa *et al*., 2009), Nigeria (Mokwenyu and Aghughu, 2010) and Sudan (Gafaar, 2011). The species has a wide geographical distribution in Africa and is a rather variable species with four varieties recognized namely *senegal, kerensis, leiorhachis* and *rostrata* (Brenan, 1983; Cossalter, 1991). A number of trials were established to understand the performance and productivity of the species in different parts of Africa, making it one of the most studied African species, e.g. in the dryland Savannahs of Niger (Larwanou *et al.,* 2010), in Baringo District of Kenya (Lelon *et al.,* 2010), the Sahel region of West Africa (Diallo *et al*., 2015), Nigeria (Fakuta *et al.,* 2015) and Zimbabwe (Barnes *et al.,* 1999).
A. senegal is important to many countries in Africa. It has been proposed to strengthen regional programs (e.g. the Network for Gum Arabic and Resins for Africa – NGARA) for the rehabilitation and development of the species with the aims of increasing income of rural communities from gum Arabic sales, increasing government tax revenues from domestic and export sales, increasing foreign exchange earnings from export, and promoting soil fertility, pasture growth, and firewood production.


Figure 8. Gum Arabic trees at Kilo 26 refugee camp, Sudan (Photo source: IUCN Photo Library © Intu Boedhihartono)

In the dry regions of Africa, acacias are the common natural regeneration species on degraded lands. Being indigenous, they do not pose a threat of invasion other than in a pioneering capacity. On the other hand, their valuable contribution to agriculture can be sustained through management to make them effective climax species in the agricultural system (Barnes *et al*., 1996). The second most studied Acacia species is *Faidherbia albida* (previously *A. albida*). It is widely distributed in Africa (Wickens, 1969) where it grows under varying conditions of rainfall, soils and altitude. Its importance as a multipurpose tree in agroforestry in Africa is well recognised, with both leaves and pods used as fodder, especially at the end of the dry season, when other sources of fodder are scarce. The tree also positively affects soil fertility and produces a wide range of other products used by rural communities. The species is managed in parklands in many countries of West Africa, and is planted in fields and along farm boundaries. *F. albida* is widely planted and tested in different agro-ecological zones in many countries in Africa although the area planted is difficult to estimate as it is planted in fields and on farm boundaries. Extensive collections of different seed sources of *F. albida* are kept by the former Oxford Forestry Institute and a series of trials were established in a number of countries (Fagg *et al.,* 1997).

Other acacia species of interest in Africa include *A. nilotica* which is also managed and grown for timber in Sudan; *A. karoo A. erioloba* and *A. tortillis* which were also assembled and tested in a network of trials in Southern Africa (Fagg *et al.,* 1997; Barnes *et al.,* 1999). Thus, acacia represent an important genus that can significantly contribute to the sustainable management of forest resources in Africa.

2.5.1. Seed production for Acacia species

Seeds of *Acacia* species are easy to collect and the species generally produce large amounts of seed which store easily (because of the hard seed coats), but genetically improved planting stock is yet to be distributed for operational planting. The genetic description of the species, particularly for the African acacias, is not yet complete, and understanding of the genetic variability and adaptability is crucial for increasing productivity and quality of gum Arabic production.

2.6. Australian Acacia species grown in Africa

A number of phyllogenous Acacia species from Australia were introduced into Africa, mainly for fuelwood, soil stabilization and browse (Vercoe, 1987) and for food in dryland tropical Africa (House and Harwood, 1992). Species introduced and tested include *Acacia colei, A. cowleana, A. tumida, A. adsurgens, A. ampliceps, A. aneura, A. eriopoda, A. holosericea, A. kempeana, A. ligulata, A. neurocarpa, A. saligna, A. sclerosperma* and *A. victoriae*. Promising species in West Africa include *A. colei*, *A. holosericea* and *A. neurocarpa* (Cossalter, 1987). *A. saligna* is the most important acacia in north Africa (El- Lakany, 1987) whilst in Zimbabwe, *A. holosericea, A. aneura, A. auriculiformis, A. leptocarpa, A. cowleana* and *A. ligulata* showed early promise (Gwaze, 1987).

The major disadvantages of the Australian acacias are that they are short-lived and do not coppice very well, thus creating the necessity to replant more often. This is not attractive from a management perspective for the target community groups who are often constrained in terms of resources. Seed supply is not a problem since most acacia species produce large amounts of seed which have hard seed coats making them easy to store and can remain viable in the soil for many years.

2.7. Indigenous commercial species

Commercial indigenous tree species have been the main source of timber in countries rich in natural forests, e.g. in WA and CA. Special hardwood timbers are also harvested in countries with dry forests, e.g. Zambia and Mozambique. Due to their superior wood qualities and the need for conserving natural populations, most African countries are supporting programmes to plant indigenous commercial species. Examples of priority species include, *Khaya senegalensis*, *Nauclea diderrichii, Terminalia* spp., *Entandrophragma* spp, *Milicia excelsa* and *Triplochiton scleroxylon* (in W/CA), *Acacia* spp., *Cordia africana, Markhamia* spp. and *Vitex keniensis* (in EA) and *Afzelia quanzensis*, *M. excelsa*, *Baikaea plurijuga*, *Khaya anthotheca* and *Pterocarpus angolensis* (in SA).

Planting of commercial indigenous timber species is more wide-spread in W/CA than in other regions of Africa. This is mainly because the species are commonly harvested for timber and there are concerns of over-exploitation of the species. The main seed sources for indigenous tree species are natural forests because they have not been tested in provenance trials. In general, bulk seeds collected from natural stands and from remnant trees scattered in farmlands constitute the major source of material for establishing plantations and woodlots. Therefore, seed supply for most of the indigenous tree species are grossly inadequate and the use of genetically superior planting stock is uncommon.

A few species and provenance trials have been established, for example, in Gabon a trial of 13 provenances for *Aucoumea klaineana* from throughout the species distribution, was planted in 1967 in the M'Voum Reserve. More recently, provenance trials for *Baillonella toxisperma* (Moabi), *Distemonanthus benthamianus* (Movingui) *and Erythrophleum suaveolens* and *E. ivorense* (Tali) collected from different populations across the climatic regions in Cameroon, Gabon and Republic of the Congo, were established in forest gaps in Cameroon and Gabon (FAO, 2014 cited in Avana-Tientcheu, 2016).

A list of the most common species is given in Table 7. Species planted included *Terminalia* spp., *K. ivorensis, C. pentandra, Lovoa trichilioides, Entandrophragma angolense, Prunus africana, T. scleroxylon, Milicia* spp., *Diospyros crassifolia* and *Baillonnella toxisperma* Technologies for the production of high quality seedlings include selection of plus trees or pest resistant individuals and adaptation of conventional vegetative propagation techniques for mass production. In most countries in W/CA, the main technologies for the production of high quality seedlings are vegetative propagation techniques, especially for tree species that have poor and difficult seed production (Avana-Tientcheu, 2016). In EA, commonly planted indigenous species include *Khaya* spp., *Cordia africana*, *Terminalia ivorensis, Vitex keniensis, Makhamia lute* and *Milicia excelsa* (Msanga, 2016). In southern Africa, the commonly used species include *Khaya anthotheca*, *M. excelsa* and *Pterocarpus angolensis* (Marunda, 2016).

Table 7. List of common indigenous commercial species for planting

Species	Common Names	Potential uses	Regions
Khaya ivorensis, K. grandifolia, K. angolensis	African Mahogany	Plywood, Veneer, Boards, Furniture	CA, WA, EA, SA
Terminalia superba	Ofram Veneer/Frake/Limba	Plywood, Furniture	WA
Pycanthus angolensis	Otie Plywood/Ilomba	Veneer, Boards, Furniture	WA
Canarium schweinfurthii	Bediwonua Plywood/Aiélé	Veneer, Boards, Furniture	WA
Dalbergia sissoo, D. retusa	Rosewood Furniture	Veneer, Plywood	WA, EA
Tieghemella heckelii	Makore Plywood	Veneer, Boards, Furniture	WA
Pterygota macrocarpa	Koto Plywood	Veneer, Boards, Furniture	WA
Triplochiton scleroxylon	Wawa Plywood/Ayous	Boards, Particle Board	WA, CA
Entandrophragma angolensis	Edinam Plywood/Tiama	Veneer, Boards, Furniture	WA, CA, SA
E. cylindricum	Sapeli Plywood	Veneer, Boards, Furniture	WA
E. candolli	Kosipo Plywood	Veneer, Boards, Furniture	WA
E. utile	Sipo plywood	Veneer, Boards, Furniture Plywood	WA
Ceiba pentandra	Ceiba	Veneer Plywood, Boards	WA, CA
Hallea stipulosa	Subaha	Furniture Boards	WA
Milicia excelsa	Odum/Iroko	Furniture, Parquet	CA, WA, EA, WA
Terminalia ivorensis	Emire/Framire	Veneer, Plywood	CA, WA
Nauclea diderrichii	Kusia/ Bilinga	Furniture, Parquets, panelling	WA

2.7.1. Tree germplasm for indigenous commercial species

A major concern for the planting of indigenous commercial species is the availability of planting stock. Rather than relying on seed alone, some species can be propagated vegetatively. For example, in Ghana, the Forestry Research Institute has developed techniques for production of *M. excelsa* (Iroko) clones that are tolerant and resistant to the gall forming insect *Phytolyma lata* using vegetative and tissue culture protocols to capture resistant lines. The techniques and protocols developed have opened up opportunities for large scale planting of this important timber species in Ghana and Cote d'Ivoire and also as a way of addressing plantation failure of African Mahoganies (*Khaya* and *Entandrophragma* spp, *K. ivorensis, E. utile), T. scleroxylon* and *M. excelsa.* (Acquah *et al*., 2013).

Priority species for regional cooperative research include *Khaya* spp., *Milicia excelsa, Entandrophragma* spp., *Terminalia* spp., *Triplochiton scleroxylon* and *Dalbergia* spp. A good starting point for research will be a review of the level of use of these species in plantation development and the availability of seed sources. Most of the species have not been systematically collected. A key strategy will be to collect the seed during harvesting operations and use them to regenerate the harvested areas. This strategy would require detailed knowledge of the ecology of the species and how they regenerate under natural conditions. For example, most of the tropical forest species regenerate by responding to gaps created after felling and there is need to use appropriate silvicultural interventions favouring the attainment of the canopy of selected species (e.g. Bongjoh and Mama, 1999). This process can be augmented by collecting and using seed from the harvested trees for regeneration. The use of seed from harvested trees ensures that the best possible seed sources are used and contributes to genetic conservation.

The challenge of planting ICS is to access a supply of genetically superior seeds since existing seed trees are continuously being depleted by indiscriminate felling as well as other deforestation and forest degradation drivers. In response to this depletion of natural forest resources, activities have been carried out in recent decades on tree germplasm production and improvement to meet growing demand from public and private plantation owners. African countries will need to conduct joint seed collection of key species such as *Khaya* spp., *Entandrophragma* spp., *Terminalia* spp., and *Milicia* to exploit the genetic variability throughout the geographical distribution of the species. As a default strategy, harvested areas should always be planted with seed collected from the same area as this could provide higher chances of successful regeneration than using seed from other locations that might have different climatic and ecological conditions.

2.8. Agroforestry - Indigenous fruit trees

Domestication and commercialisation of IFT has been promoted in most African countries through the leadership of the World Agroforestry Centre (WAC) in partnership with government agencies, NGOs and farmer groups. The programmes aim at promoting the domestication and improvement of IFT with economic potentials as new cash or novel crops, and provide incentive to subsistence farmers to grow such trees that contribute towards achieving poverty reduction, enhancement of food and nutritional security (Awodoyin *et al*., 2015). The choice of species is as diverse as the ecological regions of Africa. Species that cut across regions of Africa include *Adansonia digitata*, *Sclerocarya birrea*, *Uapaca kirkiana*, *Ziziphus mauritiana*, *Cola* spp, *Parinari* spp., *Tamarindus indica*, *Allanblackia* spp. *Vitellaria paradoxa*, *Garcinia cola*, *Strychnos* spp and many others. The choice of species is highly localised. Domestication of IFT has been done in a participatory way in all the regions of Africa, and the involvement of farmers in the selection of species and seed/fruit trees/source has explicitly involved genetic selection of the best trees or provenances suggesting that seed-lots held by research organisations are of good genetic make-up (Tchoundjeu *et al*., 2006).

Figure 9. Planted baobab trees in a farmer's field near Ouagadougou, Burkina Faso (Photo by Henri Bouda 2005).

Research on the domestication of local fruit trees started recently through projects concentrating on some of the most important indigenous species in Africa. In the last couple of years, new concepts and approaches have been developed, case studies have been produced and the potential and feasibility of their domestication and commercialization has been explored (Akinnifesi *et al*., 2007, Jusu and Cuni-

Sanchez, 2016). Priority lists of species have been agreed upon by national, regional and international research organisation (e.g., WAC/ICRAF). The lists have been developed using the approach described by Franzel *et al*. (1996) which constituted a combination of focus-group data, field observations, market surveys and ranking exercises to determine which IFTs have highest potential for domestication and commercialisation. IFTs have so far been grown around homestead as shade trees, nurse trees, in community protected sacred forests, wild and volunteer stands on farms, market squares, village lands and forest areas.

Table 8. Priority indigenous fruit trees for domestication in sub-Sahara Africa.

Species	References
West Africa (Sahel region)	
Adansonia digitata; Parkia biglobosa; Tamarindus indica; Vitellaria paradoxa; Ziziphus mauritiania	Raebild *et al*., 2011
Central Africa	
Irvingia gabonensis; Dacryodes edulis; Ricinodendron heudelotti; Chrysophylum albidum; Garcinia cola	Tchoundjeu *et al*., 2006
Parinari excels; Cola lateritia; Pentaclethra macrophylla; Heritiera utilis; Bussea occidentalis	Jusu and Cuni-Sanchez, 2016 - list for Sierra Leone
East Africa	
Adansonia digitata ; Carissa edulis ; Parinari curatellifolia ; Sclerocarya birrea; Tamarindus indica ; Ziziphus mauritiana ; Balanites aegyptica; Berchemia discolour; Borassus aethiopium; Cordeauxia edulis; Strychnos cocculoides; Vangueria madagascarienses	Teklehaimanot, 2005
Southern Africa	
Uapaca kirkiana; Strychnos cocculoides; Parinari curatelifolia; Ziziphus mauritiana; Adansonia digitata; Sclerocarya birrea	Akinnifesi *et al*.,2006

2.8.1. Germplasm supply for indigenous fruit tree species

The situational analyses in Africa has shown that collection of seed/fruit has been limited to supply the demand for tree improvement by international organisation (e.g. ICRAF) and conservation by national tree seed centres. For communities, collection targets the fruit for consumption or processing into other products (e.g. baobab for powder), *V. paradoxa* for shea butter rather than collection for seed or tree germplasm. The challenge to widespread adoption of IFT is the unavailability of high quality planting stock of high priority species. Caradang *et al*. (2007) observed that activity on IFT is constrained by availability of planting stock, distance to seed/fruit sources (often remote as the trees near villages are harvested first), lack of propagation techniques, and lack of awareness among the farmers. In many parts of Africa, exotic fruit trees are deployed as improved planting stock in the form of potted seedlings. This tradition might give guidelines for the future development of IFTs. Deployment of improved grafted material might offer a solution to the limited availability and improve domestication uptake. The widespread uptake of IFT is slow and there is need to change research and deployment strategies and community/household attitudes toward IFT from depending on wild sources to engaging in domestication processes.

Tree germplasm for most species is still scarce with national tree seed centres still not able to supply seed. A few nurseries have reported the supply of IFT seedlings. A small number of IFT species are scarcely grown deliberately by the farmers, who most times depended on wildings they came across for transplanting and regeneration of their selected local fruit trees. Knowledge and technical know-how of propagation and nursery management of the IFT are more or less lacking and there is need to identify new technologies to promote the propagation of the priority species. Unlike other species, IFT require vegetative propagation (grafting, air-layering, marcotting) to advance the time to fruit production, as for *Ziziphus mauratiana* (Kalinganire and Koné, 2010). More research is needed to expand knowledge to other useful species within the region. Seedlings rather than seed could be the best way to deploy improved planting stock of IFT to farmers. Efficient vegetative propagation based on simple horticultural techniques was shown to be possible for most IFT species (Tchoundjeu *et al*., 1998).

2.9. Agroforestry (MPTS) species planted in Africa

MPTS and agroforestry species have had a fairly recent history in the region. The World Agroforestry Centre (ICRAF) based in Nairobi, Kenya, with regional and country offices in some African countries, has spearheaded the research on MPTS. Most of the species used in agroforestry are exotic leguminous species and the main ones include *Acacia crassicapa, Azadirachta indica, Calliandra calothyrsus, Glyricidia* spp.*, Leucaena leucocephala, Senna siamea, Sesbania sesban* and *Tephrosia vogellii* for the E and S African regions. For W/CA, common species include *Acacia auriculiformis, Albizzia lebbeck, Flemingia congesta, Gliricidia sepium*, *Leucaena leucocephala* and *Piliostigma malarborium*. A wide range of indigenous species are also grown in agroforestry systems and the species depend on the region. The most commonly mentioned species is *Faidherbia albida* (*Acacia albida*) which has been collected throughout its geographical range in Africa and tested across many sites. Gradually the species is becoming the default species for planting in farming systems in the sub-tropical parts of Africa. ICRAF has led the tree improvement programmes of selected species and most of the research outputs are targeted for the densely populated regions of EA, SA and W/CA.

2.9.1. Seed production and supply for MPTS

The seed production of many MPTS is still very informal. There is a lot of germplasm in the region that is being deployed to farmers. Most NTSC, except Malawi, reported that they did not collect or distribute agroforestry tree seeds. The perception reported by most seed centres is that putting in place a strategy to collect agroforestry seed is difficult and may be costly since priorities for end-users keep changing. The fact that most of the demand for such species is driven by donor projects creates a level of uncertainty, and Forestry Departments tend to favour long-term research funded from government fiscal allocation. In countries where there is a strong demand (Malawi), the seed business has attracted several stakeholders and there is no control or capacity to monitor the quality of the seeds. There is need to set some standards and improve the capacity by government to monitor seed quality. Sustainability of planting agroforestry species beyond the tenure and involvement of international organisations need to be evaluated since the perception that the activities are donor driven is quite common and in-grained.

Seed production of many agroforestry species is still very informal. ICRAF has led the tree improvement programmes of selected species and most of the research outputs are targeted for the densely populated regions of EA, SA and W/CA. Problems were reported in the supply chain of agroforestry germplasm with seed still being collected by farmers and on rare cases by national tree seed centres from introduction trials, home-gardens, demonstration plots, and extensive trials initiated through donor funded programmes. Some of the trials have however been abandoned after the donor funded projects ended. Local farmers collect seed from their own plantings and share the seeds amongst themselves. Farmers prefer to collect from trees on their farmland to minimise collection costs. This strategy, though prudent, does not guarantee the genetic and physiological quality of the germplasm.

Seed deployment has been reported to be through three channels, viz. central government through NTSC, NGOs through donor funded projects and farmer to farmer exchanges. There is still a perception amongst national developmental practitioners and farmers that agroforestry is a donor driven process, and this negates local initiatives and can be a barrier to uptake of the agroforestry technologies. In some countries, such as Zambia, it was indicated that long-term strategic planning for improving agroforestry tree species and the supply of genetic resources is difficult because of changing priorities, changing end-products and uses, and the short-term nature of funding.

3. Threats to tree germplasm in Africa - pests, diseases and climate change

Eucalypt genetic resources in Africa are facing threats from pests, namely Blue gum chalcid (*Leptocybe invasa*), Red gum Lerp (*Glycapsis brimblecombei*) and termites that have been reported in West Africa (Bosu, 2016), East Africa (Gichora, 2016) and Southern Africa (Kojwang, 2016). These pests have caused increased rates of deformed trees and mortality. Diseases have also been reported in *Pinus* spp., *Cupressus* spp. and *Acacia* spp. *P. patula* seedlings have shown susceptibility to Pitch canker caused by *Fusarium circinatum* (Couitinho *et al*., 2007). There are concerns by the forestry industry in Southern Africa over ongoing severe post-planting mortality of *Pinus patula* associated with *F. circinatum* and many tree breeding programmes are looking at how to control the disease through tree breeding (ICFR, South Africa, 2014, Gapare, personal communication, 2016). A rust fungus caused by *Uromycladium* has been reported on *A. mearnsii* and is causing sudden death of the species in South Africa (McTaggart *et al*., 2015).

In West and Central Africa, many pests and diseases have also been reported on indigenous species (e.g. Bosu, 2016). Integrated pest and disease management strategies have been implemented, and there are consistent calls to include tree breeding to manage pests and diseases. This may involve introducing resistant seed sources (provenances) into the current genetic pools and introduction of hybrids bred for resistance. This would require African countries to increase investments in forest research and development, and tree germplasm acquisition and testing.

The threats of diseases and pests on forest genetic resources has been linked to climate change but the impacts of climate related events remain poorly understood although there is good evidence for increased pest problems in some situations (Sturrock *et al*., 2011). Any linkages would need increased emphasis on forest health management and also adaptation of strategies to deal with a changing climate.

The pests on eucalypt species have been linked to movement of people across borders and the importation of vegetative materials, e.g., eucalypt clones from South Africa to other countries (Kojwang, 2016). Given the dramatic increases in the movement of pests globally (Liebhold *et al*., 2012; Santini *et al.*, 2013), forest health will be an increasingly important constraint to forest productivity. Investment in forest health research is globally significant and organisations such as IUFRO (www.iufro.org) are coordinating major global initiatives on forest health including, for example, newly established task forces on these topics (Koskela et *al.*, 2010). Tree breeding through testing resistant seed sources and creating hybrids with genetic resistance could be some of the broader integrated management strategies that can minimise losses. It is clear from reviews of pests and diseases problems on trees and forests in Africa and from the associated literature that these are giving rise to increasing levels of loss in planted forests.

4. National tree seed centres (NTSCs)

Tree seed production varies from year to year and across different seed production zones. In order to maximise economies of scale, there is need to have capacity to store seed for long periods to meet future demand. In most countries in Africa, seed centres were established through national and international support and a network of National Tree Seed Centres (NTSC) exists. The seed centres are the bridges though which high quality germplasm passes to the users. For example, in Southern Africa, the SADC Tree Seed Centre Network was funded by the Canadian International Development Agency (CIDA) and seed centres were established in all the 11 countries in the region. In East Africa, DANIDA and NORAD supported the establishment of the seed centre in Tanzania and Uganda, respectively. The Rwanda Tree Seed Centre was supported by the Australian Tree Seed Centre (ATSC) with ICRAF supporting and promoting agroforestry technologies in the country. The Kenya tree seed centre was supported by the German Agency for Technical Co-operation (GTZ). In West Africa, the Burkina Faso and Senegal Tree Seed Centre (Centre National de Semences Forestières (CNSF) – Programme National de Semences Forestières (PRONASEF)) were supported by the Royal Botanic Gardens, Kew (UK), Ministère de la Région Wallone, Direction Générale des Ressources Naturelles et de l'Environnement (Belgium), Plant Resources of Tropical Africa (PROTA) Network Office Europe (Netherlands) and DANIDA Forest Seed Centre (Denmark) (Henri Bouda, personal communication, 2016).

4.1. Challenges facing NTSC

Most NTSCs were intended to be high quality facilities that had the potential to play a leading role within a tree improvement programme and to support deployment of seed and planting stock to tree planting programmes. The operational status of the seed centre varies from country to country but those countries with fully equipped functional seed centres show consistently high rates of tree planting e.g. Burkina Faso, Kenya, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zimbabwe.

NTSCs were designed for supplying seed to the plantation industry but struggled to meet smallholder demand for tree seedlings and seed. This is due to the fact that small-scale farmers are often widely dispersed and require only small volumes of particular tree species, making it expensive to reach them. More decentralised models of tree germplasm delivery, supported by many donors and carried out by NGOs, do not appear to have improved the general situation for small-scale farmers, due to a range of factors including the restricted timescale of projects, the lack of attention to the promotion of high quality material, and insufficient technical knowledge in handling tree germplasm (Lillesø *et al.*, 2011).

In other countries, seed centres are facing challenges from competition from the private sector and lack of support from the Government. In countries like South Africa and Mozambique, the private sector has taken the lead in the development and deployment of seed for commercial species and for own use with specified products (e.g. fiber gain in South Africa, sawlog and poles in Mozambique). This means that whilst seed is available for commercial planting, other planting programmes such as community woodlots and environmental restoration efforts will face seed shortage (e.g. in South Africa).

Most seed centres reported a decline of funding for research especially tree breeding resulting in loss of capacity to advance the breeding programmes to yield superior planting stock. Tree seed centres in many countries are failing to meet the demand. For example in Tanzania, the demand is 40 tons of seed but the NTSC can only supply 12 tons, Kenya needs 30 tons but supply is 7 tons, Uganda demands 30 tons against a supply of 15 tons. In other countries, such as Malawi, Zambia and Zimbabwe, most of the pine seed orchards are old and have lost vigour to produce large quantities of seed.

In Zimbabwe, some eucalyptus seed orchards were illegally logged. The seed centre in Mozambique was transferred to the Department of Agriculture (*Instituto de Investigacao Agraria de Mocambique*) resulting in the seed centre losing its visibility and ability to prioritise tree seed deployment. In other countries, such as South Africa, the functions of the seed centre were privatised and most private companies such as SAPPI provide their own seed and sell the excess. However, seed for non-commercial species are not readily available as the private companies focus on commercial species.

In W/CA, most of the tropical hardwood species have recalcitrant seeds (i.e. lose viability after a short period of time and are difficult to store). In such circumstances, the supply of seed becomes a critical constraint. The situation is further exacerbated by the fact that commercial trees of good phenotype are targeted during harvesting and the genetic make-up might be eroded. Most species are propagated using vegetative cuttings, but this technology is expensive for most countries, and nurseries are struggling to meet the demand. This would suggest strong collaboration between seed centres and nurseries to meet the demand for good quality planting stock.

All seed centres reported a lack of investment in new equipment for collecting, storing and testing seeds. As mentioned earlier, most seed centres were established with support from donors with the hope that they would become sustainable. The decline in investments in forestry research resulted in seed centres not being able to restock seed. Seed storage in some countries, e.g. Zambia is virtually non-existent, and in Zimbabwe, the frequent power cuts have damaged the cold storage facilities with large amounts of seed losing viability. Testing of seed quality (purity and viability) follows international standards set out by ISTA but is limited to commercial species. The Zimbabwe TSC and SAPPI Seed Technology Programme use the effective kilogramme concept where seed is sold based on its germination capacity and not weight. For example, SAPPI is selling pine and eucalypts seed as for ZAR 0.10 (select seed), ZAR 0.3 (select seed), ZAR 0.17 (elite seed) and ZAR 0,02 for Acacia seed.

4.2. Germplasm deployment models

Seed deployment pathways vary from country to country and are also dependent on the species. The following are common pathways:

- the government model – National tree seed centre,
- the NGO model,
- informal decentralised model,
- private sector,
- nurseries

Most countries with established NTSCs use the government model, where research on tree breeding and tree seed production is conducted by national institutions. Seed production areas are established in different ecological regions to maximise seed production. The seed is collected and stored at a central location for future distribution to tree planting projects or for exporting to international markets. This model ensures good control of genetic and physiological parameters. The government model allows for better forecasting seed demand through access to national forest statistics. This model has been supported by donors and has worked well in many countries, although recent reviews by Avana-Tientcheu (2016), Marunda (2016) and Msanga (2016) have shown that most NTSCs are struggling to meet demand.

The NGO model has been applied mainly to agroforestry and indigenous species, especially fruit trees. ICRAF has been on the forefront providing tree germplasm to farmers. In collaboration with its partners in Africa, it has promoted participatory tree domestication approaches to better share the benefits at a local level and to make use of tree species that are important both at local and regional levels. Most of the seed originates from genetic trials, source countries or from farmers' fields. A number of NGOs have advocated for tree planting projects in many Africa countries, and have been supplying seed to rural communities. The government model focuses on commercial species (pines and eucalypts), creating a gap on the supply of other species. The NGO model is effective as it reaches out to the small-scale growers who are disadvantaged and geographically dispersed.

The informal decentralised model involves individual farmers exchanging seed amongst themselves. Traditionally, farmers have been exchanging crop seeds for many generations. Many fruit trees have been introduced through this model. It is difficult to quantify the level of tree seed exchanges currently taking place. There are reports in Kenya, for example, that farmers are collecting and exchanging seed from eucalypt clonal trees resulting in reduced growth (Cheibowo, personal communication, 2016). This calls for the need to raise awareness on the importance of genetic quality and for a national system to control access and use of such genetic resources.

In countries with large private forest companies (e.g. South Africa), tree germplasm is being produced and distributed by private companies. For example, SAPPI has a Seed Technology Programme which is committed to providing high quality, genetically improved tree seed. SAPPI supplies most of the commercial pine (*P. elliottii*, *P. patula*, *P taeda*, *P. caribaea*, *P greggii*, *P. kesiya* and P. *tecunumanii*) and eucalypt species (*E. dunnii*, *E. grandis*, *E. macarthurii*, *E. nitens*, *E. smithii*, *E. badjensis*, *E. benthamii*, *E. dorigoensis*, *E. pellita*, *E. saligna*, *E. urophylla* and *E. viminalis*). The seed is primarily used by the company and the excess is sold to other customers. The private model guarantees seed supply but is often limited to a few commercial species. In South Africa, the Department of Agriculture, Forestry and Fisheries (DAFF) reported on shortages of seed of other non-commercial species for community tree planting projects (Modise, personal communication, 2014).

Nurseries are increasingly becoming a pathway for distributing tree germplasm. A number of private companies are sub-contracting nurseries to raise seedlings for commercial species. Some IFT are now being grafted (e.g. *Z. mauritiana*) and tree germplasm is being exchanged as grafted material. The nursery model will become an important pathway for distributing high values species that are difficult to grow from seeds. However, the technical and financial capacity of nursery managers have to be strengthened on aspects such as selecting seed sources, collecting, handling, processing and testing seeds of high value exotic, indigenous and agroforestry species.

5. Tree germplasm documentation, regulation and agreements

A critical part of tree germplasm production and distribution is documentation, and following national and international regulations and agreements to seed movement. Because of the long nature of tree growing, records of seed origin and genetic status is important. Reviews of tree breeding and tree germplasm supply in Africa showed that most countries have records of seed sources and genetic trials. This information is important when making decisions on site-species matching.

Tree germplasm for most commercial species (pines and eucalypts) in countries with established tree breeding programmes have some form of classification based on the level of genetic improvement. The main seed categories include: source-identified, selected, untested seed orchards, and tested seed orchards. Most countries are members of the Organisation for Economic Cooperation and Development (OECD) and follow international regulations for the production of high quality seeds although most countries apply the rules only to crop seeds. A few countries, such as Burkina Faso, Ethiopia, Rwanda, Kenya, Tanzania and Madagascar, follow the OECD Forest Seed and Plant certification scheme. Other countries, like South Africa and Zimbabwe, have seed categories based on the generation of selection and whether the material is hybrid or clonal.

The International Seed Testing Association (ISTA) rules are not applied when testing seed purity and viability, but established seed centres such as those in Burkina Faso, Tanzania, and Zimbabwe apply ISTA rules to a few commercial species (pines and eucalypts) especially on seed sold to large forestry companies and for export. When exporting seeds, most countries adhere to phytosanitary regulations and requirements of the importing countries.

The Nagoya Protocol on the forestry sector's research and development activities adopted by the Convention on Biological Diversity in 2014 could have implications on the exchange of research seed-lots as providers of germplasm might put some restrictions on access and movement across countries or between providers and users (Koskela *et al.*, 2014). This may add a new layer on the cost of importing seed for research. African countries might want to create a platform for controlling, improving and supporting the movement and utilization of tree germplasm for research through a common pool approach.

6. Main recommendations

6.1. Policies on afforestation and reforestation

There are renewed calls to increase the rates of tree planting in Africa to secure future wood supplies, increase the supply of non-timber forest products and provide environmental services such as climate change mitigation and restoration of degraded sites. The statistics on planted forests are not reliable in several countries because of lack of inventories, frequent fires, and lack of maintenance and/or uncontrolled clearing (e.g. Guinea, Ghana, Liberia, South Sudan and Chad). Forest agencies and departments need to track changes in policies and collect forest statistics so as to plan for future choice of species and amounts of seed.

6.2. Identifying priority species for action

Precedents for priority species for inclusion in tree planting programmes have been set in all regions of Africa (Table 9). Lists of species have been tested and tried in most African countries.

Tree breeding programmes have been initiated and attempts made to produce good quality germplasm albeit with different outcomes. Some countries have chosen to depend on seed from other countries thus laying out a basis for seed import and export transactions. Any regional tree breeding and tree germplasm management is better handled using a species approach. Given the high number of forest species present in each country, it is impossible to develop research activities or programmes for all. Priority species should be identified at regional, national and sub-national levels, and these priorities should be shared in existing regional and international fora so as to provide better focus and more efficient resource use.

Thus there is need to update priority species lists regularly at both country and regional levels and provide international support for the development of guidelines for species prioritization and for the identification of priority areas of research. From the analyses of the situation in the four regions of Africa (Central, Western, Eastern and Southern Africa), most countries have a wide diversity of species shared across regions and countries providing the scope for joint research ventures and pooling of resources to acquire new genetic resources to enrich existing pools. Based on the regional analyses, the priority lists in Table 9 are recommended for research activities at regional or Africa wide scales. Obviously, the lists will require refinement through collective expert opinions distilled from literature reviews and first hand experiences from each of the countries.

Table 9. Priority indigenous fruit trees for domestication in sub-Sahara Africa.

Species	Potential Regions
Eucalypts	
E. camaldulensis	CA, EA, SA, WA
E. grandis	CA, EA, SA, WA
E. tereticornis	CA, EA, SA, WA
Interspecific hybrids (GxU, GxC)	SA, CA, WA
Pines	
P. caribaea	CA, EA, SA, WA
P. maximinoi	SA, EA
P. oocarpa	CA, EA, SA, WA
P. tecunumanii	SA, EA
Interspecific hybrids	SA
Commercial *Acacia* spp.	
A. senegal	CA,WA, EA. SA
A. mernsii	EA, SA
Acacia seyal	CA,WA, EA, SA
Acacia mangium	CA, WA
Indigenous Fruit Trees	
Ziziphus mauritiana	CA, WA, EA
Adonsonia digitata	CA, EA, SA, WA
Cola spp	CA, WA
Uapaca kirkiana	SA, EA
Viterallia paradoxa	WA
Strychnos spp	EA, CA
Parkia biglobosa	WA, EA
Agroforestry species	
Acacia auriculiformis	CA, EA, SA, WA
Grevillia robusta	EA, CA
Gliricidia sepium	CA, EA, SA, WA
Calliandra calothyrsus	CA, EA, SA, WA
Cassia siamea	CA, EA, SA, WA
Faidherbia albida	WA, EA, SA
Indigenous commercial species	
Milicia excelsa	CA, EA, SA, WA
Entandrophragma spp.	CA, EA, SA, WA
Khaya spp.	CA, EA, SA, WA
Pterocarpus spp.	CA, EA, SA, WA
Triplochiton scleroxylon	CA, WA
Others	
Tectona grandis	CA, WA, EA
Hevea brasiliensis	CA, WA
Gmelina arborea	CA, EA, SA, WA

6.3. Development of forest genetic resources

The state of tree improvement in the plantation sector in Africa varied with South Africa having very sophisticated programmes. Investments in tree breeding in Zimbabwe have declined over the years, and there are nascent and growing programmes in Rwanda and Uganda. In most other countries, there has been no significant investment in tree improvement for decades and there is no adequately trained staff. The genetic resources of most countries (i.e. species and provenance trials, clonal banks) have been damaged from years of neglect and inadequate documentation of species and originality. This has resulted in a resource that is unclear in nature, untested and insecure. The continuing degradation of the genetic resources in Africa's plantations is indicative of a lack of planning for the future and has left the forestry sector dependent upon the importation of seed from abroad (e.g. Malawi, Mozambique). There is need for Africa to invest more in tree breeding and deployment strategies that should be developed in parallel to ensure that the genetic improvement can be delivered operationally in a cost effective manner. For many commercial species, seed may be available from the private sector although some private companies have specifically bred trees for specific end products (e.g. fibre gain in South Africa) and may not be suitable for other purposes (e.g. for saw-log) and site conditions.

6.4. Documentation of forest genetic resources

Most countries have a long history of introducing exotic species (mainly eucalypts, pines, acacias, *T. grandis* and *Gmelina arborea*) for plantation forests and many other exotic species (mainly leguminous species) for agroforestry development. A lot of species and provenance trials were established and hold immense data and information on species growth, provenance variability and productivity. Landraces of the introduced species are the main sources of seed (e.g. *Tectona* and *Gmelina*) and the genetic diversity maybe unknown. It is therefore paramount that genetic material be tested in trials and guarded against inbreeding depression and increasing vulnerability to pests and diseases. The data should routinely be collected and analysed to give information needed to make long-term decisions on species selection, tree germplasm development and deployment. Documentation and writing up research result are keys to successful tree breeding and tree germplasm deployment.

6.5. Deployment of forest genetic resources

Seed centres were established in many countries in Africa, e.g. the SADC Tree Seed Centre Network funded partly by national and international organisations. These seed centres raised the awareness of the need for good quality planting stock for successful tree planting programmes. Countries with functional seed centres have consistently showed good tree planting outcomes. However, most countries have neglected their seed centres after donor funded projects ended. There is need to put seed centres on a sound technical, financial and institutional foundation to ensure sustainability. This is achieved by making seed centres key bridges between tree breeding and tree planters. This would require investment in personnel, equipment and technical know-how of the roles of seed centres in reforestation and afforestation programmes.

6.6. Enrichment of forest genetic resources

Many countries in Africa started importing exotic species during the late 1800s and early 1900s. These early introductions formed the basis of forest plantations as we know them today. Many species were introduced, tested, improved, hybridised on the basis of the current planting stock. Over the years, there have been reports of reduced growth vigour of certain species. Some are beginning to succumb to the pressure of diseases and pests e.g. *E. camaldulensis*, *E. grandis* and *E. tereticornis* in Southern Africa are threatened by pests such as bronze bug, blue gum chalcid (*Leptocybe invasa*) and red gum lerp psyllid (*Glycarpis brimblecombei*); *Pinus patula* in Southern Africa is being attacked by *Fusarium circinatum*. Given the dramatic increases in the movement of pests globally, largely driven by anthropogenic factors, the threat to tree germplasm will be an increasingly important constraint to forest productivity and the application of modern breeding and other technologies can reduce the impact. Tree breeding programmes might need to import new provenances or species to mitigate the threats posed by pests and diseases through seed collection and importation agreements with institutions such as the CSIRO Tree Seed Centre for Eucalypts and CAMCORE for pines, and the Teak Network for *T. grandis.*

6.7. Understanding the ecology and regeneration of indigenous commercial species

The availability of commercial seed for indigenous species is very limited. Not much research has been done on genetic variability of species. Seed is collected from natural stands. There is need for more research on the use of seed collected from felled trees in regeneration of tropical forests. This would require knowledge of the ecology and regeneration processes of the species (e.g. seedling recruitment in forest gaps). The demand for seeds of native tree species will increase considerably in Africa as a result of new interest in planting such species and their potential to provide high quality timber and NTFPs with a relatively short period. This offers income opportunities for farmers to fill a market niche not occupied by large forestry companies, which traditionally focus on growing exotic trees species for saw-logs and pulpwood.

6.8. Patterns of flowering and seed production

A number of species have been reported to be shy-seed producers. These include *E. nitens* in South Africa, G. *robusta* in Kenya, *P. maximinoi* and *P. tecunumanii* in Malawi, Mozambique and Zimbabwe; *P. oocarpa* and *P. caribaea* in Mozambique, and *Tectona grandis* in West Africa. To understand the flowering and seed production patterns of some of these species, it would be necessary to observe the behaviour of the species on particular sites and landscape positions through-out the range of planting locations in sub-regions, and recommend seed production areas. This may require countries to engage in joint cross-border seed production areas and programmes for mutual benefit.

6.9 Clonal forestry

Inter-specific hybrids of pines (South Africa), eucalypts (Uganda, Mozambique, Angola, DRC, Congo, South Africa) and *T. grandis* (Nigeria, Ghana, Sudan, Uganda) are now widely planted. Other countries have been trying to import clones to test and then rapidly deploy the planting material into plantations which would appear to be a cheaper and quicker way to increase forest productivity compared the lengthy process of species and provenance introductions and testing. Clonal forestry may be prone to failure if the clones are not fully tested in the new environments, exposure to new pests and diseases and changing climatic conditions. In Kenya, Tanzania and Uganda, eucalypt clones are being promoted through the GCF funded Tree Biotechnology programme, and the mother trees (ramets) should be conserved in resources conservation stands so as not to lose the original materials. Some countries have reported failures of clonal plantations (Zambia and Zimbabwe).The growing of hybrid clones may not be an optimal choice in establishing plantations in resource poor countries (contrast with South Africa) and the fact that some of the hybrids are difficult to root, clonal hedges are difficult to establish, and most countries do not have enough financial and technical resources to develop a sustainable clonal programme. There is a need to be aware of narrowing the genetic base of the species and clonal material over several cycles of selection and the financial and technical implications.

6.10. Development of new models to deploy agroforestry germplasm

While Forestry departments, NTSCs and the private forestry sector have been successful in delivery of commercial tree germplasm, the same cannot be said for agroforestry species. There is a general expectation that seed for MPTS will be provided by or obtained from the World Agroforestry Centre for specific projects. The demand for seed of agroforestry tree species is largely driven by donor-funded projects, but when projects end, the priorities for target farmers change, meaning that any efforts to improve the species and deploy good quality tree germplasm ends. Also the end use of the species are varied (fallow, fodder, wood, fruits, soil amelioration) and to have a breeding strategy focusing on multiple traits and products is almost impossible. This forestalls realising the full potential of the agroforestry tree species and lead to low attention to and investment in seed production system for such species. Such expectations are quite common in agroforestry projects or indeed any other donor-funded intervention. Over the years, most countries in Africa that introduced MPTS are facing shortages of high-quality certified seeds for tree planting projects. It is recommended that a germplasm supply strategy for agroforestry is developed that would see national institutions partnering with potential small-scale germplasm suppliers to identify needs, supply chains, monitoring and evaluating of impact on agroforestry plantings.

6.11. Tree germplasm transfer agreements

Traditionally, tree seed was exchanged without much documentation, and trees were established in gardens and arboreta. Systematic collections of key species, e.g. eucalypts and pines, were conducted in the mid-1900s and agreements on seed movements were between institutions or researchers. The exchange of forest reproductive material is sometimes based on various bilateral agreements and there are discussions for Material Transfer Agreements (MTAs) and Memoranda of Understanding (MoUs) between donor and recipient countries nowadays. African countries willing to import seed to enrich their FGR stocks need to be aware of the need to enter into formal agreements and share trial data and information with the donor country. For example, the ATSC now requires partners receiving provenance collections to share data and information from trials and in some cases share germplasm with Australia should the base populations in Australia get lost or be depleted (Midgley, 1999).

6.12. Documenting genetic quality

Several African countries (Burkina Faso, Kenya, Malawi, Madagascar and Rwanda) are members of the OECD Forest Seed and Plant Scheme which recognises four categories of forest reproductive material: 1) source-identified; 2) selected; 3) untested seed orchards; and 4) tested seed orchards. Some countries use local seed classification based on the generation of selection, inter-specific hybridisation or clonal material. It is recommended that control of genetic quality through national certifying bodies be part of the tree germplasm and supply process.

6.13. Tree germplasm supply in a changing climate

The impacts of future climate related events remain poorly understood although there is good evidence that some exotic and indigenous species are succumbing to drought, pest and diseases in some countries. This will require importation of new provenances targeting those from the extreme edges of the natural distribution.

6.14. Regional networking and strengthening institutions

Most regions and countries share common priority species. Many species have been tested in different countries. Whilst the maintenance of the trials, data collection and analyses was not reviewed during the studies, it was reported that some of the trials were "lost" due to uncontrolled harvesting, fires or simply abandoned due to lack of funding. These species and provenance trials are expensive to set up, and the best that can be done is to get as much information as is possible. Researchers should look beyond their trials more often to identify superior material and deliver genetic gains to operations. Scientific cooperation and distillation of expert opinion under a regional framework (e.g. AFF) could help in selecting and recommending high performing species, provenances and seed sources across countries and regions. A good starting point will be the formation of a formal network of tree breeders and tree germplasm experts to share ideas, information and exchange research germplasm. The network will need to have strong links with nursery operators and tree germplasm users. The network could be mandated to conserve, utilise and develop the forest genetic resources of Africa for the benefit of the forest plantation sectors and community tree planting activities. The main activities could be the conservation of existing genetic resources, the testing and utilisation of them and the development and deployment of such resources.

7. Conclusion

The synthesis report, which was based on the three regional reports from W/CA, EA and SA, has brought together common issues affecting tree breeding and tree germplasm supply in Africa. These two activities form key components of SFM. The importance of forest statistics to forecast tree planting activities and ultimately seed demand was highlighted. Priority species for planting in Africa include *Eucalyptus*, *Pinus*, *Acacia*, *T. grandis*, *G. arborea* and *Hevea* sp. A number of agroforestry species, indigenous fruit trees and indigenous commercial species are gaining attention as new products and services from trees are being demanded. A new wave of tree planting has been observed in all regions of Africa and this will create a huge demand for tree germplasm on the continent. There are gaps in the supply of germplasm in many parts of Africa caused by de-investments in research and development, lack of capacity to maintain seed production areas and collect, store and test the seeds. There are reports of significant threats of pest and diseases, particularly for eucalypt species, that might affect productivity of trees and forests. A critical concern is that the new wave of tree planting happening in Africa could face bottlenecks in the supply chain of good quality tree planting stock and, given the threat of pests, diseases and climate change, the planted trees might be sub-optimal affecting productivity in the future.

Lists of priority species have been identified and the common species could form the basis of regional or continental collaboration in the form of information exchange, joint trials and cross-border seed-production areas. The levels of activities with regards to tree breeding and improvement varied from country to country with South Africa having an advanced tree breeding and tree improvement programme. In terms of species, pines, eucalypts and acacias have advanced generations of selection and the first two groups of species have inter-specific hybrids that have been developed. A few indigenous fruit and commercial species have been commercialised and grafted, and vegetative material is available as planting stock. Seed production areas have been identified in most countries although the status and quality of the seed collected is generally inferior. Large planting programmes appear to be depending more on external seed sources (except for South Africa) pointing to a huge deficit of good quality tree seed in most countries.

The exchanges and trade of germplasm would require good documentation and application of regulations and agreements pertaining to seed movement. A number of seed deployment strategies are in place and they vary from country to country and from species to species. A gap in tree seed supply exists for small-scale tree growers, and countries are encouraged to invest more in this area. Small-scale tree growers are going to be important in the growing of forest resources in the future, often in partnership with the private companies. Supply of tree germplasm in the informal sector needs to be regulated through monitoring tree planting activities and ensuring that high quality seed is being used.

A number of recommendations have been given to improve the tree germplasm supply. Increasing investments in seed production areas, national seed centres and human resources were highlighted for most countries in Africa. Conversion of provenance trials into seed production areas after selecting plus trees and thinning out inferior trees is one strategy of ensuring a good and cost effective way of tree germplasm supply. Whilst clonal forestry, especially for eucalypts and pines, is gaining momentum, there is need to be cautious of the negative impacts of narrowing the genetic base. Collection of indigenous species is still on an *ad-hoc* basis with most collections on an opportunistic basis. This activity needs to be refined and focused on the most important species, especially for ICS that are harvested on a large scale. This will ensure that the species are conserved for posterity. The participation of local communities in seed collection and distribution offers an opportunity for inclusive SFM programmes were communities can be paid to collect germplasm and for conservation of forest genetic resources in their landscapes.

NTSCs were identified as important components of infrastructure and drivers of tree planting in most African countries. The review indicated decreased levels of investment in equipment and human resources resulting in most NTSCs operating at below capacity. The synthesis recommended increased investment in NTSCs to provide the impetus towards increased tree planting activities and meet projected seed demands.

The synthesis report has highlighted that SFM has several components that include the management of natural forests and tree planting. Tree planting has the potential to reduce deforestation and degradation of natural forests and ensuring a faster way of providing products and services. Tree breeding and tree germplasm supply, together with effective tree culture (silviculture, forest protection), are important aspects of SFM.

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